An Affordance-Based Design Task Clarification Framework for Speech and Language Therapeutic Toys

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ABSTRACT

The task clarification stage is characterised by a high degree of uncertainty due to the lack of information available to the designer at the beginning of a new design project. For this reason, designers find this stage the most challenging, especially if the designer does not know the context in which the proposed artefact and its end users will operate. Given that the success of a new product highly depends on how well the product requirements have been elicited, communicated and understood by the designer, early design support in this regard would alleviate the activities within the task clarification and subsequent design stages.

The motivation of this research concerns early childhood speech and language therapy (SLT), which is facilitated through toys and play. For SLT to be effective and efficient, therapy must continue beyond the clinical setting. For this reason, apart from speech-language pathologists (SLPs), caregivers have a relevant role in treating language disorders in children. Thus, the end users of intentionally designed therapeutic toys for SLT, referred to as speech and language therapeutic toys (SALTTs), are the clinicians (SLPs), caregivers and children.

Through research carried out in this dissertation, it was established that the affordances of toys highly influence children's attention span and engagement with toys. Moreover, affordances permit designers to understand how a product will be used by its users. A literature review determined that designers lack a suitable means by which designers can elicit affordance-based end-users requirements for SALTT.

By looking at the affordances that SALTT artefacts need to offer during their use phase, the descriptive Speech and Language Therapy Potential Model (SALT-PM) was developed. A prescriptive framework architecture, Design of Speech and Language Therapeutic Toys (D-SALTT), was also proposed to support novice and experienced designers to elicit and understand end-users affordance-based requirements. These were implemented in a prototype computational tool called ACQUAINT-SALTT.

The evaluation of the D-SALTT framework architecture and ACQUAINT-SALTT showed that practising designers positively welcomed the provided user-centred design support for the task clarification stage, particularly the efficiency by which affordance-based requirements can be elicited, enabling them to understand the context of the end users without restricting their creativity.

ACKNOWLEDGMENTS

At the beginning of this journey, I read that it takes a village to finish a dissertation. Still, I did not fully understand it until I sat down to write this section, which made me realise how many people I am deeply indebted to. First, this doctoral research would not have been possible without the funding received for the SPEECHIE project from the Malta Council for Science and Technology (MCST) through the FUSION Technology Development Programme 2016 (R&I-2015-042-T).

I feel privileged to have had Prof. Ing. Philip Farrugia as my supervisor. His critical and valuable feedback allowed me to grow academically and develop a fondness for research. I am forever grateful for his encouragement and incredible dedication. He always gave my research work his full attention and made time for long discussion sessions. I especially thank him for giving me opportunities to pursue my studies in a field that means a lot to us. His friendship and mentorship will always be cherished.

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Dedicated to

Joanna, and our children,

Emily and Jacob

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LIST OF ABBREVIATIONS

AAA	Artefact-artefact affordance
AAA-BR	Artefact-artefact affordance-based requirement
AAC	Augmentative & Alternative Communication
ABD	Affordance-Based Design
ABR	Affordance-Based Requirement
ACQUAINT-SALTT	Affordance-based Requirements Generation Tool for Speech and Language Therapeutic Toys
AI	Artificial Intelligence
ASLP	Association of Speech-Language Pathologists
AUA	Artefact-user affordances
AUA-BR	Artefact-user affordance-based requirement
AUCA	Artefact-use context affordance
AUCA-BR	Artefact-use context affordance-based requirement
CMS	Content Management System
D-SALTT	Designing Speech and Language Therapeutic Toy
DAM	Desired Affordance Model
DBD	Decision-Based Design
DFA	Design for Assembly
DFM	Design for Manufacturing
DIF	Design Information Framework
DLD	Developmental Language Disorder
DMS	Data Management System
DPO	Data Protection Officer
DS #	Designer study (participant #)
DV #	Dependent Variable #
EAT	Electronic Assistive Technology
EC #	Evaluation Criterion #
EDR	Engineering Design Requirement
EMR	Electronic Medical Record
EO #	Evaluation Objective #
ES #	Evaluation Study (participant #)
ESD	Engineering Systematic Design
FL	Freelancer
FMP model	Functional Manipulation Potential Model
FR	Functional Requirement
FWR #	Framework Requirement #
GCE	Graphical Control Element
GUI	Graphical User Interface
HCI	Human Computer Interaction
IL	Information Layer
IoT	Internet of Things
IoToys	Internet of Toys
KBE	Knowledge-Based Engineering
KBS	Knowledge-Based System
KML	Knowledge Management Layer

KL	Knowledge Layer
LCA	Lifecycle Analysis
LFD	Lifecycle-oriented Function Deployment
MBSE	Model-Based Systems Engineering
MESA	Maltese-English Standard Assessment
MDE	Model Driven Engineering
ML	Machine Learning
MT	Mainstream Toy
NFR	Non-Functional Requirement
NFR	Non-Functional Requirement
PD	Product Development
PMS	Practice Management System
PSS	Product-Service System
QFD	Quality Function Deployment
QML	Qt Modelling Language
RB #	Research Boundary #
RD	Requirements Development
RE	Requirements Engineering
RM	Requirements Management
ROC	Rank-Order-Centroid
SALT-PM	Speech and Language Therapy Potential Model
SALTT	Speech and Language Therapeutic Toy
SAP	SALTT Artefact Potential
SAP_{max}	Maximum SAP
SAP_e	Explicit SAP
SAP_i	Implicit SAP
SBPD	Scenario-Based Product Development
TR #	Tool Requirement #
TT	Therapeutic Toy
TTS	Text-to-Speech
TUET	Toys and games Usability Evaluation Tool
SL	Stakeholders Layer
SLD	Speech-Language Department
SLP	Speech-Language Pathologist
SLT	Speech-Language Therapy
SPD	Sensory Processing Disorder
SysML	Systems Modelling Language
UCD	User-Centred Design
UI	User Interface
UML	Unified Modelling Language
UX	User experience
VS #	Validation Study (participant #)
VO #	Validation Objective #
YOE	Years of Experience

NOTATION

$A \coloneqq B$	A is defined by B.
$A \cup B$	The union of A and B, consisting of all the elements of A and all the elements of B.
$\|A\| = n$	Size of set A is n.
$b \in C$	b is a member of C
x OR y	Either x or y
x AND y	Both x and y

GLOSSARY

Term	Definition
Affordances	An affordance is defined as the (possible) relational and beneficial action for a user offered by an artefact (Cormier et al., 2014; McGrenere and Ho, 2000).
Artefact-Artefact Affordances	An affordance provided by one sub-system (or artefact) to another subsystem (Maier, 2011).
Artefact-User Affordances	An affordance provided by one sub-system (or artefact) to the user (Maier, 2011).
Atypical child	Child with DLD or other impairment.
Assessment *(as related to speech-language therapy)*	Clinical assessment is performed on an individual to understand the current developmental age of the patient/client. Several assessments exist to help elicit the necessary information to diagnose the disorder.
Chronological age	The actual age of a person, that is, the number of years (and months) that a person has been alive.
Customer	The entity that purchases for the product.
Customer needs	Customer needs are product requirements statements articulated "in the language of the customer".
Design knowledge	Tacit and explicit knowledge that allows the designer to execute his/her profession. This includes knowledge about manufacturing processes, material performance, best dimensional tolerances, etc.
Design brief	Also known as *product proposal* or mission statement. It is a document which is developed by the product planning team for a new design project. It contains the core details about the product to be developed, including who the end user will be and the desired objectives.
Design support tool	Also referred to as design support system (W. Wang and Duffy, 2007). It is a knowledge-based support system which aids the designer in making informed decisions.

Developmental age	It is an indicative age bracket of when children should reach milestones.
Domain knowledge	Design artefact knowledge is the knowledge that concerns the nature of the artefact and its application, how it should work and what the components should be. Domain knowledge is founded on explicit knowledge, but experience within a domain may build up implicit knowledge.
End user	The person that will use the product or system.
Explicit knowledge	It is the knowledge that can be structured, articulated, written down, stored, and shared—for example, market trends and research articles.
Expressive language disorder	A disorder where the child/person finds it difficult to share one's thoughts, ideas, or feelings.
Functional requirement	The task required to be accomplished by the product for the user to perform a goal.
Human-Centred Design (HCD)	Like UCD, HCD focus on the human user and the social problems that a particular community has.
Implicit knowledge	It is the practical use of explicit knowledge, such as skills that can be used throughout different jobs and can be easily taught to others by following a procedure.
***Intervention** (as related to speech-language therapy)*	The treatment provided to patients/clients to reduce the symptoms (developmental language disorder) using evidence-based practices.
Non-Functional Requirement	These are also called performance requirements which serve as constraints for which a function or usage must be executed, example, accuracy, reliability, pleasantness, cleanliness, etc.
Ontology	An ontology provides a structure to formalise and construct reusable domain knowledge into models.
Product development process	The sequence of steps that transform an idea into a saleable product.
Product lifecycle	The stages through which a product is transformed from an idea into actual product up to disposal, at the end of its life.
Receptive language disorder	A disorder which makes it hard for the child/person to understand what others say.
Requirements	The interpreted or derived end-user needs that describe what the product needs to do or a quality that it will own.
Requirements elicitation	It is is the process of capturing, extracting, and obtaining needs from relevant stakeholders
SALTT artefact potential (SAP)	The potential benefit that a SALTT artefact has for a user receiving speech and language therapy.

Speech Disorder	Speech disorder refers to a condition that makes the child/person hard to understand due to problems in articulation, voice and/or fluency.
Speech-language therapy	A form of care provided to patients/clients that have difficulties with communication and swallowing in the form of treatment, support, and care (Paul and Roth, 2011).
Specifications	Technical or design specifications or engineering characteristics (Dieter & Schmidt, 2009) which are requirements statements that prescribe an exact need (e.g., a particular material) or metrics value (e.g., dimensions) or a range of values (e.g., minimum and maximum speed).
Tacit knowledge	In contrast to implicit knowledge, explicit knowledge cannot be passed to others because it cannot be easily expressed. This knowledge is gained through experience. For example, being a good speaker and engaging listeners. Tacit knowledge is the practical application of implicit knowledge. It mainly depends on the expertise that one has, depending on the domain he works.
Typical child	Also referred to as Mainstream child. A child whose developmental age conforms with his/her chronological age.
Users	The user of an artefact is anyone that comes in contact with the artefact during its product lifecycle. A user can be someone who is manufacturing the product, transporting the product or even servicing the product.
User-Centred Design (UCD)	In contrast to HCD, UCD focus on individual users with particular characteristics in order to create user-friendly products. During such a design approach, end users are normally involved frequently during the design process in order to provide the right user experience when using the product.

1. INTRODUCTION

Design engineers work in different industries

Through their careers, design engineers tend to change their employment several times. Statistics show that 38% of design engineers change their jobs every 1-2 years[1]. In doing so, they augment their skillset, and their experience can be relevant in solving problems in new positions. Nevertheless, every industry has specific needs that are mostly determined by the product or service that end users require. Figure 1.1 illustrates a non-exhaustive overview of different industries in which design engineers can work.

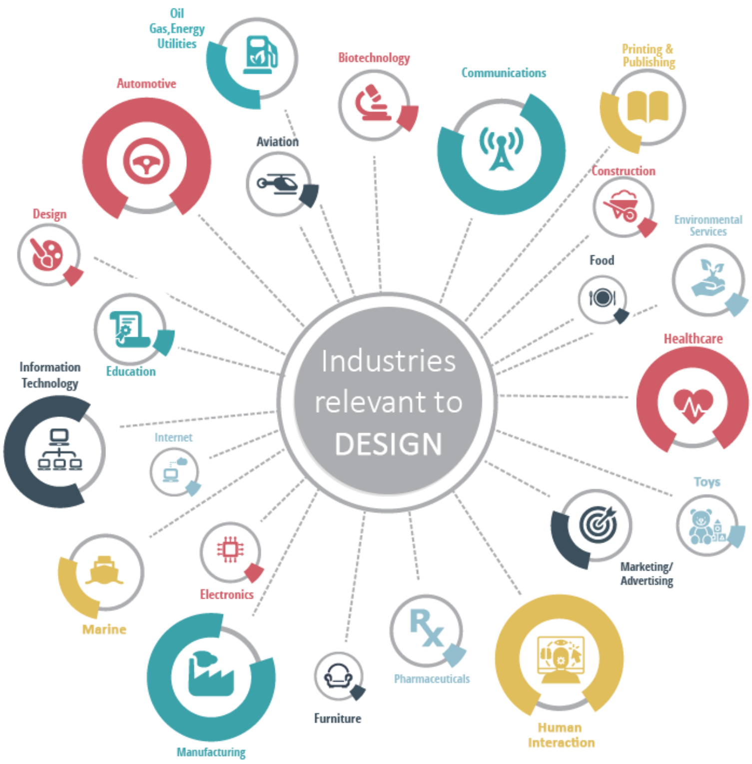

Figure 1.1: Different industries relevant to Design Engineering

Importance of explicit knowledge to guide designers

Albers, Turki and Lohmeyer (2012) investigate the differences between novice and experienced designers and apply the five-stage Dreyfus Model of skill acquisition (Recollection, Recognition, Decision, Awareness, Mastery/Expertise) to explain

[1] https://www.zippia.com/design-engineer-jobs/demographics/

how engineering design students gain competences through theory and practice, advancing from novices, to advanced beginners, to competent, to proficient and, finally, to experts. As their skill level in design engineering increases, designers rely on gained tacit knowledge to solve problems intuitively. Nonetheless, explicit domain knowledge about contexts in which their designs will be used, end users and end-users needs remains a crucial and "*active variable that influences the problem-solving process*" (Peña, 2010).

Solutions involving multiple disciplines

In an effort to solve real-world problems through the creation of new or improved products such as rehabilitation devices, a multidisciplinary team is required to address customers' problems (Choi and Pak, 2006). However, the task to collate the requirements, design and build the solution remains in the hands of design engineers (Pahl et al., 2007; Ullman, 2010).

1.1 Requirements Elicitation Reality

Requirements from product development sta*keholders*

The activities carried out at the task clarification stage are much different than those done at later design phases. The task clarification stage is characterised by complex information processing, decision making and uncertainties which often result in wrong assumptions, time delays or product failures (Florén et al., 2018). During its lifecycle, a product encounters many *users*, including product development (PD) stakeholders during the manufacturing phase, the actual *end users* during the use phase, and repairers, during the maintenance phase of the product. Designers with previous PD experience may be familiar with the needs of production. However, use phase needs differ significantly across domains.

1.1.1 Understanding end-users requirements

Functions and Aesthetics

The designer's role is to design a solution that meets the end-users' need(s). Thus, the understanding of end-users needs is the basis of any design process (Kim and

Lee, 2010) because a wrong interpretation of the demands can lead to an unsuitable or undesired solution. A satisfying need is actually accomplished when a relationship is created between the human and the product through its pragmatic and hedonic attributes (Hassenzahl, 2005).

User-Centred Design

A bigger challenge exists when multiple groups of end-users require the same solution but their needs and mode of use would be different. To better meet their requirements, end users should be considered during the whole PD process. Through the work of Don Norman's *user-centred design* (Case, 2013), designers realised the benefits gained from observing end users for further development and/or allowing them to participate as co-creators (Sanders and Stappers, 2008). This empathetic approach allows designers to understand why customers need a particular artefact, in which context the artefact will be used, and what the anticipated tasks will be (Vredenburg et al., 2001). The theory of affordances elucidates the interactions possible between living organisms and their environment.

1.1.2 Design Affordances

Design affordances

The theory of affordances looks at the relational opportunities that exist between living organisms and the environment they inhabit (Gibson, 1979). The term '*affordance*' has been given various interpretations in literature (Davis, 2020; Gaver, 1991; Maier and Fadel, 2003; Norman, 2013). The definitions assigned to affordance by Cormier, Olewnik and Lewis (2014) and McGrenere and Ho (2000) have been combined and used as reference for the rest of this dissertation. An affordance is defined as the (possible) relational and beneficial action for a user offered by an artefact. For example, a ball affords its user to throw it, shoot it, roll it across the ground, sit on it or precariously balance on top of it, among other things.

Affordance-based design

Maier and Fadel (2007) introduced the notion of *affordance-based design* (ABD) to cater for limitations introduced by design theories that do not support non-transforming products (such as static toys with no moving parts) whose requirements are non-functional (i.e., not necessary for the artefact to be used but important for a high-quality experience for the end user, e.g., stability or portability). The affordances of any artefact depend on what the designers create and make possible. However, just as a ball affords a user to stand on it, fall over and break an ankle, an artefact may provide affordances which the designers do not wish for, have not anticipated or would like to avoid. Therefore, it is important for affordances to be properly understood and worked out in a collaboration between designers, users and the artefact.

1.1.3 Early challenges in the design process

Designing complex systems

Owing to the fact that both technical and social issues need to be understood before developing long-lasting solutions, and the fact that ICT and internet-enabled devices are advancing at a fast pace permitting increased number of features that can be integrated into a product, designers are experiencing more complex customer requirements (Brace and Cheutet, 2012). For these reasons, to remain competitive and support the needs of niche areas, technical solutions need to be considered with respect to the use context (Siddiqi et al., 2014). Although approaches such as engineering-design methodology (Pahl et al., 2007) explain how to systematically generate requirements, they are often not contextual enough to the end-users needs. As a result, without relevant experience and explicit knowledge, designers find the task clarification stage challenging (Balzan et al., 2021).

Challenges in the early design phase

These challenges spiral when the problem is too broad for design engineers working in small firms or research projects with limited resources. Differences in the *modus operandi* have been noticed between designers working in small and big companies. Short time-to-market development cycles restricts designers and other stakeholders, such as the Marketing and Sales team, on how deep they can investigate a problem, empathise with the end user, generate domain knowledge, and find a gap in the market.

Although user-centred, participatory and meta-design approaches call for greater user involvement and collaborative design, in reality, designers have limited interactions with end users. Agreeing with literature, such as (Darlington and Culley, 2004), the findings discussed in Chapter 2 disclose how designers complain that requirements are often vague, and that knowledge or key experts are not readily available. This leads to an incomplete understanding of the customers' needs and an incomplete list of requirements. Although unmatured markets provide fewer barriers to entry, they also pose fewer points of reference.

1.2 Research Context

Speech and Language Therapy

This dissertation presents a case study for the discussed design task clarification problem within the field of speech and language therapy (SLT). It is estimated that 7% of the entire population possesses a considerable deficit in language ability, which cannot be attributed to any causative health factor (Leonard, 2014). Such conditions can persist in children's adult lives and, if left untreated, children may suffer repercussions in their educational, behavioural, emotional, and social development. As early childhood interventionists, Speech-Language Pathologists

(SLPs) work to prevent or reduce speech and/or language developmental disorders in children as young as two to five years old, an age range in which intervention is most successful (Roulstone et al., 2015).

Toys facilitate language development

Developmental psychology suggests that both mainstream and atypical children develop the foundations of learning through play (Goldstein, 2012). Play is crucial for language development and, for this reason, toys are given great importance in therapy and children's lives (Robins et al., 2007). Furthermore, the development of language sustains progress in the way children play because, as children get older, play moves from being symbolic (pretending that toys are equivalent to the real objects they represent, e.g., a toy car represents a real car) to abstract and more complex play (e.g., pretending that a shoebox is a car and creating a whole car scenario from one's imagination) (Pellegrini and Jones, 1994). In fact, SLPs working in early intervention deemed that SLT services were much more needed in households where children lacked toys (Nwokah et al., 2013). Their research explains how SLPs devote around 70% of their sessions with children to using toys and other play media which have been adapted for assessment and intervention activities.

Conventional toys adapted for therapy

Although not specifically designed for SLT, SLPs have learned to adapt conventional toys for therapeutic activities. Consequently, they must use an extensive range of toys to cater for diverse needs of children, which becomes problematic when they need to work away from clinics.

Dedicated tools are unavailable

Although toys and play are very important in children's lives, not enough tangible, commercially available mediums for therapy—which in this dissertation will be referred to as *Speech and Language Therapeutic Toys* (SALTT)—have been developed so far. One of the reasons for this is that designers' own knowledge and experience of developing such niche products is limited, or they may find it difficult to transfer skills they use in other domains to this one (Fikar et al., 2018).

1.3 Research Hypothesis

To address the identified design task clarification problem, a hypothesis was formulated for a solution that supports designers in the early design phase:

> *If designers are made aware of the end-users needs and the context of speech and language therapeutic toys (SALTT), they would be in a better position to design such products as the requirements from end users can be better understood.*

To be able to design SALTT, designers should be made aware of:

1. The end users and their activities
2. The suitability of mainstream toys (MT) in the field of SLT
3. The different therapy-related considerations needed to enhance the benefits offered by SALTTs

To cater for the challenges and limitations presented in Section 1.1, Duffy and O'Donnell (1998) argued that computer-based support systems can provide active support during the design process. The provision of a computer-based tool at the task clarification stage will enable designers to better understand SALTT requirements, and therefore, generate solutions for such artefacts.

1.4 Research Methodology

For engineering design research to have effective outcomes, it must be based on systematic methodologies (Blessing and Chakrabarti, 2009). To methodically address this design problem, the design research approach by Duffy and O'Donnell (1998) was adopted, with the aim of developing a computer-based tool that supports the design of SALTTs, as can be seen in Figure 1.2.

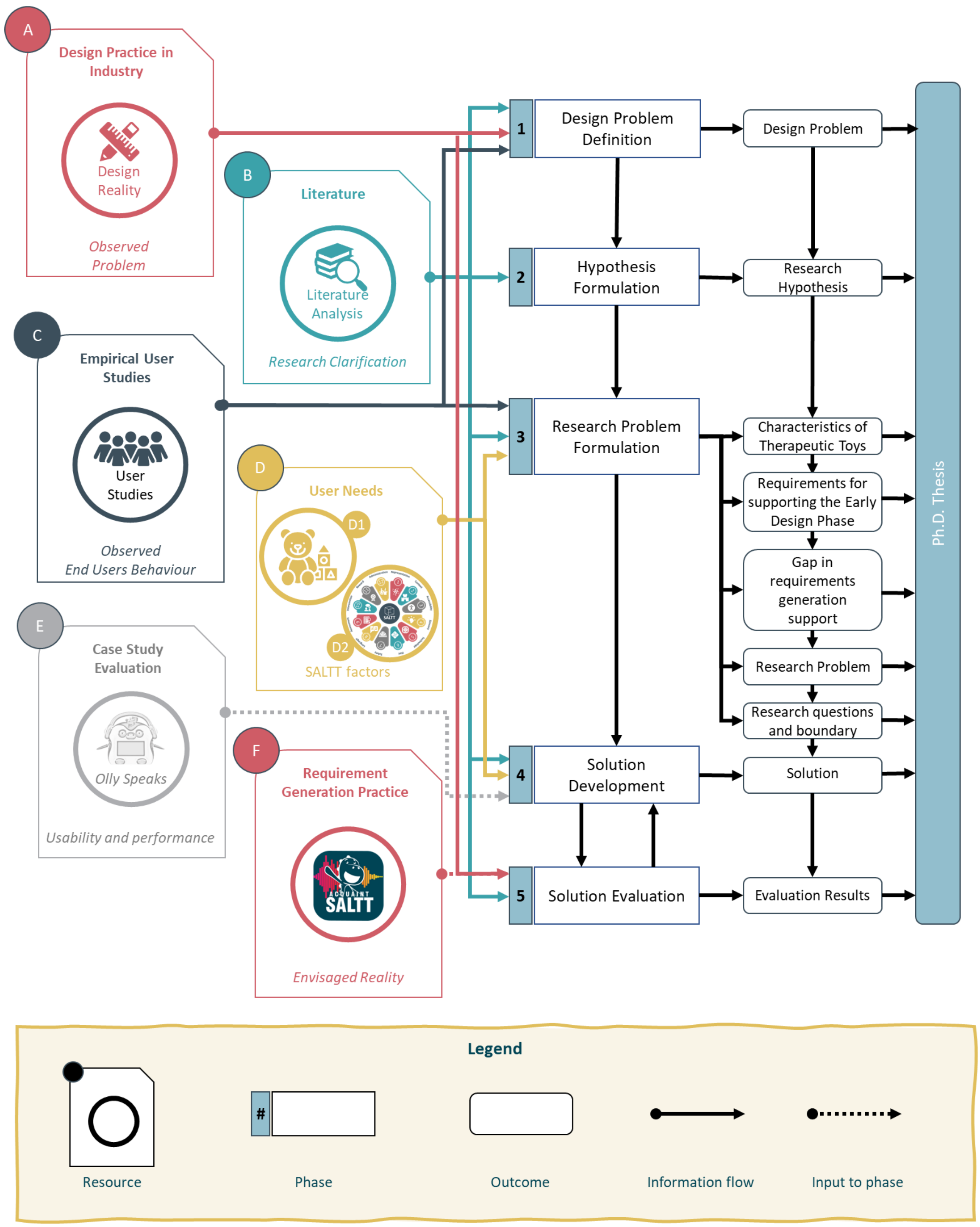

Figure 1.2: Research Methodology, adapted from Duffy and O'Donnell (1998)

Phase 1: Design Problem Definition

Responses from toy designers (A) and findings from literature (B), aided in determining the design problem (1) and the key target area for improvement, that is, the task clarification stage. Understanding of the research context was achieved through focus groups with SLPs, questionnaires with parents of children attending SLT (D1), and literature.

Phase 2: Hypothesis Formulation

Furthermore, a study with preschool children (C) (Balzan et al., 2018) allowed for a better understanding of factors that capture and prolong children's attention span in toy products. These served as the foundation for the hypothesis formulation (2) explained in Section 1.2.

Phase 3: Research Problem Formulation

Within the research problem formulation (3) phase, the characteristics of speech and language therapeutic toys were established through literature, focus groups with SLPs and questionnaires with parents of children attending therapy (D1). The requirements for a framework to support the early-design phase were also determined. Relevant literature was reviewed using criteria to identify a gap in the current state-of-the-art support tools for requirements elicitation. Subsequently, the research problem was framed, and the research questions were formulated to be able to develop an appropriate solution contained by a research boundary for the design problem being investigated.

Phase 4: Solution Development

To develop the required solution (4), and as specified by the research questions being addressed, knowledge had to be generated on the specific considerations for SALTTs. These were translated into a model which determines the potential use of an artefact for speech and language therapy, hereinafter referred to as the *Speech and Language Therapy Potential Model* (SALT-PM). As part of the SPEECHIE project[2], a prototype SALTT called *Olly Speaks* was developed, and its performance and usability were evaluated through various empirical studies (E). These results along with feedback received from SLPs (D2) were used to validate the SALT-PM. As part of the information-based model, a user-centred design framework was developed. This was implemented in a prototype computer-based tool for the elicitation of affordance-based solutions for SALTTs.

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[2] A project funded by the Malta Council for Science & Technology (MCST), through the FUSION Technology Development Programme 2016 (R&I-2015-042-T).

*Phase 5: Solution Eval*uation

The prototype tool and framework were assessed (5) with toy designers in the evaluation study (F) to investigate to what extent designers were willing to use the framework in their practice and to understand how the proposed approach in generating requirement solutions would overcome the challenges that designers find in the task clarification stage, thus verifying the rationality of the hypothesis made in the beginning of this research work. From the feedback received, participants showed interest in the availability of such a tool whilst also providing improvement suggestions.

1.5 Research Aim and Objectives

In view of the described hypothesis, the research context and the challenges that design engineers encounter, the aim of this research is to:

> *Develop and evaluate a user-centred design framework and tool for the task clarification stage by which designers can better understand product requirements and generate solutions for different end users of speech and language therapeutic toys.*

To achieve this aim, the objectives of this doctoral research are to:

Objective 1 Understand what draws and keeps children's attention to interact with toy products for a longer duration, and how product characteristics influence children's preferences.

Objective 2 Identify how end-users therapeutic needs can be communicated to and understood by designers.

Objective 3 Determine what considerations are relevant to a knowledge model that supports designers in developing SALTTs.

Objective 4 Investigate what level of support designers need to develop SALTTs, and when it is most needed.

Objective 5 Develop a framework that supports designers during the design process of SALTTs.

Objective 6 Implement a prototype tool based on the framework.

Objective 7 Evaluate whether designers are effectively supported in establishing design requirements for SALTTs and their willingness to use the developed design support tool.

To accomplish these objectives and guide the development of the computer-based support tool, the framework of Duffy and O'Donnell (1998), shown in Figure 1.3, is used.

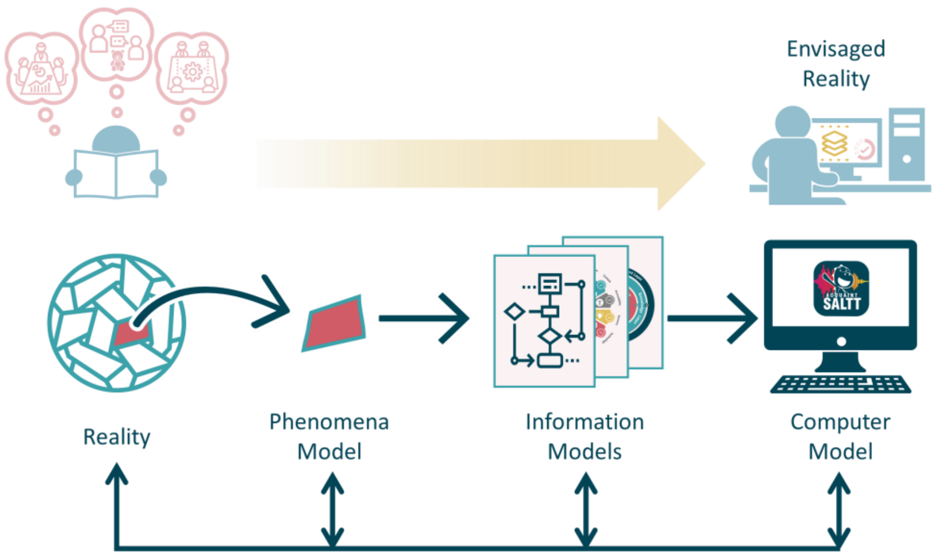


Figure 1.3: Computer-based support tools development framework, adapted from Duffy and O'Donnell (1998)

Computer-based tools are based on information models that describe the current reality, defined by the phenomena model. As described in Chapter 3, the phenomena that this dissertation is concerned with are the requirements that the end product mainly depends on, and the methods used by designers to identify and understand such requirements during the task clarification stage. The information model specifies the elements that are in play and how these should be organised so that the reality of the phenomena model is addressed, and the computer model is capable to infer that information and make computational operations. Therefore, the computer-support tool should support the designer by facilitating the understanding and elicitation of requirements for SALTT artefacts.

1.6 Dissertation structure

To reach the envisaged reality postulated by the research hypothesis, this dissertation is organised into three parts, as shown in Figure 1.4, and as discussed in the next section.

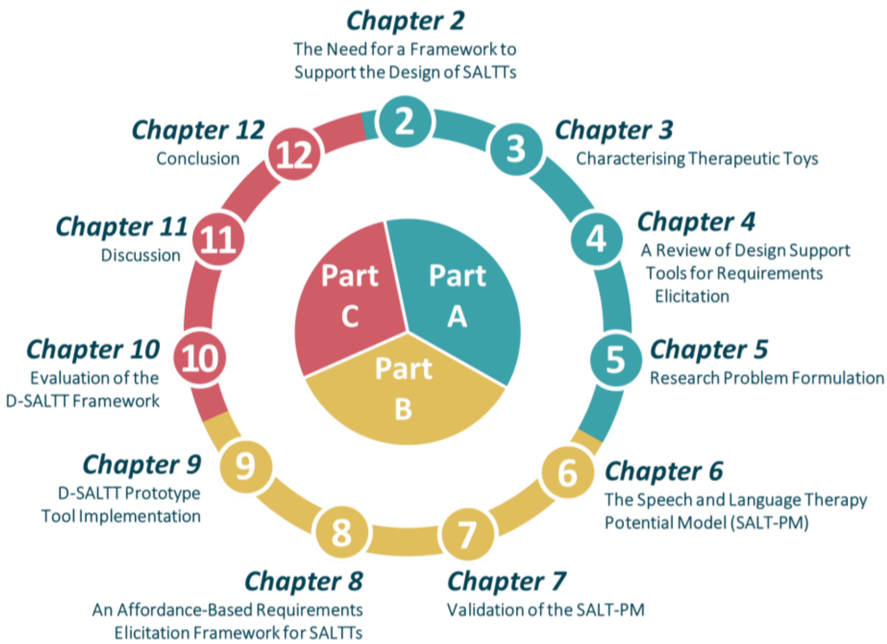


Figure 1.4: Ph.D. dissertation structure

Part A of the dissertation

Chapter 2 outlines different systematic design approaches followed by a mixed-method study demonstrating the most challenging design activities toy designers have to deal with. This chapter concludes by highlighting the phenomena being addressed in this research.

In Chapter 3, the domain that this research is concerned with is discussed, followed by two research studies aimed at identifying the requirements for SALTTs and establishing what elicits longer playtime with toy products in children. The latter phenomenon is explained through the theory of affordances. Based on the identified research direction, Chapter 4 reviews literature that provides means for supporting requirements elicitation. After identifying the research gap, Chapter 5 concludes part A by highlighting the research problem and the research boundary undertaken in this Ph.D.

Part B of the dissertation

In Part B, the development of the information models is disclosed, starting with the Speech and Language Therapy Potential Model (SALT-PM) in Chapter 6. This discusses the elements needed in a SALTT, thus providing designers with explicit knowledge about the necessary considerations needed when capturing requirements. In Chapter 7, this descriptive information model is validated with local SLPs and through the case study *Olly Speaks*. Chapter 8 discloses a prescriptive information model, called the *D-SALTT* framework architecture, which guides designers elicit affordance-based requirements. In Chapter 9, both information models are integrated and implemented as a prototype computer-based support tool called *ACQUAINT-SALTT*.

Part C of the dissertation

The final part of this dissertation starts with a second descriptive study that evaluates the *D-SALTT* framework and *ACQUAINT-SALTT*. The results from this evaluation are presented in Chapter 10. The results are analysed and discussed in Chapter 11, with respect to the major benefits and limitations exhibited by the prototype implementation and the recognised improvements. Conclusions are drawn in Chapter 12 where the significant contributions to knowledge made in this research are highlighted. This chapter finishes by outlining potential future research work that has been identified through this work.

Part A
Characterising the Research Problem

2. THE NEED FOR A FRAMEWORK TO SUPPORT THE DESIGN OF SALTTS

Why has man changed the shapes and substances of his environment? To change what it affords him.

James Gibson, The Ecological Approach to Visual Perception, 1979

This chapter looks at the role of designers during product development and investigates the challenges that they find. In Section 2.1, the general product development process is explained whereas Section 2.2 describes function-based systematic design approaches towards generic artefact design. In Section 2.3, affordance-based design is discussed. A research study with 22 international designers is described in Section 2.4, along with the requirements for a framework to support the design of SALTTs. Chapter conclusions are drawn in Section 2.5.

2.1 Role of the Design Engineer in the Product Development Process

Product development

An artefact results from a product development process consisting of a sequence of steps that transform an idea into a saleable product. The product is meant to add value to the customer and is usually developed because a company believes it is technically feasible and there is a market for it. As shown in Figure 2.1, product development involves several multidisciplinary activities, ranging from formulating goals and strategies within the product planning stage to product design during strict development. The *planning group* (Pahl & Beitz, 2007), composed of marketing and product managers (Ulrich et al., 2020), is responsible for preparing the mission statement, which is also known as the *design brief* (Ulrich et al., 2020) or product proposal (Pahl et al., 2007). This document will present the new business idea to the designer, thus triggering the start of the design process (Roozenburg & Eekels, 1995).

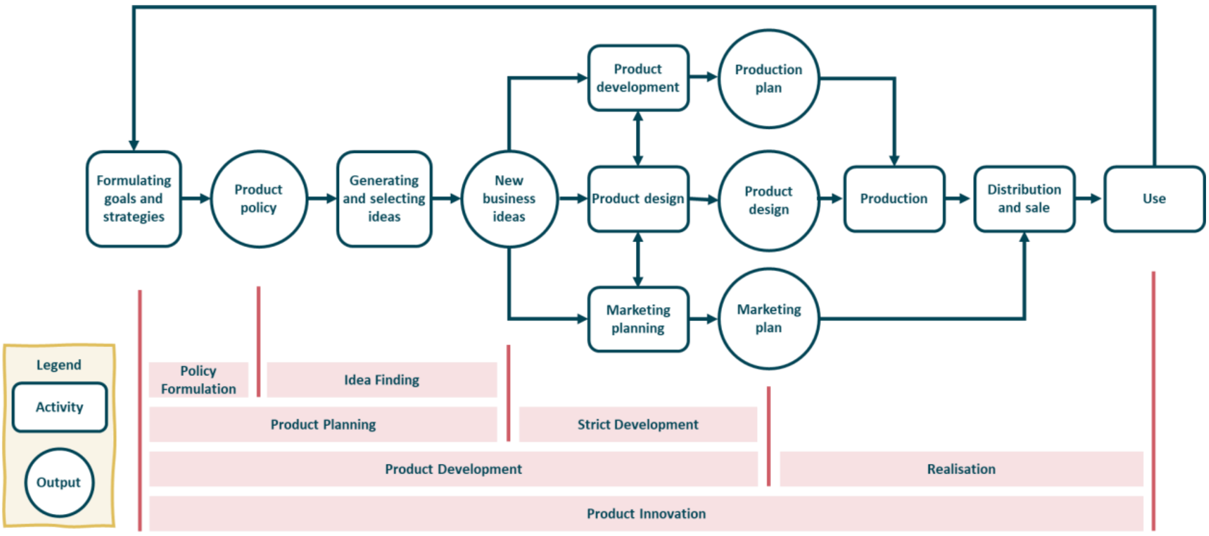


Figure 2.1: The product innovation process, adopted from Roozenburg & Eekels (1995)

The relevance of product planning to designers

Therefore, as reflected in Figure 2.1, the designer's role comes into play during the strict development phase. Nonetheless, engineering design textbooks such as Pahl et al.'s (2007) and Ulrich et al.'s (2020) devote attention to this stage. Pahl et al. (2007) insist that designers need to understand how the initial list of requirements was generated because, if necessary, they have to add requirements to the list or "*undertake this phase themselves*". Especially if "*there has not been a formal product planning phase*" (Ulrich et al., 2020).

Design and related terms

In this dissertation, the word '*design'* is mainly used as a verb, referring to the act of conceiving an idea for a solution and realising it in terms of how it works and looks (Roozenburg and Eekels, 1995). When used in the noun form, design refers to the created artefact with its different arranged sub-components. Furthermore, when mentioning the *designer*, reference is being made to the whole team of designers involved in product design, including industrial designers, electrical and mechanical engineers, and graphic designers. A formal definition of engineering design is provided by Hubka and Eder (1988), who state that design is:

> *"A process performed by humans aided by technical means through which information in the form of REQUIREMENTS is converted into*

information in the form of descriptions of TECHNICAL SYSTEMS, such that this technical system meets the requirements of mankind."

where,

- a technical system is any man-made artefact, also referred to as an artificial system (Simon, 1996), and
- technical means (or design support tools) refer to methods, simulations, prototypes, and computer-based tools that may support designers in making informed decisions.

Therefore, design is a problem-solving process in which requirements are transformed into an artefact solution. It can be facilitated if relevant information is made available because most of the activities within the design process are characterised by information processing (Simon, 1996).

Artefacts defined by their function(s)

The seminal work of Simon (1996) contributed to viewing artefacts in terms of their functions, inputs and outputs, rather than what is happening inside them. Thus, the complex behaviour of a system can be decomposed into a hierarchy of levels connected by the functional relationships between them. Once all levels and functions have been defined, the details in each level can be designed. As noted in Maier (2011), this representation was adapted by Pahl et al. (2007) to represent artefacts by their functional structure (Figure 2.2) and the flow of energy, matter and information between each function. Thus, seen from this perspective, the artefact's function is independent of the form because the function can be embodied in almost any form. However, Roozenburg and Eekels (1995) describe an artefact by the properties which enable the function(s) it is intended to provide. These properties depend on the selected form (and materials); therefore, the artefact may provide additional intended and/or unintended, desired and/or undesired functions.

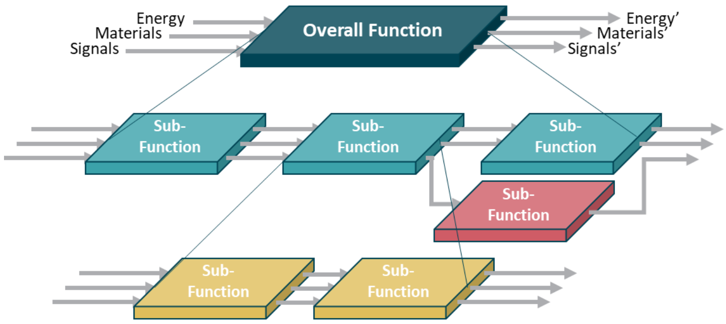


Figure 2.2: Function flow diagram, adopted from Pahl et al. (2007)

Basic design cycle

The principle of the design process can be explained by Roozenburg & Eekels' (1995) basic design cycle model shown in Figure 2.3, where the form (or the approved design of the artefact) is established by reasoning about the function. This involves design activities that may be repeated several times (during different design phases) before arriving at the final design. Experience, creativity, and external knowledge support each design iteration.

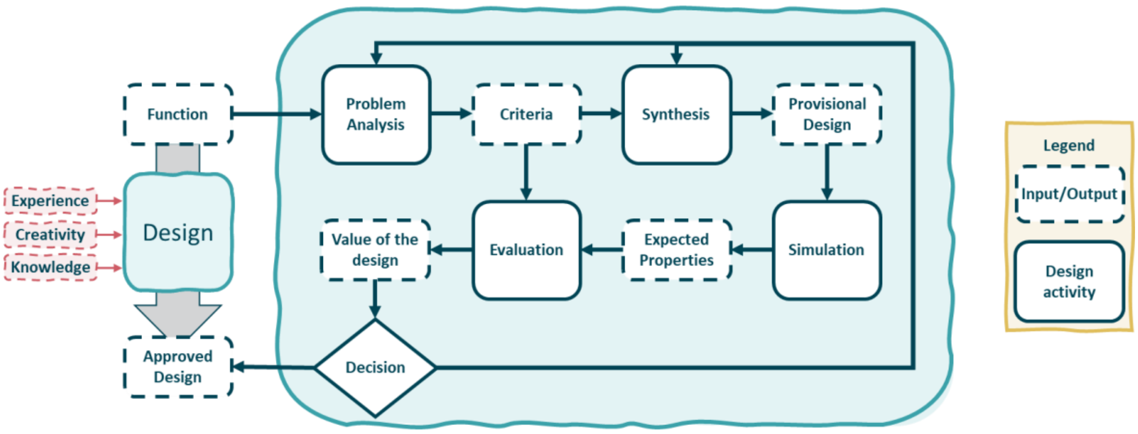


Figure 2.3: The basic design cycle, adapted from Roozenburg & Eekels (1995)

As explained in Section 2.4, this research work focuses on the *problem analysis* activity, where the designer starts to decompose the mission statement and the intended behaviour of the new product by considering its lifecycle. In this activity, the designer needs to understand the goal of the solution to formulate the criteria that the product should meet. These criteria represent the requirements for the artefact, which, at first, are roughly defined but, through subsequent iterations, get more precise in the form of design specifications.

Ambiguity of terms

The term 'requirements' has been used interchangeably in literature to refer to what the customer wants and the artefact's attributes. The *Oxford Learner's Dictionary of Academic English* (2022) defines requirements as (1) "*something that somebody needs or wants*", and (2) "*something that is necessary according to a particular law or set of rules*". The first meaning is related to customer's needs, while the second is more like the specification.

Customer needs

Customer needs are statements articulated "*in the language of the customer*" (Ulrich et al., 2020) which describe the problem in an abstract way, that is, without referring to a specific solution. Examples of customer needs are: "*I want my son to carry the toy with him*", and "*I am worried that it will break if my child drops it on the floor*". These can be obtained directly from customers or established through observations of the end users interacting with current products or envisioning future needs (Cascini, Fantoni, & Montagna, 2013). In literature, customer needs are referred to as requirements (Kannengiesser and Gero, 2015), and as customer requirements or attributes (Ulrich et al., 2020).

Design specifications

On the other hand, Pahl et al. (2007) refer to requirements in the same sense that Ulrich et al. (2020) define *technical* or *design specifications*, and Dieter & Schmidt (2009) refer to *engineering characteristics*. These are detailed requirements translated into metrics and their corresponding values. Examples of specifications or engineering characteristics are: mass (metric) to be less than 800g (value) and volume (metric) to be between 10L to 12L (value). Specifications are also used to benchmark a product's properties with other competing products on the market.

Requirements

To avoid confusion, within this research work, customer requirements, or simply requirements, are defined as *the interpreted or derived end-user needs that describe what the product needs to do or a quality that it will own*.

The need for systematic design

As explained in Chapter 3, given that, artefacts such as SALTT are complex systems, the design process can be overwhelming, even for a team of designers. The following sections discuss two particular categories of design processes, namely, function-based and affordance-based design frameworks which guide designers to execute the design process in a rational and structured way. Other approaches, such as knowledge-based design, are highlighted in Chapter 4.

2.2 Function-Based Design

Knowledge supporting the design process

Design, being a creative and multidisciplinary, knowledge-intensive process, needs to be structured. Roozenburg and Eekels (1995) suggest a design methodology that organises the design process by providing tools and methods that reinforce the designer's thinking and acting.

2.2.1 Engineering Systematic Design (ESD)

Pahl et al.'s (2007) engineering systematic design (ESD) framework, which takes a functional decomposition approach to design, is considered the consensus prescriptive model for systematic design in product engineering (Annemiek, Daalhuizen, & Roos, 2014; Maier, 2011) and is used within the manufacturing industry employing a stage-gate process (Diegel et al., 2019). The ESD framework consists of four design stages (or phases), called the *(planning and) task clarification*, *concept design*, *embodiment design*, and *detail design stage,* as shown in Figure 2.4. An illustrated example is provided to show how the requirements for a SALTT can be realised into a physical artefact, as the needed functions are concretised in consecutive design iterations.

Knowledge, guidelines, and various methods such as brainstorming, Quality Function Deployment, and Design for X, can be used at appropriate design stages to achieve the next level of design.

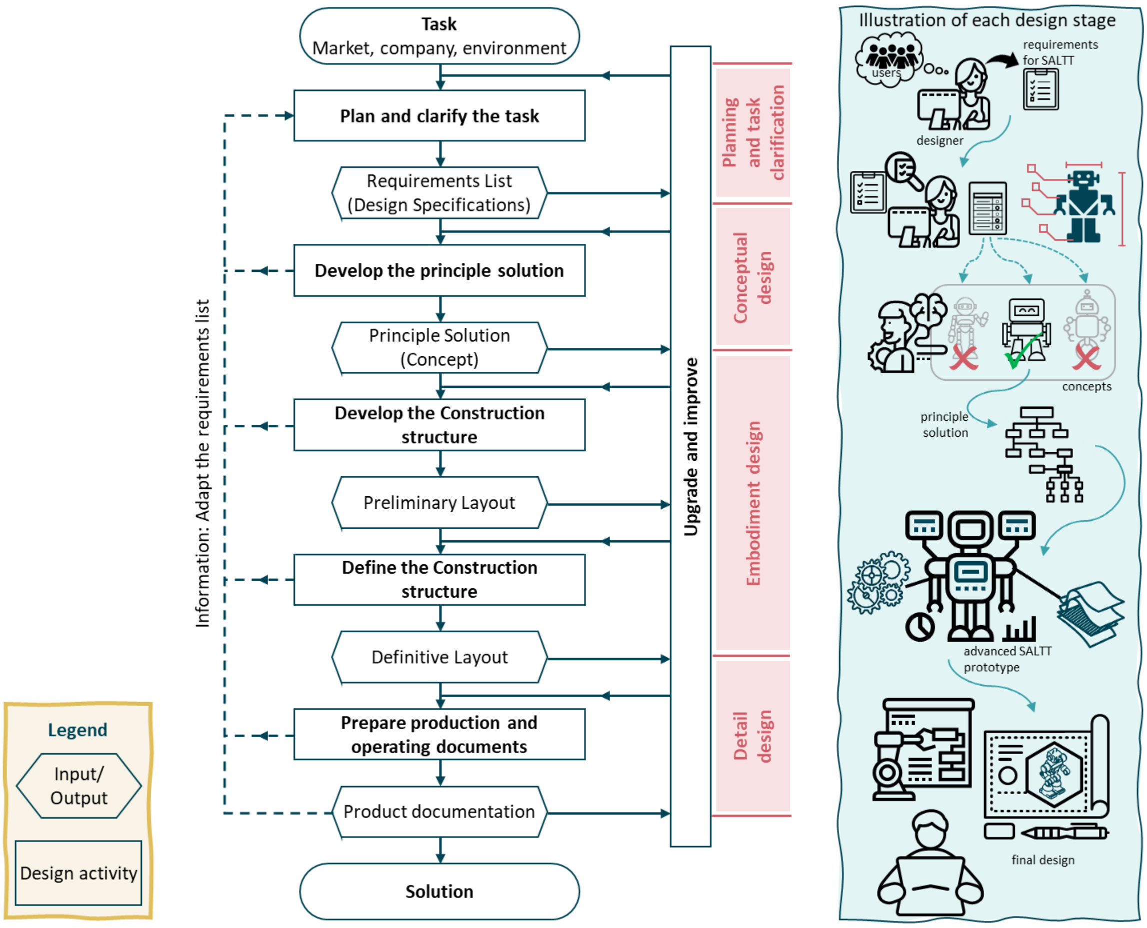


Figure 2.4: The Engineering Systematic Design Framework, adopted from Pahl et al. (2007)

The essence of each design stage

The kernel of the task clarification stage is to establish a high-level hierarchy of the functions and their related flows. Similar literature refers to this stage as the product definition (Ullman, 2010) or problem formalisation (Cormier et al., 2014). In the concept design stage, the focus is on identifying working concepts that can realise each function. After selecting the principle solution, the designer starts deciding on physical properties and the related function(s) in the embodiment design stage. Finally, during the detail design stage, the designer elaborates on the remaining details, such as tolerances, so that each part leading to a particular function can be produced.

2.2.2 Axiomatic Design

Suh (2001) defines design as a mapping between what needs to be achieved and how it wants to be achieved, using a mathematical approach called Axiomatic

Design. This approach is based on two essential axioms: the *independence axiom* and the *information axiom*. The former states that multiple functions within the system should be independent of each other, such that when a design parameter is changed, it does not affect others in any way. The information axiom states that, if multiple alternative designs meet the first axiom, the best design is the one that is the least complex.

The four domains of the design world

Suh uses the concept of domains to systemise the design activities. As illustrated in Figure 2.5, concepts are generated by crossing from one domain to another, starting from the Customer domain as explained below.

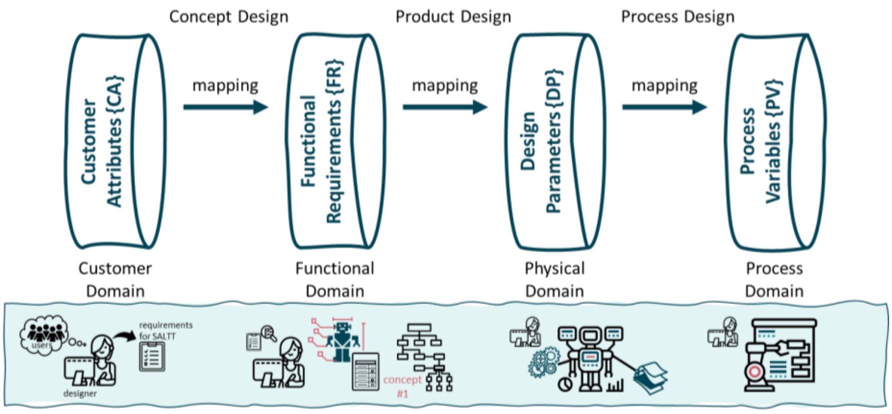


Figure 2.5: The four domains of the design world, adopted from Suh (2001)

The essence of each domain stage

The designer collects the customer needs or attributes that define what the artefact needs to do in the customer domain. In the functional domain, the designer translates the needs into a set of functional requirements. Similar to what has been explained in 2.2.1, a functional decomposition identifies lower-level functions. In the physical domain, the designer establishes the components or sub-assemblies that meet the functional requirements. These components are referred to as parameters. In the process domain, the designer looks at how the design parameter will be manufactured.

Finding 'good' designs

Since all domains are interrelated, a decision within one domain may affect another one. Therefore, the designer needs to move back upstream to check how decisions that were taken in the later domains have affected functional requirements or customer needs. Due to this mapping process, the relationships can be expressed as a mathematical equation in the form of $\{FR\} = [A]\{DP\}$, where $\{FR\}$ is a set of functional requirements, $\{DP\}$ is a set of design parameters, and $[A]$ is the *design matrix* that characterises the dependence between requirements and parameters (Suh, 2001).

2.2.3 Decision-Based Design (DBD)

Decision-based design

Decision-based design (DBD) is a systematic mathematical approach that aids decision making concerning the marketing and engineering domains. Building upon Hazelrigg's (1998) original work, Chen et al. (2013) maximise the value of the artefact and the customer demands with respect to cost and performance whilst handling risks and uncertainties that an enterprise may face. In this way, an enterprise's marketing and engineering departments can make decisions in tandem. Chen et al.'s (2013) DBD framework is depicted in Figure 2.6.

Selecting the best design

The system's attributes are separated into *customer-desired product attributes* (customer needs) **A** and *engineering design attributes* **E**. The latter are design specifications which act as constraints in subsequent design cycles.

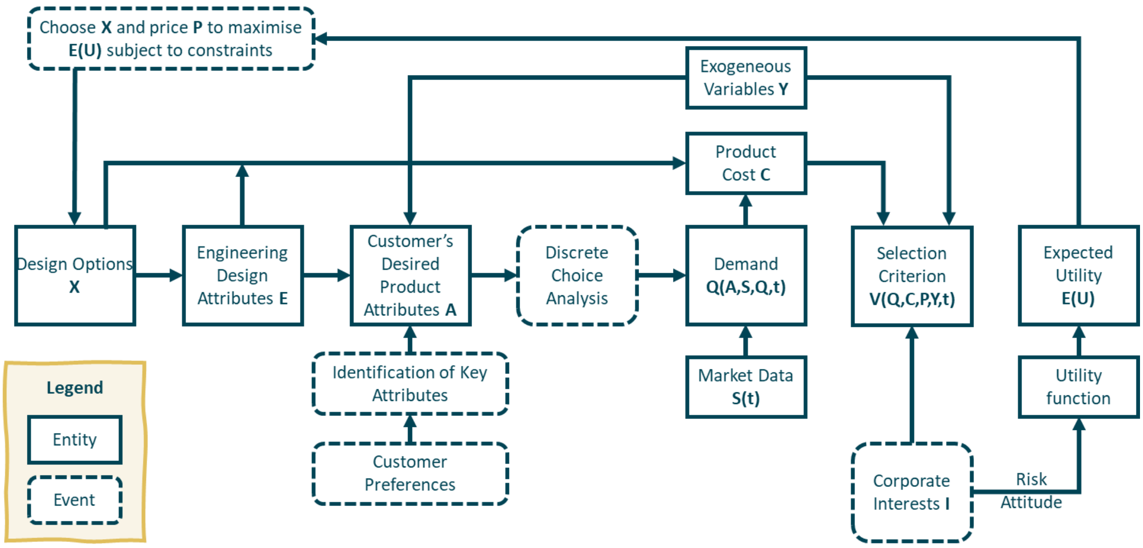


Figure 2.6: Decision-Based Design framework, from Chen et al. (2013)

Through these engineering specifications, different *design options* **X** can be produced during the alternative generation (or concept) design stage. All costs that happen during a product's life cycle add together in the *total product cost* **C**, which is affected by **X**, **E**, *product demand* **Q** and *exogenous variables* **Y** (events beyond the designers' control). The *selection criterion* **V** is driven by the present net value that a product has at the time (**t**) of consideration. Whilst considering the expected utility E(U) (Chen et al., 2013), the best product design **X** and optimal price **P** are determined by maximising the expected utility.

Weakness of DBD

While DBD increases the chances that a product reaches the market successfully, cost estimates may limit the extent to which specific SALTT aspects may be explored. Moreover, authors such as Roozenburg & Eekels (1995), Dieter & Schmidt (2009), Pahl et al. (2007), and Ulrich et al. (2020) highlight that product design is not just about decision-making but also creativity. Thus, cost factors may influence creativity in the early stages.

2.2.4 Concluding comments about function-based design

The aim of this section was not to highlight every design framework that exists but merely to understand how designers may approach the design task in actual practice. A variety of methods that support certain design activities exist. For instance, methods such as Design for Manufacture (DFM) and Design for Assembly (DFA) are more suitable during the embodiment design stage (Dieter and Schmidt, 2009).

Strengths of function-based design

The reviewed function-based frameworks consider artefacts as technical systems that perform functions to fulfil customer needs. Therefore, the designed functions can serve as criteria to objectively evaluate how the original goals have been implemented. Because function is independent of form, designers can first optimise the functional layout of the artefact and then consider how the solution will look. Functional decomposition allows designers to search for solutions for smaller sub-functions without being overwhelmed by the complexity of the parent function. Furthermore, with production cost being a key indicator of feasibility, the functions can be optimised without affecting the purpose of the product.

The need for an alternative design approach

A weakness of function-based design is that it is not adequate for artefacts that do not have a functional property which leads to transformations, e.g. soft toys. Gatti, Bordegoni, & Camere (2014) use Hassenzahl's (2010, 2018) work to explain how artefacts relate to their users. End-users perceive artefacts by their pragmatic and hedonic qualities, which aim to satisfy the *do-goals* by their function and their *be-goals* by their non-functional attributes. Maier (2011) argues that designers' aim should not be to create products that do certain functions but, instead, products that people can use. Maier (2011) uses the concept of affordance to explain affordance-based design (ABD).

2.3 Affordance-based design (ABD)

Affordances lead to interactions

Before describing ABD, an introduction to affordances is hereby provided. The word affordance was invented by Gibson (1979) in perceptual psychology. It is derived from the verb 'to afford', which means 'to offer' or 'to allow', "*either for good or ill*". For example, a zip allows pulling, or has pull-ability. He postulated that an affordance is an interaction possibility available in the environment to an observer (individual), irrespective of the observer's abilities to perceive it. For instance, both a hand-held toy and a doorknob afford grabbing (grab-ability). Affordances are opportunities for actions which invite a particular behaviour. Simply put, they do not cause behaviour but make it possible.

2.3.1 Evolution of Affordances

Communicating affordances

The concept was subsequently made popular in the field of design by Norman (1988), who described affordances as the perceived and actual properties of an object which propose how it should be used. That is, an affordance is what something "*is for*" rather than what something "*provides or furnishes*" (Maier, 2011). Norman was heavily criticised for making the existence of affordances dependent on the experiences and abilities of an individual (McGrenere and Ho, 2000). Norman later used the term *signifiers*, i.e., visual indicators that enhance the awareness of affordances, thus increasing the usability of products (Norman, 2013; Norman, 1999).

Levels of affordances

This follows from the ideas of Gaver (1991), who argued that the design provides information about the existence of possible actions.

Gaver explains complex affordances as being made of sequential or nested affordances. For example, a stress ball affords grasping and then squeezing. On the other hand, to *open* a childproof pill container, one needs to access a few lower-level affordances in a sequence by first grasping the cap, then squeezing the sides (or the cap from above), and then rotating the cap. As can be seen, complex affordances provide more interactions.

Using the Activity Theory, Bærentsen and Trettvik (2002) explained Gaver's nested affordances in three levels (Pucillo and Cascini, 2014). At the highest level, there is the need to perform an activity that includes the goals and motives to carry out the *activity*, such as winning a football match and feeling happy. They called this level *need-related affordances*. The middle level describes the possible actions required to achieve the activity. In a football match, the players have to score, attack and defend, dribble and tackle, and prevent goals. These are called *instrumental affordances*. Then at the lowest level, there are the *operations* related to Gibson's affordances, such as kicking the ball, punching the ball, and grabbing the ball. These were called *operational affordances*. Similarly, Galvao and Sato (2005) differentiate between *functional affordances,* such as manufacturability, maintainability and cleanability, and operational affordances, as described by Bærentsen and Trettvik (2002).

Therefore, customer needs (e.g. the need to provide speech and language itnervention) are generally expressed as need-related or instrumental affordances and as the artefact gets defined, so do operational affordances.

Affordances present in technological artefacts

Taking a cue from the original meaning of affordances, that is, action possibilities, it can be said that affordances are present in every man-made artefact, including technological products with embedded software, such as tablets and cars. A vehicle's engine control unit controls the engine so that the vehicle runs at optimal performance, and a central processing unit (CPU) provides the instructions and power for the tablet to perform tasks.

Bærentsen and Trettvik's (2002) three-tier classification of affordances can be used to further understand why McGrenere & Ho (2000) point out that possible affordances of computer systems are not just limited to physical interactions with the hardware (operational affordances) such as typing on the keyboard, clicking the mouse button or seeing the interface on a screen, but a myriad of possible actions that are enabled through in-built software that allows certain activities. A video editing software allows user to edit video clips (need-related affordances), but this also involves, importing, selecting, cutting, and exporting among others instrumental affordances. Studies such as Churchill et al. (2012) and Xue and Churchill (2020) describe how software-enabled technology are providing affordances through in-built tools which before were not possible. Software facilitates, replicates or eliminates the need for certain tasks, adding convenience but also reducing possibly beneficial interaction. For instance, a card-posting game would require a child to grab a card and insert it in the appropriate category box. Replicating the concept on a tablet application involves just a swiping gesture.

2.3.2 Designing affordances in artefacts

Maier (2011) looks at affordances as "*what one sub-system provides to another subsystem*", a sub-system being either a user or an artefact. Thus, when one system is an artefact and the other is the user, it is said that an artefact-user affordance (AUA) exists. Similarly, two artefacts or two internal sub-systems can interact with each other, resulting in artefact-artefact affordances (AAA). Maier views the design process as the "*specification of an artefact that possesses certain desired affordances and does not possess certain undesired affordances*". This means that the designer also needs to understand what interactions need to be restricted. Cormier et al. (2014) remark that AUA and AAA should be expressed in terms of the relational benefit that affordances shall provide to intended users.

Maier (2011) points out five characterisitcs of affordances:

- complementarity, meaning that the relationship depends on two interacting systems;
- imperfection, meaning that affordances are not the same for all users and the design can always be improved;
- polarity, in the sense that there are positive (desired) and negative (undesired) affordances;
- multiplicity, that is an artefact may posses multiple affordances; and,

- quality, which refers to how well a behaviour is allowed. For example, a briefcase is more suited for storing documents rather than sitting on it.

Maier (2011) explains that these affordances must be determined at an early stage and must be designed by designers who have:

> *"the knowledge of the context in which the artefact will be used…*
> *including everything that will need to be done with the artefact…*
> *not only what the artefact will need to do itself".*

Therefore, in affordance-based design, to completely define the properties of an artefact, the designer needs to understand the interactions that the user will have with the artefact (AUAs) and the interactions between the various sub-systems in the artefact (AAAs). The identification of these affordances along with the process of realising them are explained in a systematic design framework developed in Maier and Fadel (2009) that focuses on desired and undesired affordances rather than functions. This framework, illustrated in Figure 2.7, is structured on Pahl et al.'s (2007) engineering systematic design process explained in Section 2.2.1. Maier (2011) also adopts the idea of the function structure (Figure 2.2) in order to organise and graphically represent customer needs as affordances of the artefact, mainitaining a relational viewpoint between the characteristics of the user and the chacteristics of the product.

Task 1

The first task of designers is to establish the desired and undesired AUA that the artefact should have for all users who will interact with it, not just end users. The generic affordance structure template illustrated in Figure 2.8 serves as a checklist that identifies the product's life cycle and the possible interactions the artefact will have. The identified affordances are then prioritised and listed in the affordance structure.

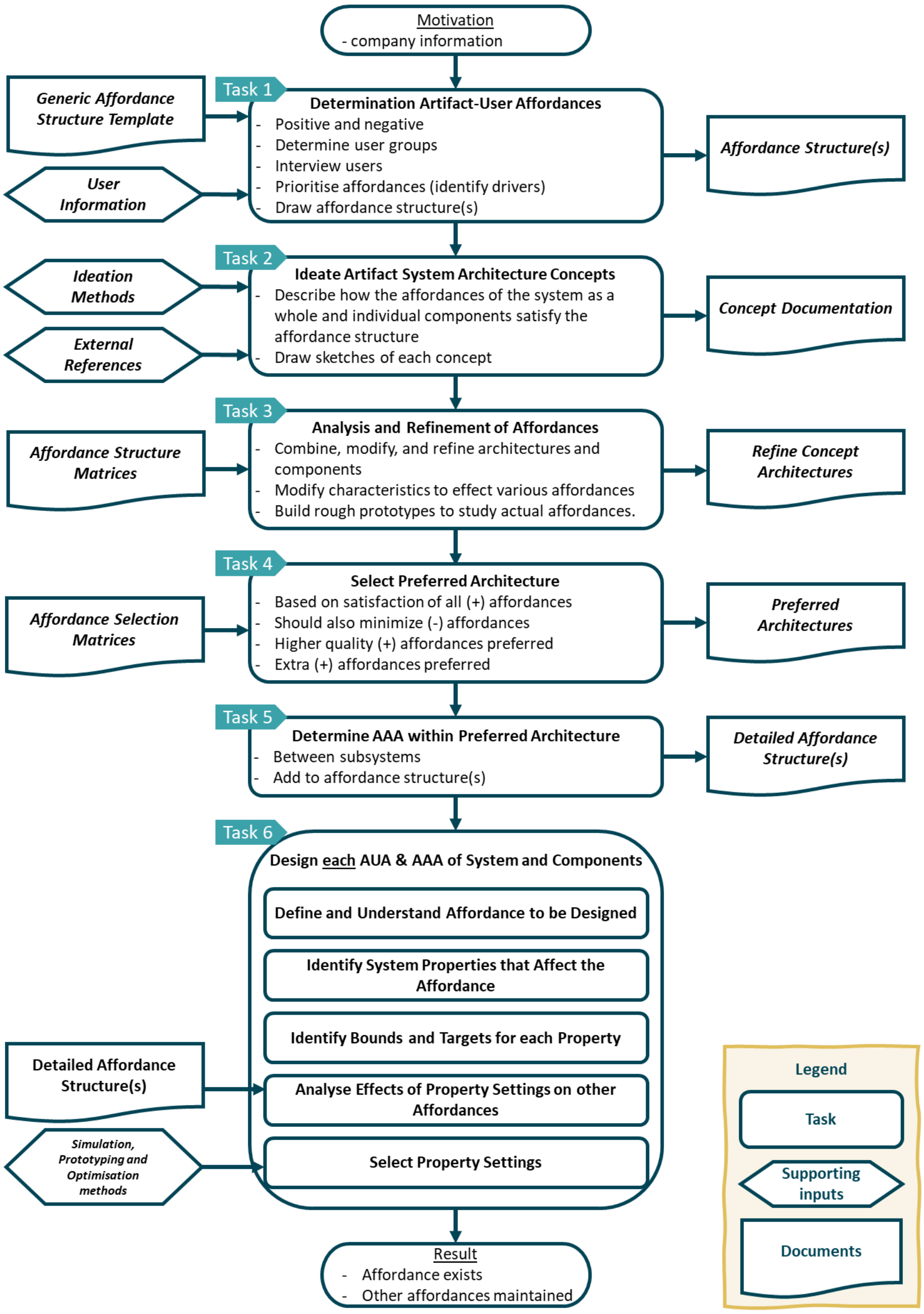


Figure 2.7: The affordance-based design process, adopted from Maier (2011)

Task 2 Like the concept design stage of the ESD framework (Section 2.2.1), the second task is to generate concepts for the artefact's whole architecture and components. Ideation methods and external references may be used to generate ideas and produce concepts. Because affordances are dependent on form, conceptual representations produced during this task will influence whether the AUA will be satisfied.

Task 3 The third task is to analyse and refine the affordances of the concepts. This is accomplished by modifying the characteristics of the concepts. Effort is made to remove the negative affordances of each concept by modifying the respective characteristics. At this stage, concepts may need to be embodied to fully understand the affordances of each component.

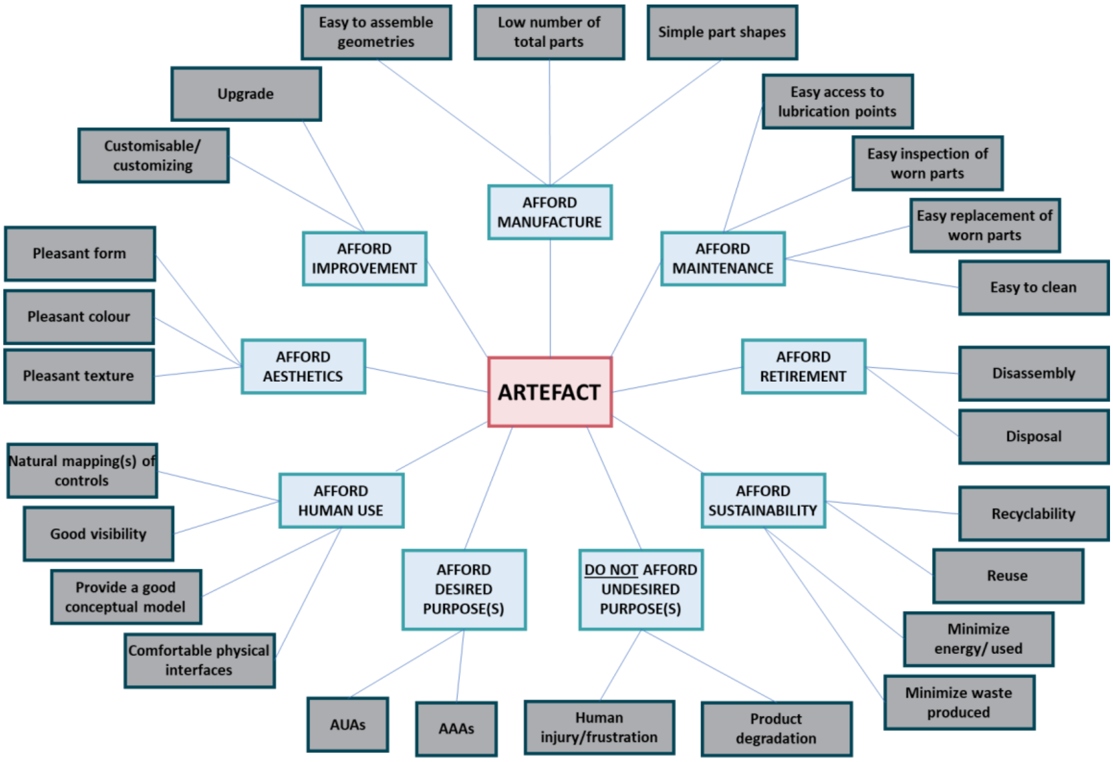


Figure 2.8: The generic affordance structure template, adopted from Maier (2011)

Task 4 In the fourth task, the designer needs to select the optimal architecture based on how well the concepts satisfy the positive (desired) affordances and eliminate the negative (undesired) affordances. A design which affords the same purpose and additional desired qualities is considered to be a better design, whereas a similar design which has undesirable affordances is considered a worse design.

Task 5 The purpose of the fifth task is to determine the AAAs that exist between subsystems in the chosen architecture. Typical AAAs are the information, electricity, forces that will be afforded between sub-systems. The identified AAAs are then added to the affordance structure.

Task 6

In the original representation of the framework, the sixth task consists of several steps. In Figure 2.7, these have been grouped for conciseness. The purpose of this major task is to design each affordance of the chosen concept architecture and components.

2.3.3 Differences between Function and Affordance-Based Design

First difference

The key difference between function and affordance is that an affordance describes how an artefact relates to the user. Function-based design describes only what action(s) the designer wants the artefact to do. Therefore, it does not look at how users will interact with the product but only at how the desired working function will be achieved mechanically, electrically, digitally or combined. Affordances are not limited to the function or the behaviour permitted by the artefact's function, but include all possible actions with the artefact. Affordance-based design describes what the designer wants the user to do with the artefact. This proves to be useful in instances where requirements are not only functional. Considering that children can play with objects that have functions other than play, like carton boxes, it is believed that the best approach to tackle the design of toy-related artefacts is through the lens of affordances.

Second difference

The interactions between function, form and affordances are depicted in Figure 2.9. Affordances invoke functions to bring the user closer to the artefact. Thus, functions are related to affordances. However, unlike functions, operational affordances are dependent on the form of the artefact. The form influences the relationship between the artefact and the user. Brown and Blessing (2005) argue that form needs to be known in advance to establish the artefact's affordances. However, seen from the lens of conceptual design, it is argued that, if the required affordances are already known, the form can be influenced.

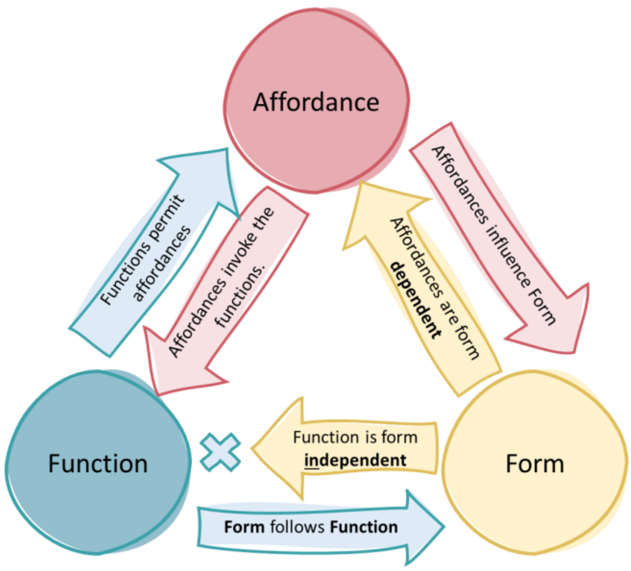


Figure 2.9: Affordance dependences

Section 2.4 describes a study conducted to understand the challenges that designers encounter in the design process and whether these challenges would be different if they had to design an artefact for speech and language therapy.

2.4 Study: Understanding Designers' needs for the Design of SALTTs

Reason for the selection of participants

Chapter 3 explains that therapeutic toys stem from mainstream toys, meaning that they have properties attributed to play. For this reason and because they are most likely to design a product for young children, toy designers were selected as participants for this study. Semi-structured interviews were carried out to investigate the current toy designers' reality.

2.4.1 Structure of Study

As shown in Figure 2.10, the overall objective was to determine the requirements for a framework to support the design of therapeutic toys. Other considerations related to the design of SALTT artefacts will be established through a study explained in Chapter 3. The questions were categorised into three parts.

The first set of questions aimed to capture current practices in the design of toys. The second set of questions enquired about the use of any design support tools.

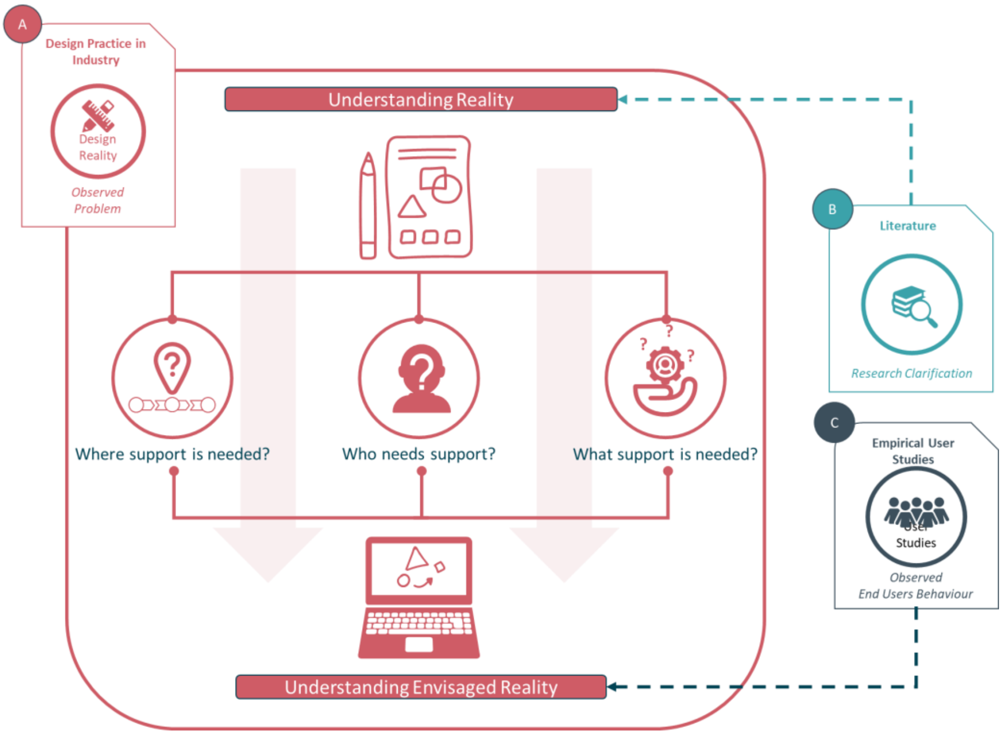


Figure 2.10: Investigating the design problem

The last set of questions probed designers on how they would tackle the design of therapeutic toys, and at which stage of the design process would design support tools be most needed. The following were the specific objectives of this study:

Objective 1 To identify the design stage that toy designers would find most challenging.

Objective 2 To understand whether experienced designers need the same level of support as novice designers when designing therapeutic toys (TTs), considering that the field of SALTTs would be new to both experienced and novice designers.

Objective 3 To investigate the type of support designers would need for the most challenging design stage.

2.4.2 Participants

The research protocol and the data-collection instruments used in this study were reviewed and approved by the ethics committee of the Faculty of Engineering at the University of Malta (application number 3886-19122019).

The study was conducted with 22 persons (12 males and 10 females) , hereinafter referred as participants, whose toy industry experience varied between one to 40 years, with a mean of 11.16 years and a standard deviation of 10.71 years. Out of the 22 participants, 17 were currently in a designer role, of which six designers were also (co)owners of companies. The other five participants were product managers directly involved in the toy-development process. Eleven participants work in large companies (> 60 employees), nine work with small (S) companies, and two are freelancers (FL). All demographic data of the participants are listed in Table 2.1.

*Table 2.1: Participants Information (*YOE: Years of Experience)*

Participant	Gender	YOE*	Current Role	Org. Size	Country
DS1	M	10	Product Manager	L	Spain
DS2	F	1	Product Manager	L	Spain
DS3	M	22	Founder, Designer	S	Italy
DS4	M	40	Founder, Designer	S	Sweden
DS5	F	6	Freelance Industrial Designer	FL	Italy
DS6	M	4	Product Designer	L	Poland
DS7	F	2	R&D Product Designer	L	Switzerland
DS8	F	11	Designer	L	Italy
DS9	F	13	Product Designer	L	Thailand
DS10	F	12	Design Manager	L	Spain
DS11	M	1	Designer	S	Spain
DS12	M	2	Product Director	L	Spain
DS13	M	26	Founder / Design Director	S	UK
DS14	M	23	Founder, Designer	S	UK
DS15	M	25	Founder, Designer	S	UK
DS16	F	1	Master's Student, Designer	S	UK
DS17	F	12	Development, Marketing and Sales	L	UK
DS18	M	5	Creative Director, Designer	S	Canada
DS19	F	21	Toy Designer & Lecturer	FL	US
DS20	F	2	Co-founder, Designer	S	US
DS21	F	4	Toy Designer	L	India
DS22	M	4	Product Designer	L	India

2.4.3 Procedure

Only ten participants agreed to participate in live semi-structured interviews. The rest wished to fill out an offline questionnaire in which they were asked to provide comments for every answer. They did not participate in live interviews because of language barriers and the length of the study. From the feedback received, it was noted that comparable results were obtained between the live and offline interviews. Three of the live interviews were conducted in person after visiting a toy-factory cluster in Spain, while the other interviews were conducted via Skype. The live interviews lasted between 60 to 90 minutes, as discussions followed every question to obtain further insights.

All live interviews were voice recorded and transcribed verbatim for post-analysis. Key phrases from all the participants were coded, sorted, and clustered into identified themes by following the procedure of Braun and Clarke (2006) for thematic analysis. The identified core themes answer the objectives described in Section 2.4.1, and quantitative input from all the participants was used to infer trends among the participants.

2.4.4 Thematic Analysis: The need for a Design Support Framework

The main themes, illustrated in *Figure 2.11*, were identified whilst trying to understand the problems that toy designers have in their roles.

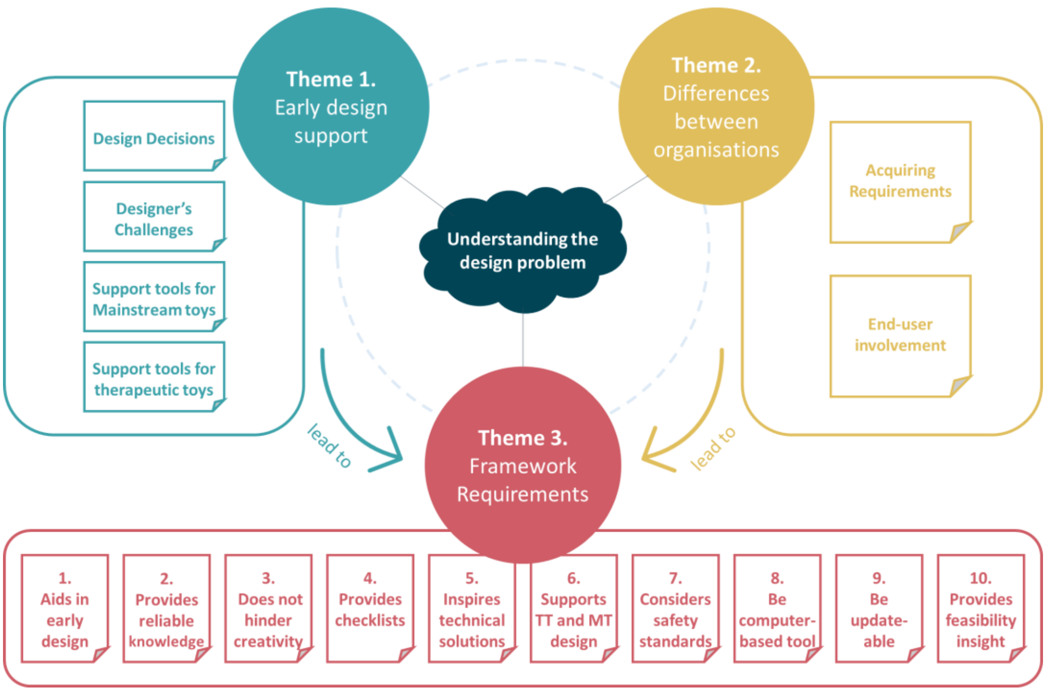


Figure 2.11: Understanding the design problem themes

Theme 1: Early Design Support

Design decisions

End users may not be involved during the design process because of the experience that designers build up along the years. DS13 explained that:

> *"Decisions in toys are often gut feelings because you believe from experience this idea will work. Sure, there are inputs at concept stage to help understand what is popular but, as the process develops, then cost normally drives most decisions"*.

The participants were asked to rank the design stages based on the most critical decisions made. Their feedback was weighted using the Rank Order Centroid (ROC) method (Sureeyatanapas, 2016). The result, illustrated in Figure 2.12, shows that the most critical decisions are made at the task clarification stage, followed by the concept, embodiment, and detail design stages.

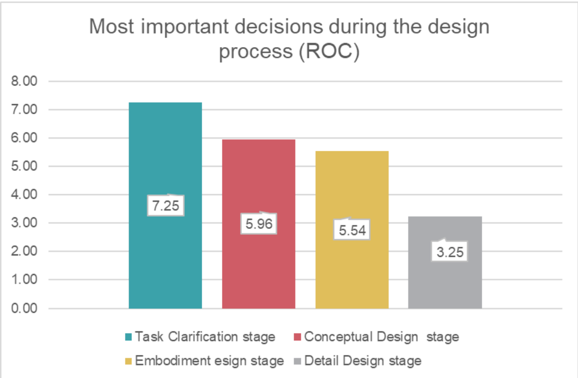


Figure 2.12: Toy designers' most important decisions

Designers' challenges

The participants were asked to mention which design activities designers find most difficult. Figure 2.13 shows that challenges occur during transitioning between the task clarification and the concept design stage, starting from "understanding of the requirements", peaking at "translating the requirements" and, then, "generating concepts". The effect of these challenges carries on into the concept stage, as five participants claimed to find it difficult to choosing the principle solution.

Figure 2.13: Toy designers' most challenging tasks

The participants explained that understanding the requirements is difficult because *"some of the requirements are not necessarily black and white - there's lots of grey space", and "translating requirements is not a formula. Even with experience, this task remains difficult because it requires thinking and creativity"*, and *"you can only interact with so many end users. And so, you only have the perspective of those end users in your biases"*. DS2 stated that if designers understand the requirements of the product correctly, they can make the right product for the market and consumer. On the other hand, DS10 confirmed that the product specifications are not available until prototyping has started, unless a client commissions the toy. In fact, DS20 reported that, *"when you get to that first prototype, you're actually making a hypothesis that this is the best approach based on everything you know"*. Although experience and tacit knowledge are important characteristics of designers, all participants said that they refer to past toys or competitors' toys located in special rooms or labs within the organisation for inspirations. However, when referring to old toys, care must be taken due to frequent changes in safety standards.

Interactions with product development stakeholders

Participants indicated the number of interactions they have with stakeholders during each design stage. As shown in Figure 2.14, the lowest number of interactions that designers have occur during the task clarification stage, most of which are with those who provide the end-users requirements.

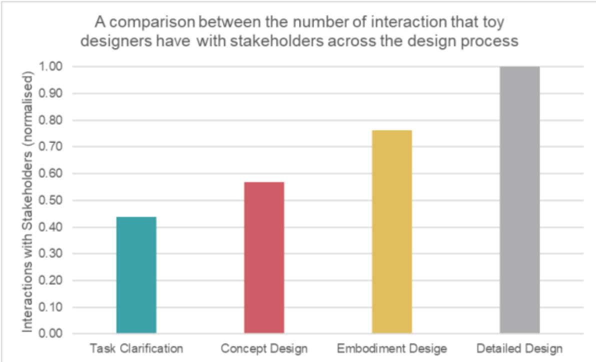


Figure 2.14: The number of interactions that designers have during the entire design process

When asked whether the increased presence of end-users during the design process would help them design better toys, 40.91% strongly agreed, 36.36% agreed, whereas 13.64% gave neutral feedback and 9.09% disagreed. A Kruskal-Wallis difference test revealed no significant difference between differently experienced participants (p-value = 0.739), implying that both novice and experienced designers have similar opinions.

Design support tools for mainstream *toys*

All participants confirmed that no design support tools are used to support decision making, except for 3D modelling software during late design stages. When asked to indicate whether a support tool would help design better toys, 27.27% of the participants strongly agreed, while 36.36% agreed. Meanwhile, 9.09% of the participants disagreed or strongly disagreed that a support tool would help. DS16 explained that a tool would be useful to justify one's decisions based on actual data such as children's preferences. On the other hand, DS17 said that toy design is an art which is experience-led rather than data-led. Only 18.18% of the participants provided a neutral reply, mainly because they could not understand how a design support tool could assist them. The Kruskal-Wallis test (p-value = 0.349) revealed no significant difference between differently experienced designers on the usefulness of support tools.

Design support tools for therapeutic toys

As listed in **Error! Reference source not found.**, for question A (QA) the majority (54.5%) of the participants strongly believed that the design process for TTs and MTs is the same. Those who disagreed claimed that the process of designing is very similar, apart from identifying the needs. For question QB, most participants (86.4%) said that they strongly believe that identifying the requirements of TTs is more complex than for MTs. A Kruskal-Wallis test for both questions showed no significant difference (p-value = 0.566, 0.068[3]) between their reply and their years of experience.

Table 2.2: Results for questions on designing therapeutic toys

	How much do you agree with the following statements?	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
QA	The design process for therapeutic toys is similar to that of mainstream toys.	13.6%	9.1%	22.8%	0%	54.5%
QB	Eliciting requirements for therapeutic toys is more difficult for general toy products.	0%	13.6%	0%	0%	86.4%
QC1	A computer-based tool for decision-making is more suitable for general toy products only.	0%	40.9%	45.5%	0%	9.1%
QC2	A computer-based tool for decision-making is more suitable for therapeutic toys only.	0%	40.9%	40.9%	0%	13.6%
QC3	A computer-based tool for decision-making is suitable for both general toy products and therapeutic toys.	0%	9.1%	31.8%	0%	59.1%

Three similar consecutive questions (QC1, QC2 and QC3) were asked to understand whether a design support tool would be suitable just for MTs, just for TTs or for both. Their responses for 'strongly agree' changed from 9.1% to 13.6% to 59.1%, respectively as shown in **Error! Reference source not found.**. In the case o f QC3, a significant difference (p-value = 0.047) was found when a Kruskal-Wallis

[3] The small p-value resulted because of the three participants who disagreed, two participants had over 20 years of experience, and the other had only four years of experience.

test was carried out, showing that the years of experience affect the need for support tools.

In a separate question, 72.7% of the participants said that design support for TT design would be needed during task clarification, 18.2% said during concept design and 9.1% said during the detail design. The two participants who preferred support in the last design stage stated that their biggest challenge is designing for mass production. No significant difference was found (p-value = 0.38) when testing for difference across participants' replies with respect to their years of experience.

Theme 2: Differences between organisations

Acquiring Requirements

The participants explained that a toy is conceived (i) from an idea, following observations (23.70%) or through intuition (8.50%); (ii) from an identified need, either as a market gap (27.10%) or by following the competition and market trends (22.05%), or (iii) from an external customer's direct request (18.65%). Participants working with large organisations said that designers are never involved in the product planning stage unless they are part of management. Thus, they would have to work with what the marketing team provides. Half the participants said that the requirements are passed either as a one-page design brief containing an image portraying the vision of the marketing and sales team/management. Less frequently, the customers' needs are communicated verbally (18.20%), or the idea is self-proposed (31.8%) via a team effort.

End-user involvement

Results indicate that end-users are likely to be involved during prototype testing in large companies because before investing money, companies must be sure that the product will work. DS5 explained that "*in a very big company, other people work with end-users and the designer is not involved… and the designer has to* *work with what they tell him*". In contrast, small companies whose designers are the (co-)founders, are more likely to go through the design process all by themselves and thus tend to be closer to the end users, and an idea is tested during the multiple design stages. Furthermore, DS21 noted the difference between design students, freelancers, and employees, and explained that, "*when you are working on a college project, you apply an accurate design methodology. When you are freelancing, you also apply research. But when you are in the corporate world, some companies do not spend much of their time in research. They want you to complete [the project] in a very short period*".

Theme 3: Framework Requirements

To help designers cope with these difficulties, ten requirements for a user-centred design support framework were identified. These requirements are cross cutting with other industries even though they were collected from toy designers. Note that all requirements within this dissertation will be articulated as per the generally agreed guidelines mentioned in Cormier et al. (2014), Pahl et al. (2007) and Ulrich et al. (2020), where each principle requirement must be:

- solution independent statements, expressed in terms of what the product has to do and not how it should be done
- statements that express the needs as precisely as the raw data
- statements that express the requirements as an attribute of the solution
- statements that do not contain the words 'must' or 'should'
- positive statements

The design support tool has to:

Framework Requirement 1

FWR1: Support the task clarification stage

Based on the participants' responses, support is needed in the task clarification stage. DS5 stated that "*the other stages are similar to other toys, but the task* *clarification has to be done well, and one must know about the specific target*". Similarly, DS20 stated that she would not know the considerations that would need to be collected.

Framework Requirement 2

***FWR2**: Provide user and therapy-related knowledge from reliable sources*

Therapy-related requirements need to be available from the beginning and come from reliable sources to help designers create appropriate SALTTs. 95.45% of the participants said that designers should consult clinicians when developing therapeutic toys, whilst DS15 stated that the needs to be met have to be researched, just as with traditional toys. Participant DS19 stated: "*I would not know where to go or how to start because I would probably try to reach out to teachers or institutions and see what they know about it*". However, she also commented that it is not always highly effective to talk to child psychologists or occupational therapists because toys are experiential, and unless the designer has a lot of experience, the clinicians may not be able to visualise that experience in their mind.

Framework Requirement 3

***FWR3**: Provide solution-independent support*

Problem abstraction is about identifying needs and not defining how solutions are to be implemented (Cormier et al., 2014). The design process should remain creative and not confined. DS3 highlighted that *"tools may help. I think they can provide data, statistics, etc. but not replace the creative stage of designing… I don't want any interference".*

Framework Requirement 4

***FWR4**: Consider the product life cycle*

Participants suggested how design support should be offered during the task clarification stage. DS20 suggested *a checklist, whilst DS18 stated that support needs to* "be *very granular so you can select information for a specific customer group*". Personas may help in understanding the users' demands and wishes by empathising with their needs (Case, 2013). This includes understanding of the different contexts of use, their abilities, development level, and cultural factors, among others.

Framework Requirement 5

***FWR5**: Provide inspiration and identify market gaps*

The task clarification stage is critical in defining the path that the final design will take. DS5 remarked that a tool can support the research for inspiration to find technical solutions and may also help her understand the cost of different solutions. Knowledge about what makes children choose and play with certain toys rather than others should be included in the framework as this can provide a competitive edge apart from better attention spans when considering TTs. Therefore, the framework should capture design knowledge from past products in such a way that the designers are able to reference them or get inspired.

Framework Requirement 6

***FWR6**: Inform about users' preferences*

The toy industry, like many other industries, is highly competitive where developing successful product requires designers to know the market well. All participants specified how important it is that the framework includes knowledge about *children's preferences, based on their age and gender.* DS19 specified that *"children should not be left out of the equation. The knowledge that we get is how they play and sometimes children play in more imaginative ways [than we* *envision they will]".* This is why research on children's preferences such as Balzan et al. (2019), is important.

Framework Requirement 7

***FWR7**: Consider safety standards*

Standards affect the design and have an influence on the price, but in the end, they dictate whether a product can be launched into the market or not. Participants were asked to rate the most important design factors for mainstream toys. Results were ranked using the ROC weighting method and are shown in Figure 2.15. Safety, function, and play value are considered the primary considerations, closely followed by target skills and cost of manufacturing. The third cluster of design factors consists of aesthetics, durability, ergonomics, and ease of manufacturing.

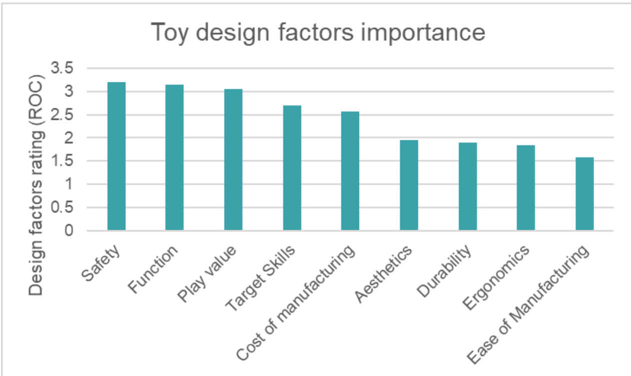


Figure 2.15: Ranking for toy design factors

Participants emphasised how important it is for designers to be up to date with safety standards, as one cannot implement a user requirement if it is not allowed by the standard. DS21 stated that safety needs to be considered from the beginning, even when developing concepts.

Framework Requirement 8

***FWR8**: Be implemented as a computer-based tool*

Through the interview, participants reported that market research is carried out through online research tools and mood boards. Although most of the time such generic tools are not specific to the required needs, they tend to provide a good starting point to kick the design process. This reveals that computers are used as early as the task clarification stage. The majority (81.8%) of the participants said that a design support should be computer-based whereas the rest said that it should be paper-based. DS21 mentioned that having a computer-based design support tool would complement the way she works, whilst DS12 complained about the use of paper in today's digital era. Rzevski (1983) points out various reasons of why designers should use computer-based tools as they can provide "*tentative design solutions*" through effective storing, processing, and displaying of large quantities of information and adequate knowledge.

Framework Requirement 9

***FWR9**: Be updatable*

The participants said that the toy industry frequently experiences radical changes in various aspects. DS18 claimed that safety standards change every year, making a lot of their old products obsolete. Furthermore, the market is very dynamic and, so, a design support tool would need to be updated regularly. Thus, apart from exhibiting their products at toy fairs, companies are also doing research on prices and trends, such as colour schemes, use of technology and characters.

Framework Requirement 10

***FWR10**: Provide economic and production feasibility insight*

One objective of designers is to stay within target budgets even when producing the initial concepts. DS13 wrote that *"it is easy to develop hundreds of ideas, but the art of picking the winners and the ones with most overall commercial viability is not"*. As explained by DS1, initial ideas are eliminated by asking economic feasibility related questions such as, "*Does it cost a lot of money?*" and "*Do we have to invest in many moulds?*". While cost estimation models make more sense during design synthesis, at the task clarification stage, requirements permit organisations to set budgets and decide which requirements can be considered.

2.4.5 Discussion

Difficulty in understanding requirements

Participants explained that their main challenges occur during the early design phase because requirements are not clear or not easily understood. For this reason, they struggle to generate the first concepts. Moreover, this phase necessitates that designers make several important decisions which will affect the course of product development and whether the artefact will be successful (Finkelstein, 1994). On the other hand, when the client provides the requirements, the design process is less uncertain, as designers know exactly what they need to deliver. Pahl et al. (2007) point out that there is less room for creativity in such situations because designers "*are bound by the planning ideas of others*" when developing made-to-order systems. Figure 2.16 depicts the relationship between design freedom, design knowledge and uncertainty. The lack of design knowledge and a high degree of uncertainty make this phase challenging. As a result, designers can be more creative. Thus, as per *FWR1*, the framework should support the task clarification stage.

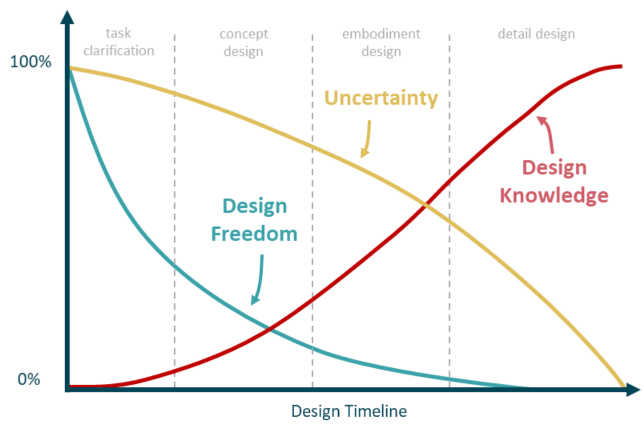


Figure 2.16: Relationship between design freedom and design knowledge, adapted from Fernández et al. (2002) and Mueller and Ochsendorf (2013)

Domain knowledge

These relationships show that as design knowledge increases, creativity and uncertainty lessen. It is also postulated that experienced designers would converge to the optimal solution quicker than less experienced designers (Youmans and Arciszewski, 2014), which may or may not be less creative if appropriate divergent methods for creative solutions are used (Lopez-Mesa et al., 2002). Thus, it is important to differentiate between *design knowledge* and *domain knowledge*. The former is attributed to the experience and tacit knowledge that the designer builds up along the years whilst the latter is about the specific field or context in which the artefact will be used. Therefore, uncertainty can exist on these two levels. In line with *FWR2,* supporting designers with domain knowledge decreases uncertainty that does not affect design creativity but increases the probability of developing a successful design that meets the intended purpose.

Clearer requirements

Participants complained about the vagueness of the design brief as during the concept design stage, the specifications are usually not mature enough. They become clearer once concepts are prototyped and tested (Ulrich et al., 2020), and keep on being refined up until the final design stage (Pahl et al., 2007). Therefore, not to affect creativity but reduce uncertainty, support should be given at the requirements level to satisfy *FWR3*.

Bringing designers closer to end users

Elicitation of requirements is a demanding and time-consuming process. Like other industries, the lead time to produce a product in the toy industry is also diminishing. This means that designers have less time to do their research, listen to the end-users, and to test ideas and prototypes before starting production. Furthermore, when working in large organisations, designers rarely interact with end users and, so, designers must use their experience, tacit knowledge, and personal preferences to guide the interpretation of the design brief, as can be seen in Figure 2.17. Although, the target product that management had in mind may still be achieved, it will be much more difficult to meet the actual end-users needs when explicit knowledge is unavailable. As a result, end-products with incorrect or missing properties are possible.

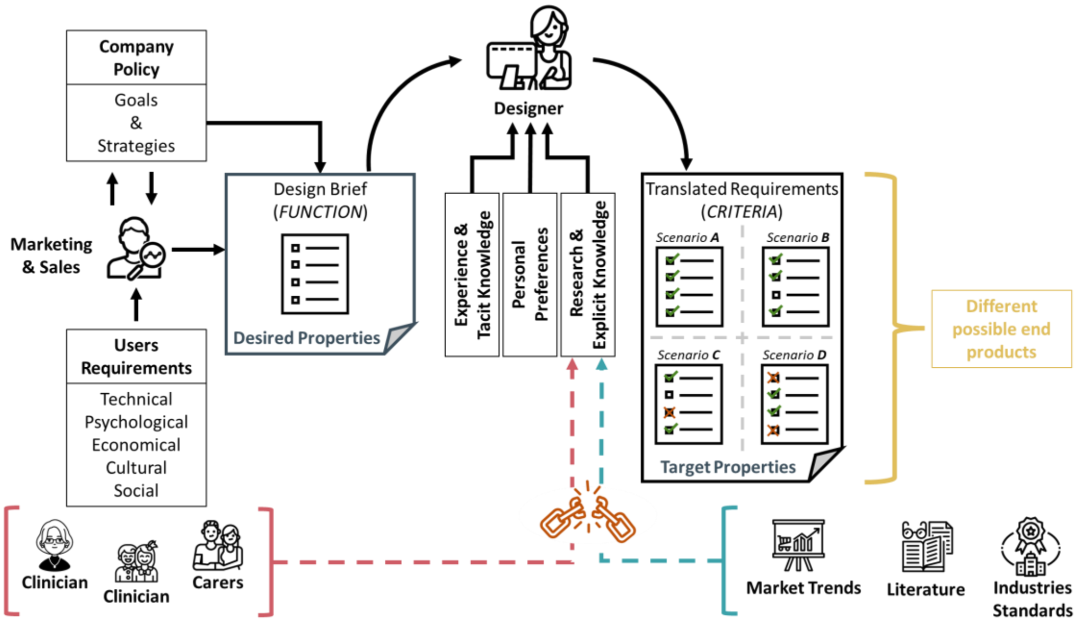


Figure 2.17: An illustration of the phenomenon when customer requirements are not taken into consideration

As explained in Chapter 3, the end-users of SALTT artefacts are the clinicians, caregivers, and children. The use phase (in which end users interact with the product) is the longest period within the product's lifecycle. *FWR4* states that support should be provided for the whole lifecycle. An affordance-based approach would reflect on every interaction that the product would have. Use-phase domain knowledge would inform and bring the designer closer to the user.

Biases in designers' preferences

Participants mentioned that the designers' vision for the product might differ from what the end users want. Direct observations of the end-users preferences or the market trends can provide insights and eliminate biases. Therefore, by implementing requirements, designers will be guided to understand what exists in the market (*FWR6)*. On the other hand, *FWR3* states that support should not bias or limit the designer's creativity. Therefore, support should remain solution independent. Being able to compare the product with what is already available on the market may inspire the designers.

In Ulrich et al. (2020), the task clarification stage is considered part of the concept development phase and is also called the front-end process of product development. This is because what is decided in the beginning will be reflected in subsequent design stages. As shown in Figure 2.18, the cost incurred during the design process is around 5%, while the remaining costs are attributed to direct materials, direct labour and manufacturing overheads (Dieter and Schmidt, 2009).

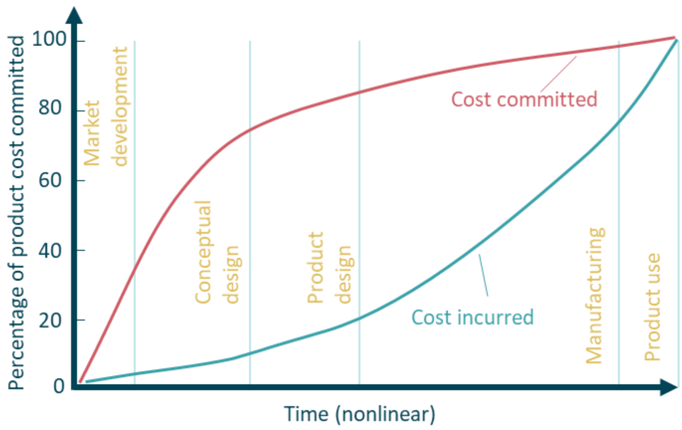


Figure 2.18: Product cost commitment during phases of the design process (Dieter and Schmidt, 2009)

The cost incurred during market development is even much smaller. However, design decisions up to this stage accumulate to about 30% of the total committed manufacturing cost. A further 50% of the committed costs are influenced by the decisions made once the design process is complete and the final 20% of the costs are affected by the commitments made beyond the design phase. For this reason, requirements engineering has been given appropriate attention within the design process (Darlington and Culley, 2002b).

Experience gained

Apart from economic feasibility, participants were mostly concerned about safety. Safety is related to the synthesised solution and can never be compromised (*FWR7*). Designers also gain experience by reviewing existing products. They explained how existing toys are referenced to understand how competitors achieve a particular function, to benchmark or obtain a reference to a specification, or to see how a design can be improved further. This is in line with *FWR5*. However, care must be taken to avoid affecting *FWR3*.

The use of computer-based tools

Overall, the participants looked forward to being offered support at the beginning of the design process to help them make informed decisions, clear doubts, and avoid risks. As a result, such means can also speed up the design process because research takes a lot of time. The benefits of a design support means for therapeutic toys were perceived better because they were not familiar with the diverse needs of their end users. On the impetus of computer-based design support tools, Pahl at al. (2007) describe that such tools should "*enhance the creativity, engineering knowledge and experience of designers*" whilst "*leaving designers free to concentrate on new designs and customer-specific one-off products*". Therefore, *FWR8* shall be complementing their workflow and mitigating the challenges unrelated to creativity if the framework can be implemented as a computer tool.

Type of design support

Whether to opt for functional or affordance-based design support depends on the nature of the end-users requirements and the designers' experience in the artefact domain. Due to the fact that affordance-based design places the user in the artefact context, it provides an edge over function-based design because it considers functional and human interaction. This means that ABD helps designers familiarise themselves with the context. Because this aligns with *FWR2,* an ABD approach would complement the framework.

The full picture

Designers want to have a solid foundation of what is required from the product before starting to create concepts. In fact, not to miss out on important considerations, in FWR4, checklists and personae were mentioned as means to see the whole picture. Similarly, designers wanted to be guided on safety standards (*FWR7*) and economic and production feasibility (*FWR10*). The affordance structure template (Maier, 2011), shown in Figure 2.8, provides a generic decomposed list of general affordances that artefacts provide.

Updating knowledge and requirements

Although requirements are presented in the beginning of the project, it does not mean that they should not be reassessed during later phases. As end-users requirements or preferences change and new knowledge becomes available, the framework should allow the designers or other experts to update the relevant information (*FWR9*).

2.4.6 Limitations of study

Finding participants

One of the challenges encountered in this study is finding further participants as no contacts were available locally. In quantitative studies, the reliability of the collected data relies on the various demographic factors, but a large sample size diminishes variations and allows the research to reach saturation. Although data were gathered from 22 participants only, the questions were not entirely quantitative, but qualitative feedback was collected. Furthermore, participants' experiences ranged from one to 40 years. Statistical analysis showed not much variation between the responses from highly and lesser experienced designers.

Most participants provided feedback through a questionnaire

Related to the previous limitation, only ten of the participants were interviewed directly, whereas 12 participants responded to a questionnaire. Because every question requested a mandatory comment for their choice, participants had to provide a reason for their answer. Although written comments were not as detailed as verbal ones provided by live interviewees, the comments were still insightful and in accordance with data collected from the interviews, especially when discussing experiences and the most challenging tasks.

Participants were related to the toy industry

All participants were linked to the toy industry and therefore the findings that resulted from this study may only be applied for the design of toys. However, none of the participants had direct experience with therapeutic toys or other special toys for children with particular needs, and the fact that they requested support during the task clarification stage means that designers would find it difficult to work in areas that are completely or almost new.

No pilot study

Due to the small number of participants that were recruited, a pilot study was not performed. However, it must be noted that all participants were asked the same questions, meaning that the protocol did not change as more participants were interviewed.

2.5 Chapter Conclusions

The need for a framework

Design is a creative and knowledge-intensive process that involves continuous decision making from start to finish, on which, the final artefact depends. Due to the complexity of artefacts and the challenging nature of the designers' tasks, systematic methodologies are available to guide the design process. Based on the arguments and findings presented in this chapter, an affordance-based approach looks at how the users will be using the artefact.

Considers domain knowledge

The affordances mindset would make designers conscious of the context in which therapeutic devices would operate. Design tasks may feel less challenging when designers build experience. However, this research study concluded that the transition from the task clarification stage to the concept design stage remains the most demanding aspect of design, often resulting from a lack of domain knowledge. The designer is expected to have a complete understanding of the domain for which the artefact is meant to be used, including the users, the context and the interactions with the artefact. Vague design briefs cannot be translated into requirements (or specifications) unless the designer has access to explicit knowledge.

Support at the task clarification stage

An avenue to provide design support in this area has been identified. It can be generally said that artefacts go through similar manufacturing and disposal processes. Therefore, certain affordances can be predicted from the affordance structure template or relevant literature. However, when it comes to the artefact's purpose, the template will not be useful to the designer in determining the need-related and instrumental AUAs, and AAAs as the interactions with the end users are specific to the domain of the artefact.

Because decisions taken at the task clarification stage will influence how the subsequent stages will materialise, designers must be provided with domain knowledge that clarifies the artefact's requirements without limiting their creative input. Although requirements derive from customer needs', with a better understanding of the end-users problems, designers can approach the design task with a mindset that can perceive how the users intend to operate the artefact. This conclusion stems from literature findings and the design problem identified in the study.

The aim of this Ph.D. work is to tackle this design problem within the specific field of SALTTs. In the next chapter, this domain will be characterised, and the overarching requirements for SALTTs will be determined.

3. CHARACTERISING THERAPEUTIC TOYS FOR SPEECH AND LANGUAGE THERAPY

Childhood is measured out by sounds and smells and sights, before the dark hour of reason grows.

John Betjeman, Summoned by Bells, 1960

Chapter 3 explores the research domain within which the study was placed, starting with section 3.1 which explores speech and language therapy (SLT). Information within this section has been gathered from literature and the focus group study described in Section 3.4. Section 3.2 focuses on the importance of play in children's lives. The concept of affordances and how it relates to play and toys is explained in Section 3.3. Section 3.4 presents findings of a study aimed to explore the main challenges that SLPs find in their work, followed by the requirements for speech and language therapeutic toys (SALTT). To comprehend how children's attention spans and engagement levels are affected by the affordances available, Section 3.5 describes a study that was carried out with preschoolers. Section 3.6 draws out the salient points of this chapter.

3.1 Speech and Language Therapy

What is Speech and Language Therapy (SLT)?

Speech and Language Therapy (SLT) is provided to adults and children who have difficulties with communication and swallowing in the form of treatment, support, and care (Paul and Roth, 2011). SLT is not just about intervention, but it includes all the activities that lead to and follow intervention.

Developmental Language Disorder

SLT services may be provided for various reasons. However, the focus of the study is Developmental Language Disorder (DLD), where children's speech and language development are not progressing as it should be. DLD, which until recently has been called specific language impairment (SLI) (Bishop et al., 2017), is not acquired or related to a causative health factor such as hearing impairment or autism but can appear in children's course of development. Speech disorder is a condition that makes the child hard to understand due to problems in articulation, voice and/or fluency. On the other hand, language disorders are divided into two components: expressive and receptive language disorders. The former, is when the child/person finds it difficult to share one's thoughts, ideas, or feelings, while the latter, is when the child finds it hard to understand what others say (American Speech-Language-Hearing Association, 1997).

Early intervention in speech

Speech and Language therapists or pathologists (SLT/Ps), hereinafter referred to as SLPs, provide early intervention in speech and language pathology to young children, from birth up to their first five years of life (Wilcox et al., 2013). SLT continues after this age if children have not successfully outgrown DLD.

3.1.1 The tasks of the SLP

Establishing whether therapy is needed

An SLP makes various decisions in the process of providing therapy (González-Fernández and Hillis, 2013). From the moment a case is referred, the SLP gathers relevant information from the caregivers, such as the case history and the child's primary language and forms a working hypothesis on the child. This allows the SLP to choose at least one assessment method to diagnose the actual difficulties that the child has. The assessment comprises observations, data collection and interpretation of the child's behaviour.

Establishing when and how therapy will be provided

If a difficulty is identified, the SLP sets the criteria for discharge, the long-term aims, the short-term objectives to be targeted during the intervention phase, and how often clinical intervention is needed. Every child has different needs, and therefore, the intervention programme is specifically tailored for the case. During speech and language intervention sessions for young children, the SLP works on the identified difficulties using play activities that target the child's condition. Intervention needs to be extended beyond the clinical setting to be efficient and effective (Mcleod and Baker, 2014). For this reason, SLPs train caregivers on how to promote speech and language intervention in the child's daily life.

Establishing when to stop providing therapy

From one intervention session to another, the SLP constantly evaluates the child's progress so that the objectives are adjusted in a scaffolded manner. If the therapy is not working, the SLP may choose a different activity, change the intervention programme, or redo the assessment. Although continuous evaluation is carried out, a child is re-assessed using a formal standard assessment at least twice a year. A child is discharged from therapy if his level of speech, language and communication skills have attained the desired level of proficiency.

3.1.2 Context of SLT Practice

Where do SLPs work?

Most SLPs work in community health centres or private clinics. Depending on their clients' circumstances, sometimes they are required to do home visits and work in schools or at the hospital. In some countries, intervention can only be provided remotely due to long distances between homes and clinics or mobility issues (Brennan et al., 2002; Drigas and Petrova, 2014). However, during the global pandemic of coronavirus disease 2019 (COVID-19), SLPs accepted tele-practice as another mode of operation and shifted speech and language therapy from in-person to remote sessions (Aggarwal et al., 2020; Wiśniewska, 2020).

Length and frequencies of SLT sessions

Locally, SLPs working with public healthcare have a daily caseload of eight to twelve clients (children/adults) per day. Each intervention session lasts between 45 minutes to an hour. Sessions may be shorter or longer depending on the level of cooperation. Assessment sessions may take longer because some procedures may be repeated.

Assessment session

Several data are collected during an assessment session, sometimes accompanied by voice recordings. After the session, SLPs review the observations and the child's performance to assign scores. These allow the SLP to establish the child's developmental stage, determine the current speech, language and communication skills, and then plan the goals and targets for intervention.

Intervention session

Intervention sessions typically take place every two weeks unless extra sessions are booked. These are typically held in the presence of the child's parent(s) or another caregiver so that they learn how to continue basic intervention activities at home. During an intervention session, the SLP performs a number of play-like activities to target the objectives. Depending on the child's needs, the SLP may work on the cognitive abilities, for example, memory games; speech, such as articulation activities; or language, like vocabulary activities. After an intervention session, SLPs write down notes in a logbook about the child's progress, reviews the goals and plan the next session. Before another intervention session, SLPs review the report of the previous session to refresh their memory. In between sessions, SLPs prepare the material required for the next intervention session if these are not available. Caregivers are assigned tasks to work out with the child between one clinical session and another.

3.1.3 Key Players in SLT

In view of the provided context, during SLT, there are three key players. As shown in Figure 3.1, these are the clinician, the caregivers and the child, and their roles are explained in Table 3.1.

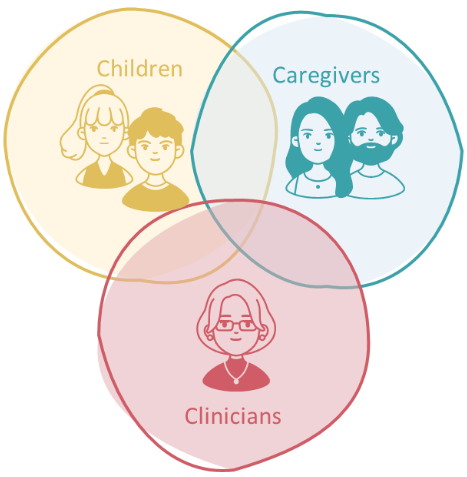


Figure 3.1: A triad of end users for SALTTs

To maximise the benefits of therapy, the roles of these individuals need to be considered on their own and together as illustrated by the seven possible scenarios in Figure 3.2.

Table 3.1: Role of the key players in SALT

#	Role	Description
1	Clinician (SLP)	The SLP is the provider of the therapy service. To generalise the role of the SLP to other clinical situations, the SLP is being referred to as the *clinician*.
2	Caregivers (parents, teachers, others)	The caregivers, that is, the parents or other people responsible for the upbringing of the child, are mediators of the therapy service.
3	Child	The child is the beneficiary of the therapy service.

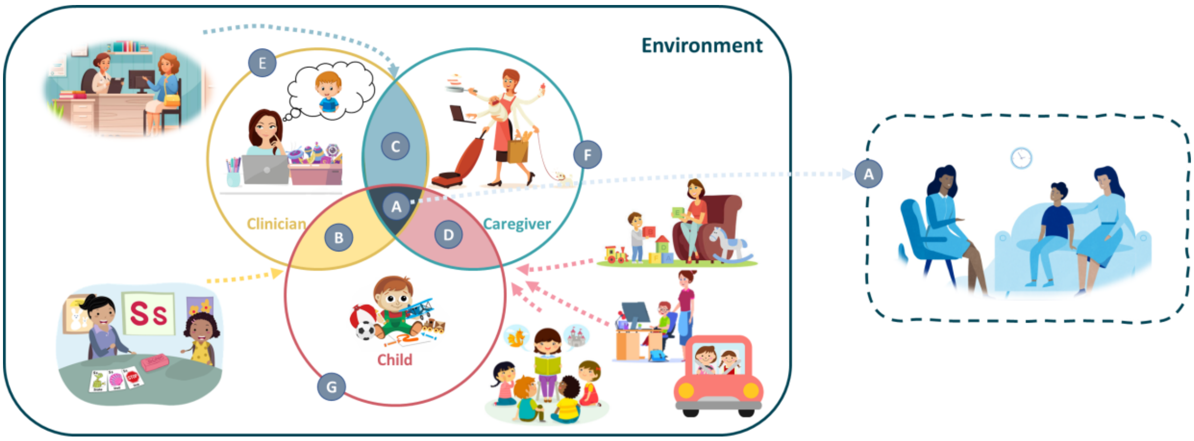


Figure 3.2:Interactions between the triad of players involved in SLT

Scenario A Given that the therapy sessions are carried out in the presence of a caregiver this allows the caregiver to learn how to extend the therapy at home and can ask questions or join in the intervention activity.

Scenario B Sometimes, caregivers do not join the session. Clinicians proceed with the session without the presence of the caregiver.

Scenario C As a result of scenario B, caregivers need to consult with the clinician after the session to understand the child's progress, the objectives, how to continue intervention at home, and pay for the clinician's service in case of a private session.

Scenario D At such a young age, children spend a lot of their time with their caregivers. Hence, there are many instances when their communication skills can be practised, including at school, while travelling, during playtime or story time before going to bed.

Scenario E When the clinicians are not conducting sessions with children, they schedule appointments, plan sessions, prepare resources, file, send children reports, report to superiors, attend meetings, and do research, among other activities.

Scenario F Apart from being responsible for the overall nurture of their children, caregivers have a lot of other duties in their life, including work. Somehow, carryover therapeutic activities need to be embedded between chores.

Scenario G Language can be practised through play or play-like activities when children are on their own. As disclosed in the first chapter, playful activities are opportunities where children may learn and develop their skills, even if the toy or game was not intentionally designed for learning. Play stimulates children to talk and make sounds to initiate and sustain play (Pellegrini and Jones, 1994).

Given that SLT concerns three different roles, any product used during therapy should factor in their individual needs. In the subsequent sections, clinicians, caregivers, and children are referred to as end users.

3.2 Children and Play

The right to play Children development and play are popular research topics among psychologists (Gibson, 1979; Sutton-Smith, 2000), healthcare professionals (Deák, 2014; Healey and Mendelsohn, 2019), toy designers (Coelho and Fernandes, 2013; Kudrowitz and Wallace, 2010; Mertala et al., 2016), game designers (Salen and Zimmerman, 2004) and marketers (Guinard, 2001), among others. This is because the two topics cannot be separated. In fact, Article 31 of the United Nations Convention on the Rights of the Child (UNCRC, 1989) confers children "*the right to rest and leisure, to engage in play and recreational activities appropriate to [their] age… and to participate freely in cultural life and the arts*".

3.2.1 Children's Stages of Cognitive Development

Among the various developmental theories that explain how children grow and act, Piaget's Cognitive Developmental Theory concerns the thought processes of children and how these shape their interactions with the world (Charlesworth, 2008). Piaget suggested that children's development goes through a sequential order of four stages, and thus, children's mode of play evolves as they learn to blend imagination with action. Although the age bracket of each stage varies between children, what matters is that for a child to proceed to a higher cognitive stage, one must have acquired all the skills from the previous stage.

Sensorimotor Stage

Between birth and the age of two, infants do not use imagination but engage in *practice play* where they learn that their actions produce reactions and that things continue to exist even if they cannot be seen. Smilanksy (1968), as reported in Besio et al. (2016), subdivided this mode of play into *functional play* (simple actions with objects) and *constructive play* (doing or building something with objects). At the end of this stage, children realise that objects have names and are independent of their perception.

Pre-Operational Stage

Between the age of two and six, children's communication skills significantly improve, and they become able to communicate their thoughts and use their imagination during *symbolic play*. However, their cognitive level is not mature enough to grasp the logic of complex relationships.

Concrete Operational Stage

Children develop logical thinking between the ages of six and twelve and can engage in *rule-based play* where they employ simple problem-solving skills. They also become aware of the thoughts of others, becoming less egocentric.

Formal Operational Stage

Between the age of twelve and adulthood, children start to use deductive logic to foresee an outcome by forming constructs and systematically recognising patterns and reasoning. During this stage, play is more social and competitive.

3.2.2 Toys: Children's First Consumer Products

Relevance to the design of toys

Research within the field of play (Correia et al., 2012), toy design (Coelho and Fernandes, 2013) and Human Computer Interaction (HCI) (Bruckman et al., 2009) employs this development theory because it helps designers understand how children's play behaviour is shaped by their interactions and their level of reasoning. Kudrowitz and Wallace (2010) state that these stages determine whether a particular toy would be suitable for a given age bracket.

Toys are objects that offer play

Within the context of children, the Oxford dictionary, defines a toy as "*an object for children to play with*". Children play with many artefacts, including those that were not intentionally designed to be used as toys (e.g., carton boxes).

What is play?

There is no single definition for play because play can be viewed from different perspectives (Miller, 1973; Sutton-Smith, 2000). Besio et al. (2016) adopt Garvey's (1990) definition for play, stating that it "*is a range of voluntary, intrinsically motivated activities normally associated with recreational pleasure and enjoyment*". On the other hand, Kudrowitz and Wallace (2010) use Salen and Zimmerman's (2004) definition of play for game design. It states that "*play is free movement within a more rigid structure*". Kudrowitz and Wallace argue that the 'rigid structure' is provided by a product's affordances, and the 'free movement' is the activity's characteristics that captivate and intrinsically motivate the user to interact. Subsequently, they define play for toy design as "*fun, free movement with given affordances*".

Toy Product

Kudrowitz (2014) defined the term *toy products* as objects that are intentionally designed for play and manufactured to be sold. Toy-associated terms are explained in the subsequent paragraphs.

Game

A game is a play activity which may or may not be enabled by the manipulation of objects, it is bounded by a set of rules and often lead players to either win or lose. Video games, for instance, offer play through gaming consoles, and the criteria for winning are determined by objectives and conditions (Salen and Zimmerman, 2004).

Low-tech, high-tech, smart and hybrid toys

Low-tech toys, that is, play objects that do not involve any electronic hardware (e.g., construction blocks, puzzles, dollhouses, and kitchen sets), are still popular nowadays and provide rich and engaging experiences. However, technology has become a primary influence within the toy industry and this has led to the creation of high-tech toys which possess electrical components and need to be powered to enable their designed, intended use. These include toy laptops, radio-controlled cars, and toys that play music. As technology gets cheaper, the spectrum of high-tech toys expands and transforms play experiences. High-tech toys that contain sensors, cameras and Artificial Intelligence are called smart toys. Nowadays, toys can also communicate with other devices when connected to the internet, allowing for what Berriman & Mascheroni (2019) call ‘connected play’. This era of the Internet of Toys (IoToys) has bridged physical toys and digital environments in video games through hybrid toys. This latter trend consists of technologically enhanced dolls, soft toys or action figures that can be physically modified in the real world and changes are reflected in the digital world.

3.2.3 Toys used in the Therapeutic Environment

Toy-mediated therapy

Clinicians working in early intervention utilise various mediums to deliver treatment in the form of playful activities (Landreth and Bratton, 1999) so that skills gained from play can be effectively used in their daily lives (Williams and Matesi, 1988). The reason is that when clinicians play with children, children feel safe, open up and connect with the adult. Play relieves children from pressure and anxiety caused by unfamiliar environments and people, allowing them to blend reality with their imaginary world to explore, ask questions, and reflect (Da Silva et al., 2016). Thus, enabling communication.

Adopted and adapted toys

Hence, toys have an important role in therapy-related healthcare. Mainstream toys are used in therapy so that children can play with them, and in return, clinicians can observe and intervene on their behaviours and skills. Clinicians can either adopt or adapt a toy for therapy. When the toy's play goal(s) match(es) with the objective(s) of therapy, then it is a case where a toy has been adopted and used as is. For instance, educational puzzles, such as pairs-that-go-together can assist language comprehension intervention goals. However, when the therapy goals are different from the expected play outcome of the toy or how it was intended to be used, then it is a case of an adapted toy. For example, a puzzle is used to support articulation intervention. As described in Roulstone et al. (2015), toys are used for listening or talking tasks and for rewards during intervention. Adapted toys can also be physically modified to enable specific interactions so that children with severe motor impairments can play with them (Williams and Matesi, 1988).

Alternative and augmentative communication (AAC) devices

Means of high-tech devices that are used with children that have severe speech and language impairment are alternative and augmentative communication

(AAC) or speech-generating devices. AAC devices have built-in screens or several buttons through which users can communicate by pressing or tapping a combination of words, sentences, or images which the device then says out loud.

Defining therapeutic toys

In order to discern mainstream toys from toys that are intentionally built for the scope of therapy, it is necessary to define what *therapeutic toys* (TTs) are. TTs are specifically designed to promote a particular skill, such as social interaction (Tseng et al., 2016) and facilitate therapy. Fikar et al. (2018) argue that a TT must sustain both the playful/motivational and the therapeutic efforts and should "*afford the therapists… and proxies/playmakers in-between toy and child*". Fikar et al. (2018) propose five design lenses to guide the development of TT:

Lens #1 - The toy shall afford the Zielreaktion

Fikar et al. (2018) define *Zielreaktion* as the desirable target reactions to be elicited in a child due to toy-mediated therapy. In the case of SLT, an example of the Zielreaktion is the understanding of object categories such as, the different types of clothes. These are enabled by the intentionally or unintentionally designed features of the TT.

Lens #2 - The potential of technology in providing interactions

Technology can be used to provide various sensory stimuli to meet the specific needs of children. Technology can be used to provide incentives for interaction through enhancement or reduction of a particular stimulus.

Lens #3 - Playfulness and ease of use

In early childhood intervention, play goes hand-in-hand with intervention because children need to be constantly motivated to prolong their attention span. Play in the field of therapy is not just limited to playing a game or playing with a toy. Other forms of play activities include singing or making interactive stories.

Lens #4 - Flexibility and improvisation

Clinicians must deal with variations in children's abilities, characters, moods, and needs, meaning that there are always factors that will be unexpected during therapy. Thus, a therapeutic toy should provide enough flexibility to complement children's different preferences, abilities and behaviours.

Lens #5 - Practicality

Therapeutic toys are used daily and by different children. So, they need to be practical. Fikar et al. (2018) highlight that designers must factor in storage, transportation, handling, robustness, hygiene and maintenance considerations.

Therapeutic Toy definition

Having the right tools is fundamental to supporting the therapeutic effort. Given the above definitions for play and toys and the fact that there are three acting players. In this dissertation, a therapeutic toy is defined as:

a purposely designed medium in the form of a toy by which clinicians working in the field of early intervention and caregivers can provide therapy to children. Such toys have dual roles during therapy. From the social perspective, they allow clinicians and caregivers to establish a relationship with the children, and from a play perspective, they instil motivation towards the therapeutic effort.

3.3 Affordances: Leading Children to Play

Goals and affordances

Similar to Bærentsen and Trettvik's (2002) hierarchy of affordances (see Section 2.1.1), Hassenzahl (2010) explains the hierarchy of goals when interacting with products. The desire to perform actions with a product, that is, do-goals, is driven by be-goals, that is, the desired activity. Do-goals (activities) are accomplished through motor-goals (operations) while manipulating the artefact. A child's desire to play (do-goal) and subsequently manipulate a toy (motor-goal), is triggered by the need to feel happy or the need to learn (be-goals).

In Pucillo and Cascini (2014), experience affordances are discussed as features of an artefact that allow the realisation of be-goals when the user is in the right usage mode, that is, when not focusing on the do-goals *per* se, thus providing pleasurable interactions. Features in toys encourage children to manipulate the toys and use them as per their desire to be immersed in play experiences. For instance, a child may feel the need to be stimulated by the feeling of how the wheels of a pull-back toy car rotate automatically when the internal spring system is engaged. The experience felt when the toy car is held in hand rather than letting it go on the surface is different because the latter deals with the satisfaction of causing the effect, and the former is about the pleasure attained.

Effect of emotions on affordances

According to Dolan et al. (2010), "*emotional associations can powerfully shape our actions*" and choices. They explain that all perceptions have an element of emotion, allowing us to have preferences and perform behaviours, thus orienting us to particular objects and events. Jensen & Pedersen (2016) argue that one can pursue an affordance depending on the affective stance at a particular moment, in relation to the intrinsic attractiveness (or aversiveness). Cognitive theories of emotion, such as (Desmet, 2003; Lazarus and Lazarus, 1991), can be used to understand the likelihood of engaging with specific affordances.

Emotions and other factors affecting the conditions of affordances

Because emotions are subjective, the likelihood of engaging with something that generates (meaningful) pleasure is far greater than with something that does not elicit positive emotions. Thus, Davis' (2020) work on the mechanism and conditions of affordances can be extended and analysed from the lens of emotion. How would an individual's emotional state affect the interaction with an object? Would a winner interact with a trophy differently than a bystander or a loser? Most probably, driven by their motives, all people would want to hold the trophy, but would their interaction be different or longer? Indeed, only the winner *deserves* the chance to drink champagne from the trophy, at least at that moment (*time* and *place*). The conclusion here is that affect and context play an important role in defining why events happen, such as the likelihood of embracing the affordances of an artefact.

3.3.1 Play Affordances

The Functional Manipulation Potential model

Mertala et al.'s (2016) Functional Manipulation Potential (FMP) model, shown in Figure 3.3, provides the foundation to describe toys in terms of their built-in purposes by combining Piaget's theory about children's cognitive development process (described in Section 3.2.1) to how children engage in play with objects.

Functional manipulation potential		
Functional play value		
Attractive affordance	Pragmatic affordance	Adaptive affordance
Representational element realistic; fantasy-oriented		
Gender element female; male		
Sensory element visual; tactile; auditive; olfactory		
	Productive element constructive; esthetic; given; open-ended	
	Performative element performative; transitive	
	Normative element	
	Technological element	
	Social element competitive; collaborative	
	Motoric element cross; fine	
	Academic element mathematic; linguistic; memory; conceptualization	

Figure 3.3: The functional manipulation potential of toys (Mertala et al., 2016)

Pragmatic and symbolic thinking lead to interactions

Mertala et al. (2016) claim that children interact with or manipulate toy products through pragmatic and symbolic thinking by responding to their designed functional play affordances. The former occurs when an object's affordances are used for play, like kicking a ball or moving a chess piece. Symbolic thinking is when one needs to think of ways to realise an object's intended affordances, such as caring for a doll or making soup by mixing ingredients in a container. These examples are portrayed in Figure 3.4 (a) and (b).

(a) (b)

Figure 3.4: Playing through (a) Pragmatic Thinking and (b) Symbolic Thinking

Definitions of functional, manipulation and potential

The *functional* aspect of toys is enabled by their intrinsic features, shaped by attractive, pragmatic, and adaptive affordances. These provide opportunities for play, during which a child employs various forms of *manipulation* (interactions). The *potential* of play depends on the child's cognitive and motor skills to either recognise and interpret these affordances, or be interested in them.

Definition of attractive, pragmatic and adaptive affordances

Mertala et al. (2016) define *attractive affordances* as the inherent features that invite children to select specific toys. *Pragmatic affordances* relate to the core functional purpose for which the toy was designed, such as costumes permitting children to impersonate characters and a rolling pin allowing children to flatten play-dough. Toys that can fulfil two or more roles contain *adaptive affordances*. For example, blocks can be stacked to produce various forms.

Elements of the functional manipulation potential model

Representative element

Gender element

Sensory element

Mertala et al. (2016) explain that the FMP of toys can be described by nine elements provided by the attractive, pragmatic and adaptive affordances, as shown in the FMP model of Figure 3.3. The Representation element is provided by all three affordances and refers to the fact that a toy can represent a *realistic* or a *fantasy* object. The Gender element is only associated with attractive affordances, and these define whether a toy can be associated as masculine, feminine or gender-neutral. The Sensory element is complemented by attractive and pragmatic affordances, and these contribute to sensory stimuli such as visual, tactile, auditive or olfactory normally. It is uncommon to find toy products with a gustatory stimulus.

Productive element

The Productive element is divided into constructive and aesthetic productions. The former can be divided into given or restricted productions (such as jigsaw puzzles) or open-ended productions where the toy does not limit the manipulation possibilities. Aesthetic productions elicit sensory responses such as drawing or making sounds. Mertala et al. (2016) highlight that pressing a button to produce a sound is not an aesthetic production. It is unclear why the productive element was divided into constructive and aesthetic productions because the former also produces sensory responses in terms of visual, tactile and auditory stimuli. It is also unclear why the productive element does not fall under the attractive affordances category in the FMP model.

Performative element

The Performative element differentiates features in toys that determine the type of roles that children can have during play. A toy with a *performative* value allows the child to act a role on the toy, such as the driver of a car or the mother of a baby doll. A toy with a *transitive* value allows the child to act out a role created by the toy, for example, when the child speaks and acts on behalf of the car or doll. When rules have to be followed in order to produce functional manipulation, it is said that the toy has the Normative element. This is evident primarily in board games, but it can be felt mildly in open-ended toys too. For example, when attaching magnetic pieces to build something, they must be of opposite polarity.

Normative element

Technological element

A toy whose FMP is only permitted through the functionality of the technological components is said to have a dominant Technological element. On the other hand, if the toy still permits play when the technological elements are not working, then it has a mild or moderate technological value. The Social element defines whether a toy permits social play other than solitary, where children can have social interactions with other children. The Motoric element specifies that toys can offer *fine* and/or *gross* manipulation. As described within the context of the FDM model, the Academic element refers to features that have been intentionally implemented for learning. Children improve or learn *mathematics*, *language*, and *conceptualisations* by interacting with such toys.

Social element

Motoric element

Academic element

Dominant and moderate presence

Note that Mertala et al. (2016) assign a two-point scale for each value of the described elements, saying that it can have a dominant or moderate presence. For instance, a toy can provide dominant visual and tactile stimuli but a moderate auditory stimulus.

3.4 Study to Identify Challenges in SLT and Requirements for SALTT

Having defined what a TT for SLT is, now it is time to understand what a SALTT should provide in further detail. This first step toward product development is identifying an opportunity and recognising end users within the context of the problem being addressed (Pahl et al., 2007; Ulrich et al., 2020).

Objective #1

The first objective was to identify challenges that SLPs experience during therapy.

Objective #2

In case difficulties exist, could these be addressed by a specifically designed therapeutic toy and be accepted by the triad of end users? This was the second objective.

Objective #3

If the second objective was satisfied as well, then the third objective was to collect the requirements for a new SALTT and possibly, preferred product characteristics.

3.4.1 Data collection approach

As shown in Figure 3.5, focus groups and structured interviews were conducted to get further insight about SLT and collect the requirements for SALTT.

Restriction on field observations

Note that third parties, that is, any individuals apart from the clinician, the child and the caregivers, were not allowed to be present during therapy sessions and make observations not to impose additional stress on the children. For this reason, to augment the collected information, literature (Antle, 2008; Grist et al., 2013; Lees and Urwin, 1991) that includes personas involving the triad of users was consulted (refer to Figure 3.5).

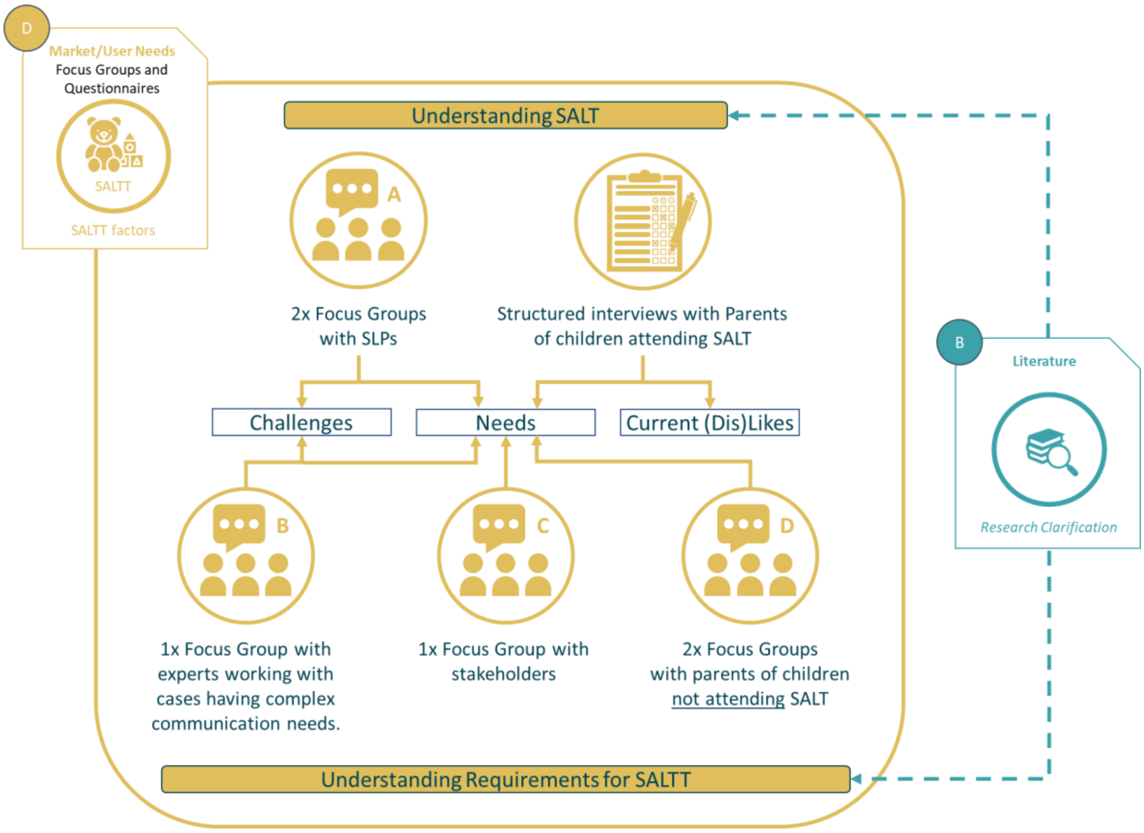


Figure 3.5: Data collection for the understanding the challenges of SLT and needs of SALTT

Data collection

Due to the limitation described above, the data collection approach was widened to ensure that suitable feedback on the child perspective was included. Given that 26 SLPs accepted to participate in the study, for Focus Group A, the participants were split into two sessions. On the other hand, difficulties were encountered in gathering caregivers to a common timeslot. Individual structured interviews were conducted in clinics after their child had participated in a speech therapy session. Focus Group B was conducted with a team of people who work in Augmentative & Alternative Communication (AAC) and Electronic Assistive Technology (EAT). In Focus Group C, relevant stakeholders were invited to share their views on a novel SALTT. One key requirement mentioned during this focus group was that a SALTT should not be stigmatic. For this reason, a fourth focus group, Focus Group D, was conducted with parents of typically developing children. This was divided into two sessions due to planning issues.

3.4.2 Participants

Ethics approval

Appendix E lists the questions asked during each focus group, while the questions asked during the structured interviews are provided in Appendix F. The research was reviewed and approved by the ethics committee of the University of Malta (parts 1 and 2 of application ENG 006/2016), and the signed consent of each participant was obtained.

1. Focus Group A participants

Only two of the 26 participants were male in Focus Group A. A considerable gender imbalance exists in the SLP profession (Byrne, 2016). The SLPs' experiences varied between 11 months and 19 years. The focus groups were conducted at the Speech-Language Department, where all the SLPs employed with the Primary Healthcare of Malta convene. Those overseeing children with DLD have between 50 to 100+ active clients.

2. Interviews participants

Twenty-nine mothers and three female guardians of children attending SLT provided their input in the structured interviews. Participants were recruited from two clinics in the centre and south of Malta. The participants disclosed that 15.6% and 28.1% of the children received language and speech therapy. The other 56.3% received both speech and language therapy. The majority (76.12%) of the children receiving therapy were preschoolers, that is, between the age of three and five years, while 6.25% and 17.63% of the children were younger and older than the preschool age bracket, respectively. Caregivers of the latter cohort stated that therapy started when the children were between three and five years old. It was also noted that 90.6% of the children whose parents participated in the study were boys, and only 9.4% were girls. Tomblin et al. (1997) point out that boys are more prevalent to receive therapy during kindergarten years.

3. Focus Group B participants

A team of people working with children with complex communication needs participated in Focus Group B due to their interest in a novel SALTT. These included an SLP with 20 years of experience, an Occupational Therapist with eight years of experience, a Learning Support Assistant with three years of experience and a newly recruited support teacher that designs strategies facilitating access to technology in schools.

4. Focus Group C participants

Relevant stakeholders that work and carry out research with children at the University of Malta participated in the third focus group. These were a freelance SLP, a child psychologist, a behavioural economist, and a professor working in early childhood and early education.

5. Focus Group D participants

Parents of typical children whose children attend It-Tajra Childcare Centre at the University of Malta or Attard Primary School were recruited through the Head of Schools, who acted as the gatekeeper. Only five and three parents from each respective education centre accepted to participate. This could have been attributed to the daily work commitments of parents. An agreement on a shared timeslot could not be reached, so two sessions were conducted.

3.4.3 Procedure

Focus groups

Each focus group was conducted in a dedicated room where each question was also shown on a screen. This helped the participants not to stray off-topic. A moderator and an assistant moderator guided the sessions to encourage the participants to speak and keep the discussions flowing. All sessions were voice recorded and transcribed verbatim for post-analysis. Key responses were coded, sorted and clustered into identified themes by following the procedure described in Braun and Clarke (2006) for thematic analysis.

Interviews

Quantitative data was collected through semi-structured interviews. Relevant information from the interviews was used to interpret focus groups findings.

3.4.4 Thematic Analysis Results

Main theme

Since all the discussions in the focus groups had the aim of discovering how SLPs can be supported in their role, the central theme revolved around Speech and Language Therapy in a Bilingual Context. However, sub-themes naturally developed whilst analysing the transcripts. These are depicted in Figure 3.6 as a chain of events that reach the study's primary objective: understanding the SALTTs' requirements. A detailed analysis of the findings is documented in Balzan (2022a).

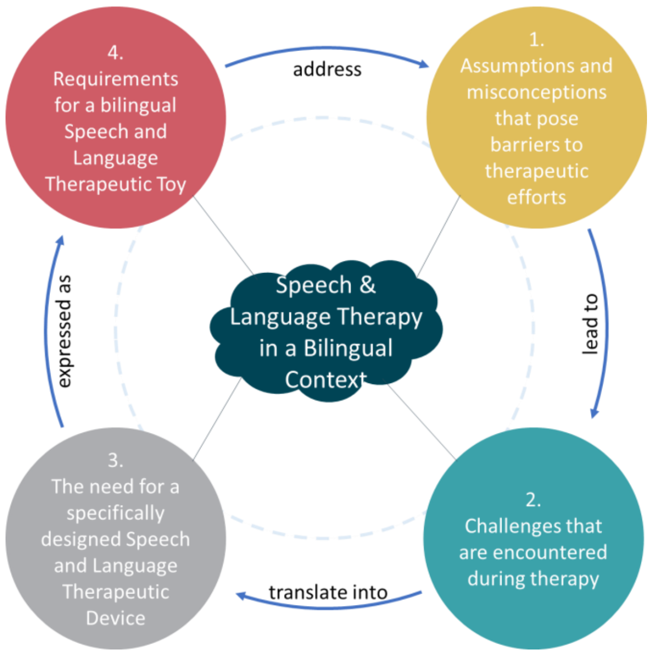


Figure 3.6: The themes that emerged from the thematic analysis

Sub-theme 1: Assumptions, concerns and misconceptions pose barriers to therapeutic efforts

Various assumptions, concerns and misconceptions have been identified as barriers to the therapeutic efforts. According to SLPs, parents' biggest mistake is treating therapy like "*a trip to the mechanic*", expecting that their children's speech and language problems will disappear just by attending therapy. Intervention can be divided into direct and indirect, where the former is the actual intervention provided by the SLP and the latter is the everyday practice. SLPs can recognise who has practised the tasks assigned in the previous session. Sometimes these tasks are only executed prior to the appointment. Another misconception is that bilingualism causes DLD. In a similar line of thought, some parents assume that children are bilingual by using a few words from a language, such as numbers and certain nouns.

Most caregivers (81.3%) declared that their children enjoy and look forward to the session because the SLP "*makes the session fun, like a game", "gives rewards*", "*uses different toys*", and "*uses a tablet*", among other comments (Balzan, 2022a). On the other hand, those parents who said that their child is not keen to attend SLT explained that their children "*want to go to school*", "*feel the session as extra homework*", and are "*tired after a day at school*".

SLPs confessed that sometimes parents treat intervention as tuition of the second language. Although all toys promote play, not all games/toys target the intended skills or the desired interest in children. Sometimes, children can play with a certain toy as a reward and not as part of the intervention. 90.6% of the caregivers said, in various degrees, that they would listen to the advice given by the clinician, educators or friends. Mixed views were expressed on the assumption that technology facilitates language learning. Although all participants agreed on how engaging smartphone devices and tablets are to children, given that there is a wide range of apps, children experts said that long exposure to screens should be limited even if there is an educational value because it can lead to negative consequences on the child's development. Screen-based devices do not promote social interactions such as toys sharing, taking turns, and eye contact.

Sub-theme 2: Challenges that are encountered during therapy

The major difficulty that SLPs mentioned is maintaining children engaged and motivated in the session. One must keep in mind that preschoolers' attention spans for atypical children are shorter than those in the mainstream category. Ruff et al. (1998) explain that a typical 5-year-old has between 5-6 minutes attention span. Without attention, there is no cooperation. Sometimes, sessions have to be cut short because a child would not cooperate. When parents were asked about the duration of a typical session, the majority (53.1%) said 45 minutes, whilst 12 caregivers (37.5%) said 30 minutes.

SLPs complained that progress is slow when there is no carry-over therapy at home, causing them to repeat the same intervention for months. On the other hand, parents feel bad when they miss a session because children or the SLPs are sick. Therapy sessions occur during school time. Apart from disturbing children's routine, working parents need to take leave from work.

SLPs need to constantly adapt to every child's needs. They explained that even if two similarly-aged children have the same intervention goals, they will intervene differently because of the children's preferences or because their attention span is different. Certain therapeutic activities depend on the time when the session is carried out. For instance, preferred activities are left for the end as motivation. If SLPs are stationed at different places throughout the week, they have to carry their resources around with them – "*our cars, it is like I have ten kids. Having a tablet helps because you can carry different apps for different goals, and it is very easy to carry it around with you when you are going on home visits*". This indicates that SLPs do not have a specific tool to support their practice but must use a range of toys and software applications.

Although SLPs have expressed numerous benefits of tablets (Balzan, 2022a), parents of typical children said that a tablet is not a toy and does not elicit the emotions that a physical toy does. As shown in Figure 3.7, this agrees with the feedback received from the interviews with the caregivers. When purchasing toys for their children, caregivers ranked the availability of a screen in the 38th position out of 41 considerations.

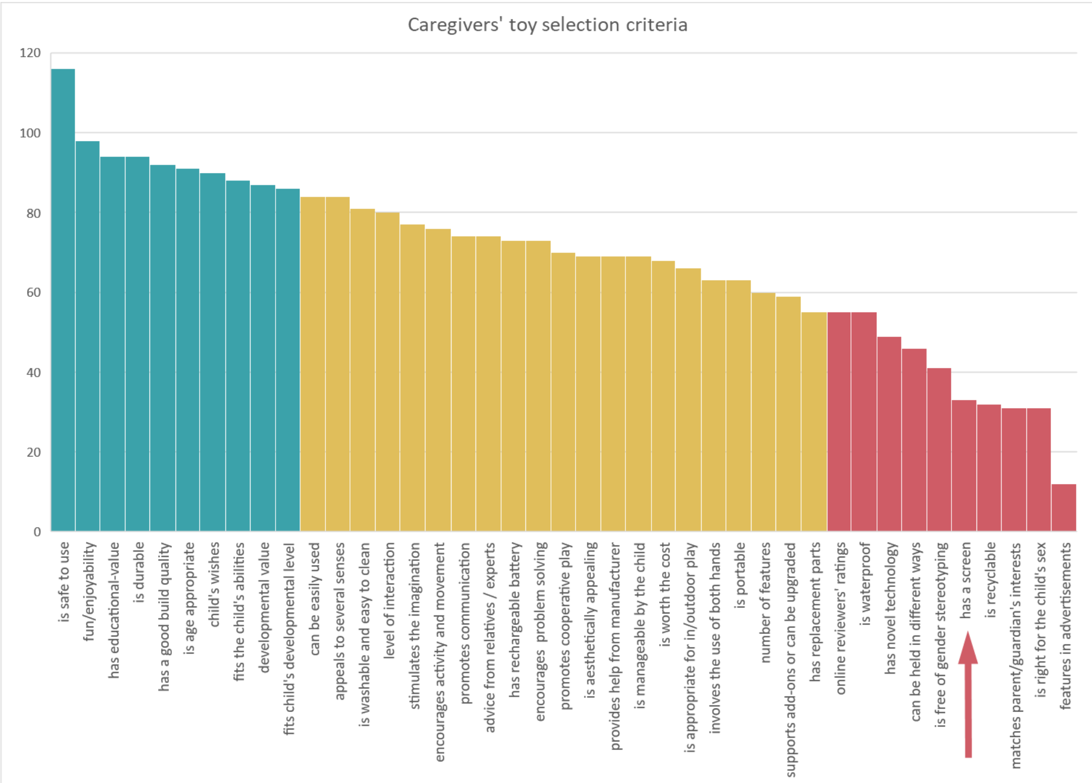


Figure 3.7: Caregiver's toy selection criteria

SLPs explained that progress tracking could be a challenging task due to the dynamicity of sessions and the number of observations they need to make simultaneously. Some assessments or intervention activities need to be done quickly due to children's short attention span.

Another challenge that both caregivers and SLPs mentioned is the lack of resources for the Maltese language. SLPs criticised that current toys and musical books in the market utilise American English, which is inappropriate. Appropriate accents should be used so that children learn the correct pronunciation.

When SLPs are formally assessing English speaking monolinguals, they can use a variety of assessments. However, there is only one standard verbal assessment for Maltese bilingual children. SLPs working with cases where speech impairment is a secondary condition claim that mainstream toys are not suitable. An SLP said that since children with disabilities cannot access toys, their parents "*do not see the necessity of play*". As stated in Besio et al. (2016), the right to play does not exclude children with disabilities. If play helps children develop their skills, how can children with motor, auditory, and vision impairments continue developing if they do not have access to play? These focus groups were conducted prior to the COVID-19 pandemic. When tele-practice was discussed, they were against the idea and did not think it would work. They also complained that teleworking would require them to work outside office hours. Furthermore, they mentioned that some parents do not have an email address and are not computer-literate.

Sub-theme 3: The need for a specifically designed therapeutic device

These challenges highlight the need to have a specifically designed therapeutic device. All the SLPs in Focus Groups A, B and C made a unanimous request that support is needed during the intervention:

> *"I would prefer an intervention tool because that's where we suffer in terms of resources. It gets tiring. You see some children for as long as you've been working… You spent years on the same goal… You have to change the methods with the same principle... and you have to strive how you're always going to make it fun."*

The availability of bilingual tools for therapy would be a game-changer for both SLPs and parents, and having the ability to switch between two languages would give them flexibility. SLPs remarked that for Maltese-based activities, they use low-tech means such as printing their own flashcards, making hand-written resources, and sometimes sticking papers to toys, which is very time-consuming.

SLPs need a common tool to guide parents, communicate the goals and objectives of intervention, whilst being able to suggest suitable activities to be done at home in between sessions. SLPs also remarked that technologies like tablets reduce the number of interactions with physical products. A balance must be reached between the integration of technology and interactive play time because the intervention goals are attained through play which involves interaction and learning: "*Play is our perfect container to learn about the language… We always emphasise playing with objects and not just with technology... because that's different. You still learn but it is different*".

This coincides with another observation that "*really and truly, what they enjoy is that someone is actually playing with them… the one-to-one attention they get and enjoy*".

From the aforementioned challenges, it can be said that there is a need for an artefact through which:

(i) SLPs can provide bilingual intervention based on the various needs and preferences of children;
(ii) parents are encouraged to be part of the children's therapy, and;
(iii) children can be engaged, in order to improve their speech, language and communication skills.

Through a speech and language therapeutic toy (SALTT), the different scenarios identified in Section 3.1.3 can be supported by responding to the challenges that all the end users have. The intention is not to replace the clinician with a SALTT but to support the triad of roles involved in therapy to improve the efficiency and effectiveness by which children with DLD make progress.

Sub-theme 4: Requirements for a bilingual therapeutic toy

The challenges and experiences that all the participants shared helped identify various requirements. These have been grouped into 12 overarching requirements and are discussed below. These requirements are not meant to be a prescriptive model but rather serve as salient factors that need to be examined when designing SALTTs.

SALTT Requirement 1

SR1: The therapeutic toy can be associated with a toy.

The first aspect that emerged from the data concerned the product's overall form, which should "*look like something children can relate to*", a toy. For this reason, the term 'therapeutic toy' was preferred over a therapeutic device. Participants in Focus Group C remarked that it should not be a toy which becomes a label "*I have speech impairment because I have this toy*". They also discussed features that elicit emotions and gender-stereotyped toys. The representation of the therapeutic toy is crucial to stimulating children's motivation. Although making an object's perceivable affordances highly identifiable is a good design practice, in the case of TTs, affordances related to therapy should remain hidden not to infer stigma (Blanco et al., 2016). Norman (1999) states that "*real affordances do not always have to have a visible presence (and in some cases, it is best to hide the real affordance)*".

SALTT Requirement 2

SR2: The therapeutic toy can be used in different contexts.

SLPs are aware that parents are busy but speech and language intervention should become part of a person's life. Opportunities for speech and language practice need to be sought and enabled. Caregivers mentioned that they talk, play, and sing with their children in the car when stuck in traffic. Such contexts need to be identified so that the SALTTs are suitable for various environments.

SALTT Requirement 3

SR3: The therapeutic toy is accessible to enhance usability and interactions.

A wider audience can be targeted if the product affords children's abilities. DLD could be a secondary impairment to other conditions such as a visual impairment. Therefore, it is important to consider accessibility aspects that improve the possible interactions and usability of the product.

SALTT Requirement 4

SR4: The therapeutic toy can provide appropriate sensory stimulation to draw interest.

In order to engage children, improve their attention span and cooperation, or stop them from a tantrum, clinicians use a variety of suitable sensory stimulations. As reported in Zubrycki and Granosik (2016), such tools can retain the children’s interest or provide a distraction when children misbehave.

SALTT Requirement 5

SR5: The therapeutic toy can be low-tech or hi-tech.

The technology used on a SALTT will limit or extend the number of features that can be embedded. Mixed views about high tech products have been expressed by both the parents and the professionals. Although a low-tech device may still be helpful for SLT, specific features, which may not be necessarily related to play, can only be implemented if advanced electronic equipment is used, meaning that technology supports the therapeutic efforts.

SALTT Requirement 6

SR6: The therapeutic toy provides a variety of playful opportunities.

Play has a central role in therapy. For a SALTT to be suitable for different children and offer prolonged usage, it must afford more than one play behaviour because it must match the developmental age of children rather than the chronological age. It should also be suitable for situations when intervention is done with groups of children. Furthermore, Tseng et al. (2016) state that different play modes enhance the degree of interactions of children. It also provides clinicians with the variety that they need during therapy.

SALTT Requirement 7

SR7: The therapeutic toy considers aspects of language.

Because children can have problems in different aspects of language, such as phonology, syntax, or semantics, the way spoken and written language are used in real life needs to be considered for proper communication. Other needs were raised because not every citizen is truly bilingual in a bilingual country.

SALTT Requirement 8

SR8: The therapeutic toy can aid the planning of intervention through assessments.

Challenges related to the assessment phase have been highlighted, especially with the availability of the right assessment for the correct language(s). Assessments are important because they are prerequisites for intervention and allow SLPs to assess children's communication skills. Although it is not considered a critical requirement, support in this regard can facilitate the steps to diagnosis and subsequently planning the intervention.

SALTT Requirement 9

SR9: The therapeutic toy provides adjustable intervention activities.

An appropriate intervention programme and its delivery are critical to the success of therapy. A SALTT can be a means by which SLPs, caregivers and children come together to work on common therapeutic goals. A SALTT can assist SLPs in creating personalised intervention programmes or caregivers to extend therapy at home whilst enabling children to practice in their natural environments.

SALTT Requirement 10

SR10: The therapeutic toy offers rewards for prolonged cooperation and motivation.

Rewards shape behaviours by motivating people towards a goal, even through hard work (Fogg, 2009). SLPs use rewards as incentives to foster cooperation and to praise their effort. Rewards should not be taken for granted or given freely. Therefore, different types of rewards should be used carefully. For instance, giving the same encouraging phrase all the time will bore children.

SALTT Requirement 11

SR11: The therapeutic toy can facilitate administrative tasks.

An SLP has a lot of administrative tasks, given that one can have over a hundred active clients ongoing. As discussed in Section 3.1, SLPs' tasks range from contacting clients to reporting, providing instructions and training parents. Demanding tasks like progress monitoring and goals update need to be closely followed to ensure children are improving and these are properly communicated to their caregivers.

SALTT Requirement 12

SR12: The therapeutic toy is safe to be used with all the end users.

Both parents and professionals want safe products, especially when children will be using them. Out of 41 criteria, safety was rated as the most important consideration they make when purchasing toys for their children (see Figure 3.7). The age of the end users determines the level of safety required by the therapeutic toy. For instance, the safety requirements for toys targeted at 36-month-old children or younger are more exigent (European Commission, 2016). Aspects of both software and hardware should be taken into consideration.

3.4.5 Conclusions from the thematic analysis

These 12 requirements summarise the data collected from the clinicians and caregivers, including input from experts working with children. These represent a need for a SALTT to support the various challenges encountered in SLT. Designers need to look at the roles that clinicians have with parents and children and how the therapeutic toy can be an artefact that facilitates therapy both inside and outside the clinic.

The order in which these requirements have been discussed does not reflect the order they should be considered. Each requirement deserves its investigation, but one must remember that they are interrelated. For instance, the representation of the SALTT (SR1) can influence the play behaviour (SR6) and the safety considerations (SR12).

3.4.6 Limitations of the study

Size of focus groups

The size of the different focus groups varied between one another. Guidelines (Morgan, 2012) suggest that a rule of thumb of 6-10 participants should be followed because when having fewer participants, it may be difficult to sustain a discussion. When having more, it may be challenging to control the discussion. These guidelines were not observed. Focus Group A's participants exceeded this range and lasted around 40mins, and every SLP contributed. All groups in Focus Groups B, C and D had participation of three-to-five people, and each session lasted between 70-100 minutes. The discussions with the smaller groups were longer as each participant had different views because their background was different. In contrast, with the SLPs groups, their profession and the difficulties they encounter daily were common.

Subjectivity

Thematic analyses are exposed to subjectivity because whoever is performing the analysis must interpret what the speaker is saying. To minimise this effect, recordings were transcribed and read multiple times to consider what was said from different perspectives.

3.5 Study to Understand the Influence of Design Affordances on Children's Attention Span and Engagement

Most studies in developmental psychology focused on actual toys preference and how this varies across gender, societal, cultural and other differences (Bathiche, 1993; Todd et al., 2016). Mertala et al. (2016) examined why children prefer certain toys over others. Their study revealed that children choose toys based on the functional, material, social, and personal values they offer. Given the disclosed importance of play and toys in Section 3.2, a study was carried out to understand how a toy's affordances contribute to preschool children's longer attention and engagement spans. A comprehensive analysis of this study can be found in (Balzan et al., 2018; Balzan, 2022b)

3.5.1 Structure of Study

The research study was designed such that children participate in two activities, namely observing and playing, as depicted in Figure 3.8 and explained later in Section 3.5.5. Several dependent variables (DVs) were used, as discussed below.

Objective of Activity 1 (Observing)

The objective of the first activity was to investigate whether a toy's perceived attributes motivate children for longer attention spans (DV1) and elicit positive emotions (DV2). Children's verbal preference was obtained through their preference (DV3) and overall preference (DV4).

Objective of Activity 2 (Playing)

The objective of the second activity was to investigate toy preference when it comes to actual play by taking note of the time they play with a toy (DV5) and their play value (DV6).

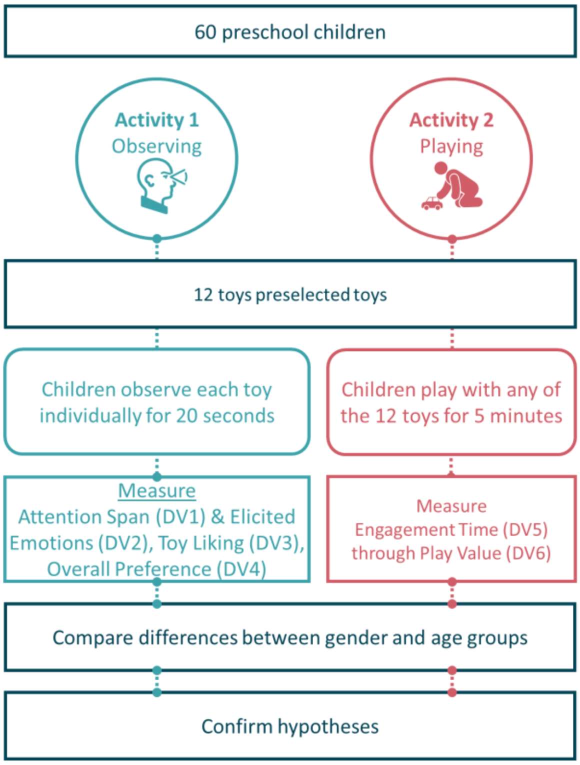


Figure 3.8: Structure of study

3.5.2 Hypotheses of the study

Sutton-Smith (1986) stated that "*it is dangerous to pretend we know what a child will do with a toy just from its characteristics alone; children have a way of doing things with toys over and beyond the apparent character of the toy*". However, it is believed that the way toys attract children will influence with what they play.

First and second hypothesis

For this reason, in this study, it is hypothesised that children would (i) prefer and (ii) engage more with toys that have a higher number of affordances.

Third hypothesis

Furthermore, with reference to Mertala et al.'s (2016) FMP model, it is also hypothesised that children would interact more with toys which offer functional manipulation elements.

3.5.3 Participants

Ethics approval

This research study was reviewed and approved by the ethics committee of the University of Malta (part 3 of application ENG 006/2016). Every child that participated in the study had a signed consent of a parent or guardian.

Recruited participants

The participants were 60, typically developing three- to five-year-old children (M = 4.33 years, SD = 0.92; 25 3-year-olds, 21 4-year-olds, 14 5-year-old), including 34 boys (M = 51.76 months, SD = 11.24) and 26 girls (M = 51.5 months, SD = 10.86). The children were all Maltese except for four children of foreign descent. Children were recruited from *It-Tajra Childcare Centre* at the University of Malta and the Attard Primary School. The children were drawn from ten different classrooms.

Pilot study

The study was first piloted with four 3-year-old children to try out the procedure and layout. During the pilot study, observations of the children's facial expressions were made by three researchers simultaneously to determine the inter-rater agreement, which was found to be 83.4%. The main disagreement resulted from the main researcher who was capturing a facial expression that the others were not. Hence, the list of observable emotions was reduced to keep the study simpler. Other improvements noted during the pilot study, such as the wording, were implemented in the actual study.

3.5.4 Toys used in the study

Rationale behind the choice of toys

For the study, eleven traditional toys were chosen based on the requirements that emerged from the expected scenarios of a SALTT for preschool children. These included:

- be a hand-held or table-top toy for indoor use;
- be large enough to accommodate a screen;
- similar to toys used during SLT or ones that would stimulate the use of language during play;
- allows for solitary play since each child will be observed individually;
- allows for open-ended play and not rule-based play;
- appeals to the child and looks like something that the child can relate to.

These toys are shown in Figure 3.9. Nine toys were specifically selected to be gender-neutral, while the other two were gender-stereotyped: one for boys (a wheel-loader) and one for girls (a dollhouse in the form of a boot). Out of the nine gender-neutral toys, four were soft toys: a lion (puppet), a pineapple, a turtle, and a gnome, while the rest were made of hard plastic materials, including a toy dog, a ladybird-telephone toy, a cash register, a school bus and a set of blocks.

A real smartphone was added to the 11 toys. Although a smartphone is not a toy, it was included in this catalogue due to findings from Focus Group D in Section 3.4. Studies such as (Wong, 2018) show that children consider smartphones and tablets as toys. The mobile phone was left switched off during the whole study, not to bias the study as the aspect of video games was not evaluated.

Figure 3.9: The 12 toys used in the study: (a) Lion (puppet), (b) Wheel Loader, (c) Dog, (d) Pineapple, (e) Ladybird-telephone, (f) Turtle, (g) Dollhouse, (h) Cash Register, (i) School Bus, (j) Gnome, (k) Smartphone, (l) Blocks

Analysis of the selected toys using the Functional Manipulation Potential model

The selected toys were analysed with respect to the FMP model described in Section 3.3.1 as tabulated in Table 3.2. During this analysis, it was noted that these toys have varying degrees of the productive, performative, and normative elements, with some toys deemed to have dominant to moderate traces. Note that the social element of toys was not investigated since children were studied on an individual basis.

Table 3.2: Functional analysis of the toys used in the study

	Types of Affordances	*Representation*	*Gender*	*Productive*	*Performative*	*Normative*	*Technology*	*Social*	*Motoric*	*Academic*
Lion	(P)AtAd	R	N	-	T, P	-	-	n/a	G	-
Wheel Loader	PAt(Ad)	R	M	✓	P	-	-	n/a	G	-
Dog	PAt(Ad)	R	N	✓	P, T	-	-	n/a	G	-
Pineapple	(P)At(Ad)	R	N	-	T ,P	-	-	n/a	G	-
Ladybug	PAt(Ad)	R	N	✓	P	-	-	n/a	G	-
Turtle	(P)At(Ad)	R	N	-	T ,P	-	-	n/a	G	-
Dollhouse	PAt(Ad)	F	F	✓	P	-	-	n/a	G,Fi	-
Cash Register	PAt(Ad)	R	N	✓	P	-	-	n/a	G,Fi	(✓)
School bus	PAt(Ad)	R	N	✓	P	-	-	n/a	G,Fi	-
Gnome	(P)At(Ad)	F	N	-	T ,P	-	-	n/a	G	-
Smartphone	(P)At(Ad)	R	N	(✓)	P	-	(✓)	n/a	G	-
Blocks	PAtAd	R	N	✓	P	-	-	n/a	G(Fi)	-

Legend:

P	*Dominant Pragmatic affordances*	*F*	*Fantasy value*	*G*	*Gross motor skills*
(P)	*Moderate Pragmatic affordances*	*M*	*Masculine value*	*Fi*	*Fine motor skills*
At	*Dominant Attractive affordances*	*F*	*Feminine value*	*n/a*	*Not considered*
Ad	*Dominant Adaptive affordance*	*N*	*Neutral value*	*-*	*Absence of value*
(Ad)	*Moderate Adaptive affordance*	*T*	*Transitive value*	✓	*Presence of value*
R	*Realistic value*	*P*	*Performative value*		

It was noted that all toys could be linked to the three types of play affordances through pragmatic and symbolic thinking. However, attractive affordances were dominant, whilst pragmatic and adaptive affordances were not always obvious. It was also deducted that the soft toys and the (switched-OFF) smartphone had fewer pragmatic affordances than the other toys, and play would only be stimulated if the child decides to engage in symbolic play. Moreover, soft toys did not have a productive value. The number of affordances of each toy was not counted to eliminate elements of subjectivity.

3.5.5 Setups and Experiments Protocol

Figure 3.10 illustrates the different setups used in this study. These activities were conducted on a one-to-one basis at the back of the same classroom to keep children in the same familiar environment and minimize class disturbances (Markopoulos et al., 2008).

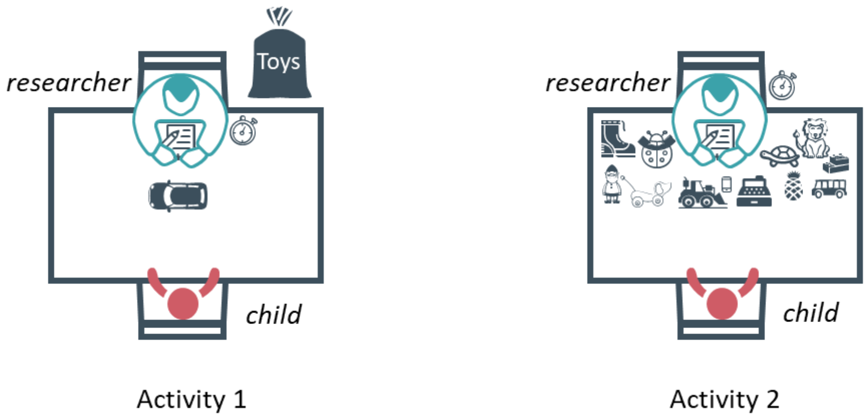


Figure 3.10: Setups employed in each activity of the study

Activity 1 procedure

In activity 1, the toys were kept hidden behind the researcher in separately numbered bags. A toy was taken out of the bag in a Balanced Latin-Square order (Kantowitz et al., 2008) to eliminate sequence effects and bias. The toy was placed in the middle of the table for an exposure period of 20 seconds. During this period, the child's attention span was recorded using a stopwatch, and their facial expressions were noted. The children were not prohibited from touching or playing with the toy but were not told they could do so. At the end of the exposure period, the toy was placed back in its numbered bag, and the participant's verbal preference was obtained, as explained section 3.5.6. This procedure was repeated until all the 12 toys were shown. The child's overall toy preference was noted at the end of this activity.

Activity 2 procedure

In activity 2, all toys were placed on top of the table and the child was told that s/he can play with any toys s/he likes for 5 minutes. The timer started after all the toys were placed on the table. Another timer was used to time the length of interactions with toys and notes were taken on how the child played with toys. Once time was up, the child was asked to help the researcher pack all the toys, and at the end of the study, the child was given a small inducement as an appreciation for her/his contribution.

3.5.6 Measurements

Activity 1 measurements

Attention Span (DV1) - Children's fixation on a toy was recorded using a stopwatch during the 20 seconds toy exposure duration.

Elicited Emotions (DV2) – Elicited emotions through facial expressions were noted on an observation sheet. The noted emotions were happiness, surprise, fear, anger, disgust and sadness based on (Russell, 1980), along with desire/fascination and boredom (Desmet, 2012). While the basic emotions in Russel's circumplex model of affect can be observed through facial expressions, the other two emotions can be seen through the behaviour. Because the child's intent is not really known from an observer's point of view, the desire and fascination emotions were combined.

Verbal Rating (DV3) – Following the 20 seconds toy exposure period in Activity 1, children's verbal preference was obtained using a 3-point scale version of the Smileyometer (Markopoulos et al., 2008), represented by the three emojis shown in Figure 3.11. A face with a large smile denoted "I like it a lot", a face with a small smile meant "I like it a little", while a frowning face resembled "I don't like it". The emojis were scored 2, 1 and 0, respectively. In some cases, it was noted that younger children tended to repeat the last option provided.

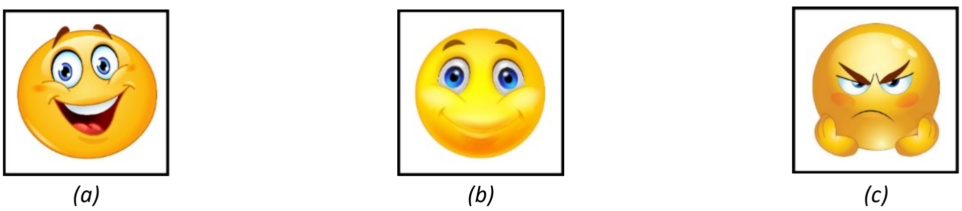


Figure 3.11: Emojis used to measure children's interest in toys: (a) "I like it a lot", (b) "I like it a little", and (c) "I don't like it"

Overall Preference (DV4) – At the end of activity 1, all toys were placed in their bags and an adapted version of the Fun Sorter method (Markopoulos et al., 2008) was used to determine their overall preferred toy. Flashcards of all the toys were placed on the table and the child was asked to pick up his/her top-3 favourite toys in sequence. Every time a toy was selected, the corresponding flashcard was removed to ease the selection process. After the third selection, the child was asked to indicate which was the least favoured toy. A score value of 3, 2 and 1, was assigned to their first, second and third toy preferences, respectively, while a weight value of -1 was given to the least preferred toy.

Activity 2 measurements

Playtime / Engagement time (DV5) – Playtime indicates the children's preference because they spend time playing with the toys that attract them. A stopwatch was used to measure the actual time spent playing with the toy. If the child started playing with another toy, the time recorder for the previous toy was recorded, and a new timer was initiated. If the child played with more than one toy simultaneously, for example, holding a soft toy in each hand while engaged in play, the measured time was assigned to both toys. On the other hand, if one toy served only as a facilitator to the play activity, time was only assigned to the main toy.

Play Value / Engagement Level (DV6)

The child's play complexity scheme of Cherney and Dempsey (2010) was adapted to measure the level of engagement as the toy's play value.

The weightings ranged from 0 to 4. A play value of 0 was assigned when the child did not play with the toy. If the child simply lifted the toy and played with it for a few seconds without exploring its features, a rating of 1 was assigned. A rating of 2 was assigned when the child played with a toy for up to a minute and started exploring some or all the toy's features. For instance, a score of 2 was given when the child inserted his/her hand in the Lion puppet and played for less than a minute. A score of 3 was given when the child played for more than two minutes. Normally, during the first two minutes, all the features of the most complex toy, that is, the dollhouse, would have been explored. A score of 4 was assigned if the participant played with the toy for more than three minutes or another toy has been added to the main toy, resulting in an increased level of engagement, such as the case when a child, while playing with the cash register, placed the smartphone inside.

Due to non-uniform data distributions, nonparametric statistical tests were used to analyse the results. The Friedman test was used to compare the different toys' mean ranks of preference metrics (e.g. attention span). The Kruskal-Wallis test compared mean ranks provided to toys between independent groups clustered either by gender or by age.

For the Freidman test, the null hypothesis (H0) specifies that the mean ranking scores (of preferences) vary marginally between different toys and is accepted if the p-value exceeds the 0.05 level of significance. The alternative hypothesis (H1) specifies that the mean ranking scores vary significantly between the different toys and is accepted if the p-value is less than 0.05 level of significance. For the Kruskal-Wallis test, the null hypothesis (H0) specifies that the mean ranking scores vary marginally between the groups and is accepted if the p-value exceeds the 0.05 level of significance. The alternative hypothesis (H1) specifies that the mean ranking scores vary significantly between the groups and is accepted if the p-value is less than 0.05 level of significance.

3.5.7 Key findings of the study with children

The following summarises the main findings for each measure employed.

Summary of results for Activity 1

Results from observations made during the study

Attention span results (DV1)

The mean ranks obtained from the Friedman test for children's attention span was highest for the dollhouse (7.99) and closely followed by the school bus (7.90), cash register (7.55), the ladybird (7.34), and the wheel loader (6.92). As shown in Table 3.3, differences between gender and age groups were noticed, where boys had longer attention spans on the Wheel Loader and the Blocks, and 5-year-old children were more curious than 4- and 3-year-olds about the mobile phone. No other significant difference was observed for the other toys because all p-values exceeded 0.05 level of significance.

Table 3.3: Attention span differences across (i) gender groups, and (ii) age groups

	Lion	**Wheel Loader**	**Dog**	**Pineapple**	**Ladybird**	**Turtle**	**Doll house**	**Cash Register**	**School Bus**	**Gnome**	**Smart phone**	**Blocks**
Gender	0.146	0.004	0.567	0.326	0.053	0. 87	0.202	0.221	0.462	0.688	0.295	0.039
Age	0.621	0.848	0.795	0.728	0.924	0.463	0.464	0.605	0.245	0.91	0.03	0.936

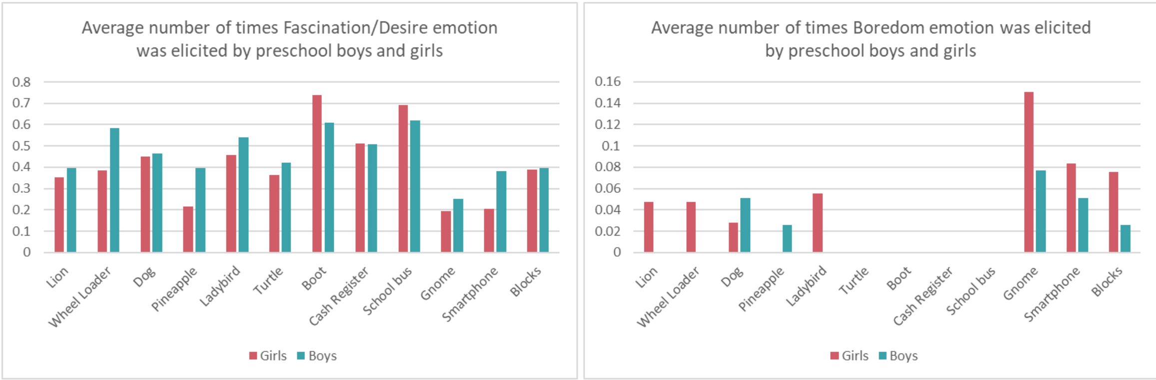
Emotions elicitation results (DV2)

Distinguishable results for the emotions elicitation method were obtained for the fascination/desire and boredom emotions, as shown in Figure 3.12. The toys that mostly induced fascination/desire were the dollhouse, the school bus, the cash register, and the ladybird. The top items that caused participants to elicit the boredom emotion were the gnome and the smartphone. Gender differences were noted through the elicited emotions but could not be validated statistically.

Results from verbal responses of the participants

Smileyometer results (DV3)

The Friedman test on the mean ranks of the children’s verbal preference (Smileyometer) showed that children mostly preferred the dollhouse (7.68), followed by the cash register (7.33) and the school bus (7.02).



(a) *(b)*

Figure 3.12: Average number of times (a) Fascination/Desire and (b) Boredom emotions were elicited by boys and girls

As can be seen from Table 3.4, gender differences were noted for the wheel loader (p-value = 0.002). Using the Kruskal-Wallis test, gender group differences were noted for the Wheel Loader (p-value = 0.013) and the Ladybird (p-value = 0.046), because boys and girls had different preferences. On the other hand, differently aged children had similar preferences because all p-values exceeded the 0.05 level of significance.

Table 3.4: Attractiveness differences across (i) age groups, and (ii) gender groups

	Lion	**Wheel Loader**	**Dog**	**Pineapple**	**Lady bird**	**Turtle**	**Doll house**	**Cash Register**	**School bus**	**Gnome**	**Smart Phone**	**Blocks**
Age	0.684	0.169	0.115	0.34	0.876	0.639	0.199	0.153	0.555	0.288	0.211	0.725
Gender	0.184	0.013	0.973	0.671	0.046	0.126	0.177	0.193	0.279	0.837	0.293	0.401

Fun Sorter results (DV4)

Again, the same result was obtained when investigating children's top 3 favourite toys using the modified Fun Sorter method: dollhouse (8.47), cash register (7.95), and school bus (6.81). However, more gender differences emerged because of the negative ranking applied for the least preferred toys. As shown in Figure 3.13, whilst boys expressed more interest in the wheel loader, blocks and lion than girls, girls preferred the dollhouse and the pineapple more than boys. Differences due to the age of children showed that younger children were more inclined towards the ladybird whilst older children preferred the dog.

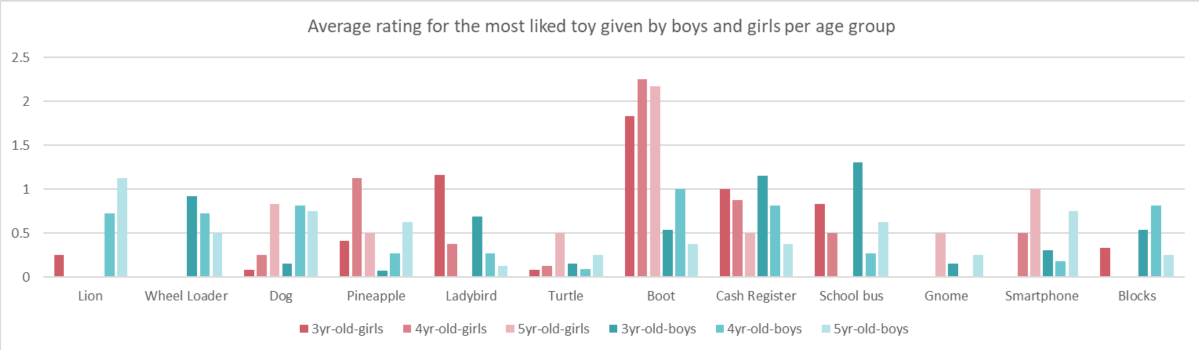


Figure 3.13: Average rating for the most preferred toys for boys and girls per age group

For the Kruskal-Wallis test, as shown in Table 3.5 gender differences were noted on the lion and wheel loader because boys had higher preferences, and on the pineapple and the doll house because girls had higher preferences. Age differences were noted for the dog and ladybird toys.

Table 3.5: Toy preference (Fun Sorter) differences across (i) age groups, and (ii) gender groups

	Lion	Wheel Loader	Dog	Pineapple	Ladybird	Turtle	Doll house	Cash Register	School Bus	Gnome	Smart phone	Blocks
Age	0.431	0.816	0.023	0.864	0.01	0.256	0.829	0.092	0.072	0.8	0.17	0.641
Gender	0.035	0.001	0.744	0.027	0.236	0.881	<0.001	0.191	0.144	0.24	0.284	0.084

Accomplishment of the objective for Activity 1

Through these results, objective 2 was achieved, confirming that certain toys promote longer attention spans and positive emotions. In fact, findings agreed when comparing the top toys that stimulated longer attention spans and invoked the fascination/desire emotion in children with the top toys that children mentioned through the Smileyometer and Fun Sorter methods. Toys without a productive value were deemed to be less attractive by children as 3-year-old children had different preferences than their older peers.

Summary of results for Activity 2

<u>Results from observations made while children played with the toys</u>

Play time results (DV5)

Figure 3.14 illustrates the average playtime in seconds for the toys provided. In contrast to girls, boys played with a wider variety of toys. Girls played with 2.56 toys (SD = 1.98) and boys with 3.44 toys (SD = 1.34). Considering different age groups, it was found that three-year-old children handled 2.96 toys (SD = 1.67), four-year-old children 3.11 toys (SD = 2.07) and five-year-old children 3.15 toys (SD = 1.14). This means that, on average, children played with three toys.

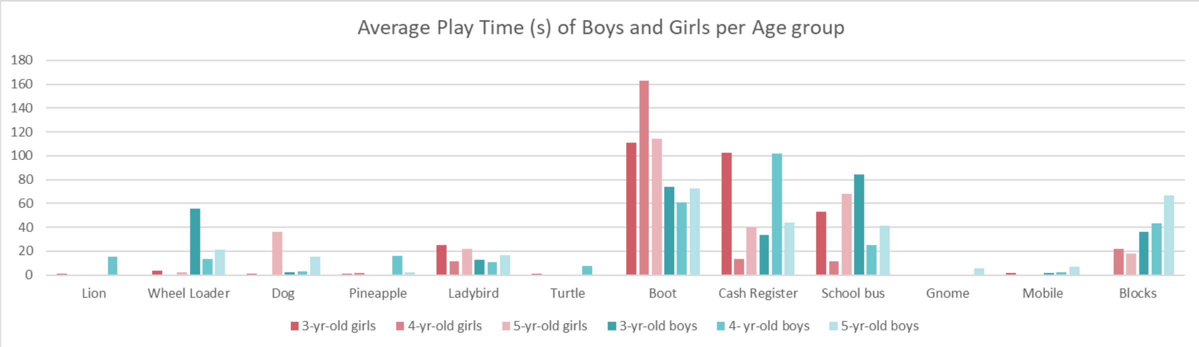


Figure 3.14: Average play time of boys and girls per age group

The top-three toys with which both girls and boys played mostly, are the dollhouse (girls: M = 128.2s, SD = 105.86, boys: M = 73.28s, SD = 84.34), followed by the cash register (girls: M = 60.6s, SD = 98.47,b: M = 58.88s, SD = 76.78) and the school bus (girls: M = 42.00s, SD = 74.33, boys: M = 55.28s, SD = 79.50). No gender differences were found, even though the dollhouse was a gender-typed toy, meaning that boys still played at length with it. Analysing the results with respect to the age of children, it was noted that 5-year-old boys played for a longer time with the dollhouse and the blocks when compared to their younger peers. This agrees with previous studies (Caldera et al., 1989) where boys are also involved in playing with feminine toys in contrast to (Cherney and Dempsey, 2010). Irrespective of the age, most girls were still immersed in the dollhouse, and consistent with other studies, (Cherney and Dempsey, 2010) boys, more than girls, occupied themselves in spatial-temporal toys such as vehicles and blocks.

Play value results (DV6)

The results obtained from the play value measure were like the previous findings: dollhouse (9.23), cash school bus (7.80), and cash register (7.77). No significant age group difference was noticed because all p-values exceed the 0.05 level of significance. On the other hand, when considering the gender group, differences in play value resulted in the wheel loader, the dollhouse, and the blocks. Although the dollhouse was the most preferred toy for both boys and girls, the play value of boys was lower than that of girls. On the other hand, boys' play behaviour with the wheel loader and the blocks was greater.

Table 3.6: Play Value differences across (i) age groups, and (ii) gender groups

	Lion	Wheel Loader	Dog	Pineapple	Lady bird	Turtle	Doll house	Cash Register	School bus	Gnome	Smart Phone	Blocks
Age	0.081	0.688	0.926	0.088	0.814	0.079	0.344	0.144	0.594	0.191	0.582	0.436
Gender	0.464	0.016	0.756	0.989	0.934	0.493	0.034	0.328	0.517	0.448	0.586	0.013

Accomplishment of objectives for Activity 2

The measures used in this activity were meant to investigate children's toy preference by looking at the level of engagement when playing with toys. Both results converged to the same top-three toys that children showed interest in when they saw the toys for the first time.

Further accomplishments

Research with young children is normally difficult because young children's verbal feedback is not reliable (Monsalve and Maya, 2012). Due to the limited research methods available for non-verbal and young participants, different metrics were explored to confirm children's preferences. The Fun Sorter and Smileyometer methods suggested in Markopoulos et al. (2008) are normally employed with older children. However, by simplifying these data collection instruments, it was possible to extract reliable verbal feedback from children, which confirmed the other methods employed in this study.

3.5.8 Discussion of Results

Validity of the first set of hypotheses of this study

This study showed that the most attractive and engaging toys that were provided were the doll house, school bus and cash register. The most interesting outcome was that the findings from both activities concurred, meaning that attention span and emotion elicitation during the child's encounter with a toy can provide information that determines whether the child will have longer engagement with the toy. Thus, providing insight into how attention span in SLT can be improved. As detailed in Section 3.5.4, these toys offer various opportunities for playful interactions, that is, play affordances, such as opening and closing doors, pressing buttons, and role play among others. The wheel loader, dog, ladybird, and blocks were another set of toys that provided the second-best interest and engagement levels. On the other hand, the third set of toys, composed of soft toys, provided minimal motivation to children. As shown in Table 3.2, the pragmatic and adaptive affordances of soft toys are not obvious. This validates the first hypotheses made in the beginning of the study which stated that children would (i) prefer and (ii) engage more with toys having the most affordances. A possible explanation to this is that by just observing the toys, children were able to comprehend the play value offered by the toy, that is, its play affordances.

In order to investigate the validity of the third hypothesis, it is important to analyse the interactions that children had during the final part of the study and why the presence of affordances enhance the attention and engagement levels.

Effect of pragmatic, attractive and adaptive affordances

Attractive affordances attracted children at their first encounter with the toy but were further augmented by the pragmatic features. For instance, the turtle and pineapple were briefly handled due to their visual and tactile influence, while the dollhouse had fantasy attractive affordances and various compartments that inspired exploration of function. Toys that have pragmatic affordances inspired children for higher quality play behaviours and longer engagement time than other toys. Most children ignored the soft toys due to their limited pragmatic affordances. On a different note, adaptive affordances were noted when children, unrestrictedly, played with small components such as blocks and bus passengers.

Other types of affordances provided by products

Results which emerged in this study show a degree of evidence that toys can have their play affordances designed in such a way to match the abilities of children and increase their motivation and level of engagement. This builds upon the work of Pucillo and Cascini (2014), by stimulating proposals for experiences. In their work, affordances are said to define both "*how these proposals are made, in terms of features of the artefacts and characteristics of the user, [and] how clear proposals are, in terms of how affordances are perceived*". Pucillo and Cascini state that products have Experience Affordances, which feature built-in products that satisfy the psychological needs of users, which are achieved after using the product. By considering Mertala et al.'s (2016) play affordances, experience affordances are enabled through the pragmatic and attractive affordances, whilst new unintended experiences can be created through the adaptive affordances.

Affective affordances

Products can elicit different kinds of emotions which can be due to personal and different (compound) reasons (Desmet, 2003). Product design can influence emotional experiences. Going deeper into what products can offer to their users may result in defining other types of affordances. For instance, why do children have a special favourite toy? Such toy attracts the child not just because of the attractive affordances or the pragmatic affordance but because overtime a child develops affection for it, creating or offering an attachment at the cognitive level represented by a meaning of importance that was given by the user. In Hood and Bloom (2008) it was shown how children preferred their own toys rather than an exact replica. Thus, in the context of toys, the concept of having an affective affordance can be postulated.

A toy can be said to afford affection to a child if (through play or otherwise) it helps in fulfilling various socio-psychological needs (e.g., happiness, safety, love, esteem, control, competence) and improve motivation. Just like in adults the feeling of belonging improves motivation, children are also motivated when their psychological needs are fulfilled. Similar to Pucillo & Cascini's (2014) experience affordance, an affective affordance is personal to the user. However, an experience affordance is exhibited when the user has interacted with it, while an affective affordance can be felt through perception and reasoning without touching the artefact. For instance, a pointy object will not afford affection if associated with pain and blood. On the other hand, seeing a toy like the one owned by a peer will automatically generate interest (affection).

Validity of the third hypothesis

Based on the FMP model, the wheel loader offered similar functional manipulation potential as the top-three toys. For instance, while playing with these four toys, children integrated other toys, such as placing blocks in the cash register drawer and the wheel loader bucket. However, due to the masculine attributes the wheel loader has, girls had much less motivation to play with it, In fact, only girls disliked this toy in the Fun Sorter measurement.

Comparing the FMP model values assigned to all the toys in Table 3.2 with the results obtained in activities 2 and 3, it can be clearly stated that toys without the productive element will offer less attraction and engagement levels to children. Differences in the assigned value for the Performative element can also be seen. Soft toys were assigned both transitive and performative values in the Performative element, meaning that children can take two different roles when playing with such toys. The Performative element is a desirable aspect of toys because it allows role play, a play behaviour in which children can use language. Table 3.2 shows that all toys had a performative value, explaining why children also talk or make sound effects when playing with the more engaging toys.

Therefore, within the boundaries of the study, since the functional manipulation elements, that is, Normative, Technology, Social, Motoric and Academic elements, of the FMP model were almost the same, the third hypothesis can be validated because toys with the productive element stimulated greater interest and engagement than those without.

The FMP model is not enough to determine the level of engagement

From this analysis, it can also be said that although the FMP model highlights whether a toy exhibits potential for functional manipulation, it does not explain the extent of that interaction or whether a toy would provide prolonged engagement levels when comparing two similar toys. The FMP model only indicates whether a feature can be found in a toy or not, but it does not provide details on the number of features that contribute to that element. Therefore, the FMP model lacks discriminative power.

The FMP model is not suitable for SALTTs

Although the FMP model also includes an Academic element that refers to features by which children are exposed to learning experiences, it does not look at the qualities desired by the clinicians and caregivers in SALTT. Therefore, a different model is needed.

Potential has dual meanings

The meaning implied by the term ‘potential’ as used in the FMP model refers to the child’s ability to perceive and carry out possible actions offered by the toy. However, as viewed by the author, the potential is a measure that relates to the product and the number of affordances at the users’ disposition. From the observed interactions, children were more attracted to toys having more affordances. The saying “*quality is better than quantity*” may apply to the type of affordances offered by the products. For instance, children were intrigued with the swing of the dollhouse and kept swinging multiple passengers from the school bus.

3.5.9 Limitations of the Experiment

The findings of this study need to be considered in the presence of the following limitations:

Sampling method and sample size

Due to the length of each individual session, the study was carried out only with 60 participants, a sample which does not represent the whole childhood population in Malta. Additionally, due to sampling by convenience, children were recruited from the centre of Malta, close to the university, and not from different parts of the country. This could have potentially introduced a selection bias. Moreover, children's ability was not ascertained prior their inclusion in the study. Nonetheless, gender and age-related findings on toys preference and play behaviours agree with international studies.

Age of participants

As explained in Chapter 5, one of the boundaries set for this dissertation is the age of children that would receive speech and language intervention. Thus, only preschoolers were considered.

Low-tech toys

Only low-tech toys were used in this study. The influence of technology was not evaluated. In fact, not to bias the results, the smartphone was kept switched-off during the entire study.

5 minutes playtime

Children were allowed to play for five minutes only during the second activity. Therefore, the extent of engagement level in proportion to time could not be tested. The total duration of the two activities were between 30 to 40 minutes which is a long period for young children during school hours. Certain play assessments such as the Affect in Play Scale for preschoolers (Chessa et al., 2011) are also five minutes long, meaning that such a duration is acceptable for children to demonstrate the preferences.

3.6 Chapter Conclusions

In order for designers to develop SALTTs, they need to be aware of the needs of the end users such that the artefact provides adequate support during speech and language therapy.

Three end users

Therapeutic toys are not toy products but facilitating means that support therapy. They are used by clinicians with children during intervention, by caregivers with children to extend intervention outside the clinical setting, and by children as toys to develop their communication skills through play. Given that three different end-user groups are interested in the same artefact, it is argued that the design process of SALTT should be supported, especially in the task clarification stage.

Play as speech and language intervention

Playful experiences are crucial for children’s language development, and having appropriate tools that reinforce intervention activities improves the chances that children improve their speech and use of language. The availability of specifically designed SALTT would assist with the challenges that SLPs encounter whilst working with children and their caregivers.

Tools that afford the needs of clinicians, caregivers and children

Children’s toys preference and engagement level depend on many factors. Whilst the overall design or representation of a toy is key to engaging children’s interest, pragmatic affordances are essential for it to serve the purpose it was designed for. Since toys (with greater functional manipulation potential and/or more affordances) can instil longer attention spans and engagement levels, appropriately designed SALTTs can help clinicians motivate children toward the therapeutic effort more easily. Finally, to facilitate therapy, SALTTs should be designed with appropriate (need-related, instrumental and operational) affordances that meet the various aspects of therapy of all end users.

Design phenomena

The number and type of interactions of the end users (children, caregivers and clinicians) with the SALTT depend on the design and embedded features of the product. The latter define the instrumental and operational affordances. As shown in Figure 3.15, a requirement (in this case, the customer's voice) guides the decisions taken during design and development to implement the corresponding affordance(s). By satisfying functional and form requirements, designers affect the interaction with the artefact. For instance, voice recording is an instrumental affordance required by the clinician for assessment and intervention. Parents can listen to the recording, compare how a word should be pronounced, and maybe make a new recording. Children can see this affordance as a mode of play by playing back the recording with added sound effects. As illustrated in this example, the end-user requirement, "*the ability to record voice*", was implemented in the product but depending on how the operational affordance was designed, the end user could interact with the recording feature in various ways.

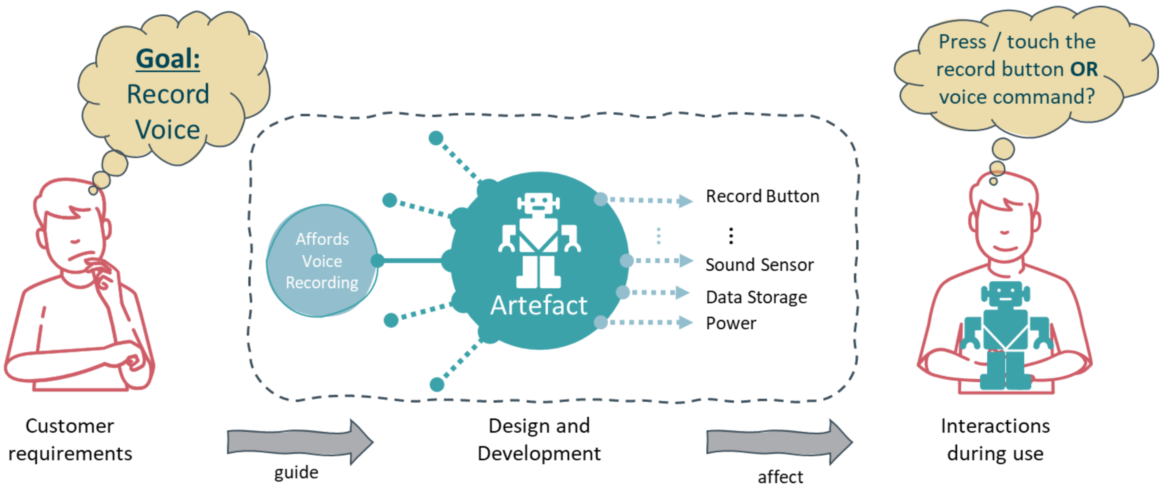


Figure 3.15: A phenomena model describing how customer requirements help shape product interactions

4. A REVIEW OF DESIGN SUPPORT TOOLS FOR REQUIREMENTS ELICITATION

If I have seen a little farther than others,
it is because I have stood on the shoulders of giants.

Richard Hamming, Turning Award Lecture, 1968

The methodology employed for this literature review is described Section 4.1. This includes the review criteria and the classification used to structure the critical review. Relevant literature is reviewed in Sections 4.3 to 4.6 and a summary of the findings is listed in Section 4.7. This led to the formulation of the existing gap in the literature, as detailed in Section 4.8.

4.1 Introduction to the Literature Review

Problem with the design brief

The quality of a solution is established by the degree to which the stakeholders' requirements have been implemented (Finkelstein, 1994). In Chapter 2, it was shown that, due to an ill-defined design brief, designers encounter several difficulties in the task clarification stage. An unclear problem definition also leads to requirements being discovered late, specifications changing during development, decisions to be retaken, and time-to-market delays (Ullman, 2002). Moreover, problems in communicating requirements, limited knowledge about the context and inaccurate requirements documentation contribute to challenges in starting design concepts (Coughlan and Macredie, 2002).

Requirements Engineering processes

Work on requirements elicitation has long been carried out due to its importance in the subsequent design activities. Whilst Darlington and Culley (2002) differ between the terms *requirements engineering* (RE) for software solutions and *engineering design requirements* (EDR) for physical products, the former term is preferred in literature (Berkovich et al., 2011; Müller et al., 2010). RE can be divided into two main activities: requirements development and requirements management (Heinonen, 2006). *Requirements management* (RM), which is not within the scope of this dissertation, is related to the control and traceability of the agreed requirements. *Requirements development* (RD) (or requirements generation) concerns activities related to the elicitation, analysis, documentation, and validation of requirements. Because the field of SALTT is novel, as shown in Figure 4.1, this dissertation will focus on requirements development activities so that the designer is supported in understanding the problem domain. Requirements elicitation is the process of capturing, extracting, and obtaining needs from relevant stakeholders.

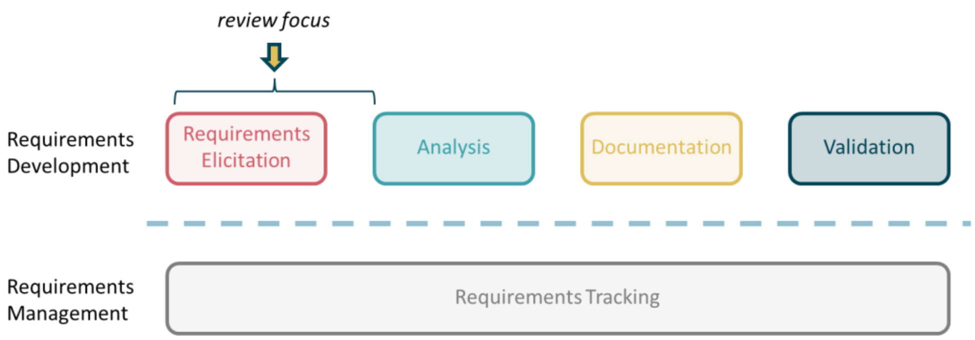


Figure 4.1: Literature review focus

Although the requirements elicitation's purpose is the same across domains, the activities carried out in the task clarification stage vary in literature (Berkovich et al., 2011; Darlington and Culley, 2002; Pahl et al., 2007; Ulrich et al., 2020).

Differences between theory and practice in RE

Darlington and Culley (2004) showed differences between the theoretical requirement capture-transformation-generation process and what happens in the real world. Starting with what is often described as a "*woolly*" wish list of very informal and incomplete customer needs, design engineers need to develop a product that satisfies these needs within the boundaries set by the available resources (technology, time, budget, personnel, etc.). However, not every design problem follows the waterfall process (Finkelstein, 1994).

Sometimes, the requirements are established concurrently while the artefact is being designed (Ulrich et al., 2020). It is also vital that designers have adequate knowledge and skills to interpret the customer's problem to properly design the needed solution (Darlington and Culley, 2004). In contrast with Pahl et al. (2007), Berkovich et al. (2011) suggest to concretise or translate the requirements (that are "*in the language of the stakeholders*") into quantitative and qualitative technical specifications ("*in the language of the developers*"), only after they have been refined rather than in the task clarification stage.

4.2 Methodology of the Literature Review

Methodology

A critical literature review was conducted to carefully identify and evaluate the existing research supporting the requirements elicitation activity. Using the guidelines for a systematic review (Kitchenham and Charters, 2007), relevant studies were established through a systematic mapping process. Therefore, the question that this literature review focuses on is:

> How are designers being supported in the task clarification stage
> to generate and understand the requirements?

4.2.1 Review criteria

Review criteria

Based on the primary literature review question, review criteria were established to provide a common basis on which literature will be analysed.

<u>CRITERION #1</u>

The type of elicitation approach used to support the designer:
- *Prescriptive*
- *Descriptive*

Darlington and Culley (2002) classified research in this field as either being prescriptive or descriptive. Prescriptive approaches formalise the *process* of eliciting requirements to get better results or be more efficient. Essentially, research works such as systematic methodologies and design support tools (e.g., Quality Function Deployment - QFD) that influence engineering practice are mostly prescriptive. On the other hand, descriptive research focuses on the *performance* of the elicitation process that touches on the competencies, activities, and behaviours of the designer. Thus, descriptive work focuses on the knowledge content and suggest solutions that inform the designer about the design problem. A combination of both approaches guides designers in establishing the right end-users needs efficiently.

CRITERION #2
The type of requirements supported:
- *Functional requirements*
- *Non-functional requirements*
- *Affordances*

The elicited requirements can either be functional requirements (FRs) or non-functional requirements (NFRs). FRs relate to how the product can be helpful to the user in accomplishing a goal. In contrast, NFRs serve as constraints by referring to solution attributes that affect user preference (Braun et al., 2015), product quality and performance (Shankar et al., 2020). In Maier and Fadel (2003), the use of affordances as requirements was postulated.

CRITERION #3
The domain for which support is provided:
- *Generic*
- *Domain-specific*

The third criterion aims to address whether the support provided will allow the designer to use it within any field of design engineering or not. Generic support means that the process, method, tool, or model is reusable within any field, whereas domain-specific support focuses on the needs for particular solutions.

CRITERION #4
The users considered for the solution:
- *All stakeholders*
- *PD stakeholders only*
- *End users only*

This criterion addresses the completeness of which requirements have been considered during elicitation. As discussed in Chapter 3, the end users of SALTT artefacts can be divided into three groups: clinicians, caregivers and children.

4.2.2 Literature review boundary

The inclusion and exclusion criteria which characterise the boundary of this review are detailed in Table 4.1. These have been set to identify research works that address the literature review question and reduce bias (Kitchenham and Charters, 2007). The first consideration was given to primary studies discussing work related to the main review question. Articles that solely focus on software engineering were excluded from this review. Furthermore, to avoid repetition, only literature post-October 2001 up to April 2022 were considered, because an extensive review of a similar study is available in Darlington and Culley (2002).

Table 4.1: Inclusion/exclusion criteria

#	Inclusion Criteria	#	Exclusion criteria
1	Primary studies	4	Duplicate studies
2	Studies that include requirements elicitation	5	Non-English written articles
3	Studies published between October 2002 and mid-April 2022	6	Other RE activities, such as analysis and traceability, are the main focus.
		7	Software development exclusive papers

4.2.3 Sources selection

Due to different terms used in this field, a search string was used to identify relevant literature within the following electronic databases: ACM Digital Library[4], ScienceDirect[5], IEEE Xplore[6], Springer Link[7], and Google Scholar[8]. Figure 4.2 shows a flowchart of the review process and the number of articles identified from each database.

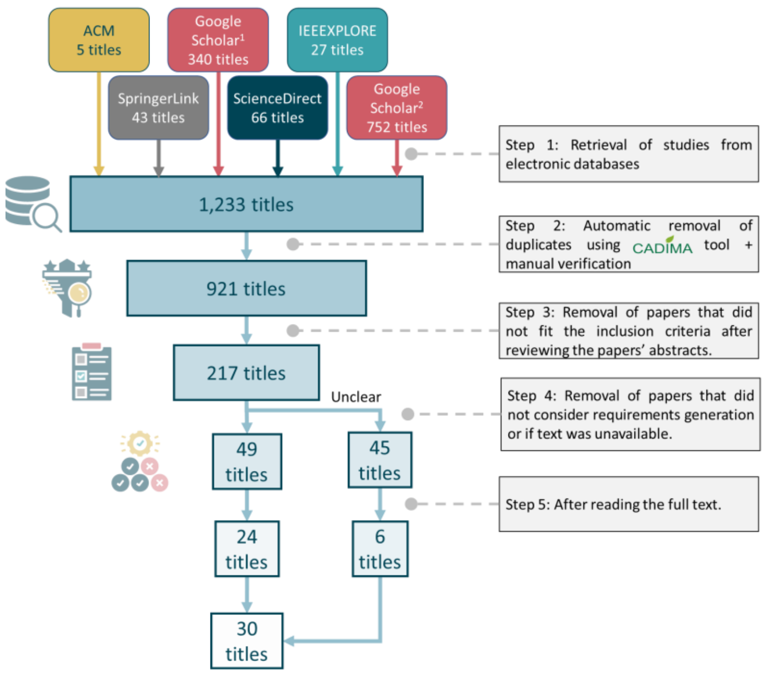


Figure 4.2: Method employed for systematic scoping

[4] https://dl.acm.org/
[5] https://www.sciencedirect.com/
[6] https://ieeexplore.ieee.org/
[7] https://link.springer.com/
[8] https://scholar.google.com/

In Step 1, the studies were retrieved using the following search string:

1. "engineering design requirements" OR "customer needs"
2. "task clarification" OR "requirements elicitation"
3. "design support" OR "support tool" OR "support means"
4. "product" OR "device" OR "toy"

which were combined as: 1 AND 2 AND 3 AND 4.

The number of search results from Google Scholar was significantly higher than that of other databases. Berkovich et al. (2011) highlight that Google Scholar contains 90% of engineering academic publications published after 1990. For this reason, a second search string was conducted in Google Scholar only to ensure that any missed studies were included. The search string included the terms "customer requirements" and "requirements engineering" in 1 and 2, respectively.

The new search result contributed 50 unique articles after Step 3 of this scoping activity. The free online software tool, CADIMA, was used to support the elimination of duplicates in Step 2 and the study selection in Steps 3 to 5, as shown in Figure 4.2. A total of 30 publications met the selection criteria and were included in this review.

4.2.4 Classification

Classification of support tools for requirements elicitation

The reviewed papers were classified based on the overarching support approach that they adopted for requirements elicitation:

1) Methodology-based approach
2) Ontology-based approach
3) Data-driven approach
4) Model-driven approach
5) Key characteristics approach

4.3 Methodology-based approach

Research works in this section are based on established design methodologies which support designers to structure and control the elicitation of requirements in the task clarification stage.

4.3.1 Requirements for wearables in Health 4.0

Bause et al. (2020) propose a framework that uses four design methodologies, namely, Inclusive, Emotional, Robust, and Participatory design, to cater for both end-users and PD stakeholders' requirements. The authors claim that designers of future wearable healthcare products should leverage human-centred and product-centric design principles to cater for user (physical and emotional) variations and information management, whilst ensuring that high-quality products are delivered.

Strengths of the wearable healthcare products framework

All stakeholders are considered

By employing both human- and product-centred design approaches, one ensures that the needs of all the stakeholders are studied at the task clarification stage.

May be applicable to other domain sectors to generate different requirements

For the same reason, different types of requirements can be elicited from such a methodology. Moreover, this approach may be suitable for developing other consumer products and not just wearable healthcare products.

Limitations of the wearable healthcare products framework

Prescriptive approach

The proposed framework follows a prescriptive approach. However, no details on how four different design methodologies can be integrated were provided.

4.3.2 Lifecycle-oriented Function Deployment (LFD)

Neramballi et al. (2020) propose a methodology for designing greener product-service systems (PSSs) based on existing solutions. Part of the proposed methodology is shown in Figure 4.3.

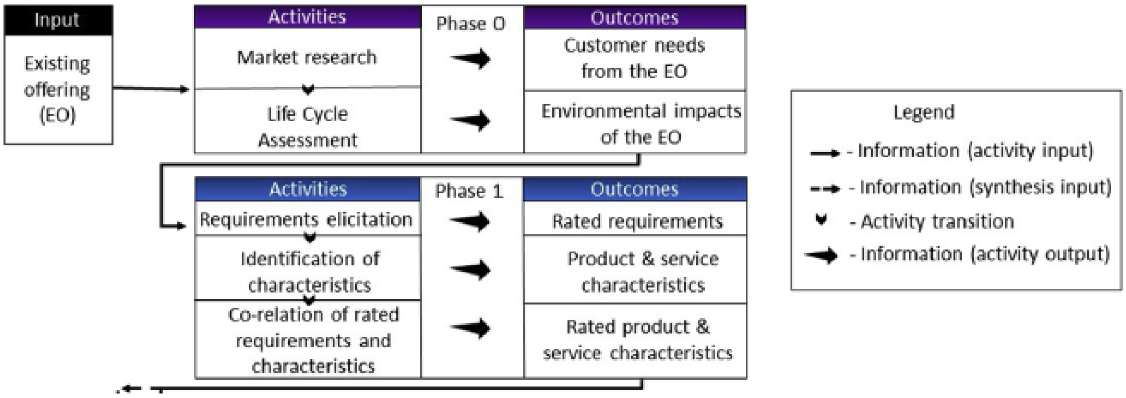


Figure 4.3: A partial view of the lifecycle-oriented function deployment (LFD), from Neramballi et al. (2020)

During the market research phase, a lifecycle assessment is carried out on existing products with respect to customer expectations for the new product and its environmental impact. Workshops with potential customers are then carried out, in which requirements are elicited and manually translated into design characteristics. Environmental requirements are rated by a weighting factor obtained through a lifecycle analysis (LCA). Then, design characteristics are translated manually by designers using their tacit knowledge or supported by literature. As a final step, the rated requirements are manually co-related with the identified design characteristics using a modified version of the QFD to prioritise requirements. This process is repeated to find suitable existing components. Then, a combination of components that matches the customers' needs is integrated and offered as the redesigned solution.

Strengths of LFD

Prescriptive approach to offer new solutions based on past products

Focus is placed on the needs of all users

The proposed methodology is well structured and based on methods (QFD and LCA) that designers are acquainted with. The requirements are considered from a product-lifecycle perspective and prioritised on their environmental impact from an early design stage. Furthermore, this methodology promotes collaboration between stakeholders.

Limitations of LFD

Applies to matured domains

Experience required to generate FRs and NFRs

This methodology cannot be applied within new product markets as it relies on knowledge from existing offerings. Novice designers are not well supported because they must use their experience to translate needs into requirements if documentation is unavailable. Further, redesigned offerings are proposed based on several weighting methods, which could generate systematic bias.

4.3.3 Systematic product development for customisable IoT devices

Further to Müller et al.'s (2010) checklist for PSSs, Gogineni et al. (2019) argue that new checklists for Internet of Things (IoT) devices are required, and propose a design methodology for customisable IoT devices based on the VDI 2206 guideline for mechatronic devices. Their methodology highlights the importance of managing requirements (such as prioritising between one that will offer the most significant impact) and using a Product Configurator. The latter can map interrelationships between internal components of the product and output different possible configurations that a product can have.

Strengths of checklists-based approaches

Descriptive and prescriptive approach

On their own, checklists are descriptive tools. They can be used during the elicitation process as a reference of what needs to be considered or used at the end of an elicitation process to refine the requirements generated. They also act as a guideline on which requirements influence the design, but do not impose that a particular requirement is implemented. However, through the VDI-based prescriptive methodology, designers are provided with an improved design process which supports requirements generation. Non-functional end-user requirements, such as reliability and lifetime concerns, add value to IoT devices. Other strengths include the ability to automatically build the product

Checklists cover FRs and NFRs

architecture, which reduces product configuration errors and workload on the designers, thus saving development time and cost.

<u>Limitations of checklists-based approaches</u>

Not applicable to a specific domain

Checklists reflect the needs of predefined users

Generic checklists tend to capture a broad range of common physical artefacts' requirements but often miss requirements limited to specific domains. Domain-specific checklists consider specific stakeholders who may not be present within other domains. Thus, multiple checklists need to be consulted to ensure that all relevant users have been considered. In the current form, checklists do not highlight how they would interact with the actual artefact.

4.3.4 Methodology for PSS design

In Marilungo et al. (2015), an approach to support the design of PSSs was proposed. Their methodology, depicted in Figure 4.4, suggests four correlation matrices, based on the Quality Functional Deployment (QFD) method, that map out: 1) consumer needs with PSS demands to prioritise them; 2) the user tasks with PSS requirements to reveal the functionality of the PSS as a hierarchy; 3) the PSS functions, modelled using Unified Modelling Language (UML), with the tangible and intangible PSS assets to identify the needed resources; and 4) the partners' resources with the needed resources to establish the most appropriate partners (suppliers) for the project.

<u>Strengths of the methodology for PSS Design</u>

Prescriptive approach that can be used in any domain.

All users' FRs and NFRs can be captured

This methodology defines a systematic approach to establishing the ideal suppliers that can satisfy the customers' needs from an early design stage. The QFD method can be applied to both the end-users and PD stakeholders' needs and can be used within any domain. Moreover, both functional and non-functional requirements can be considered.

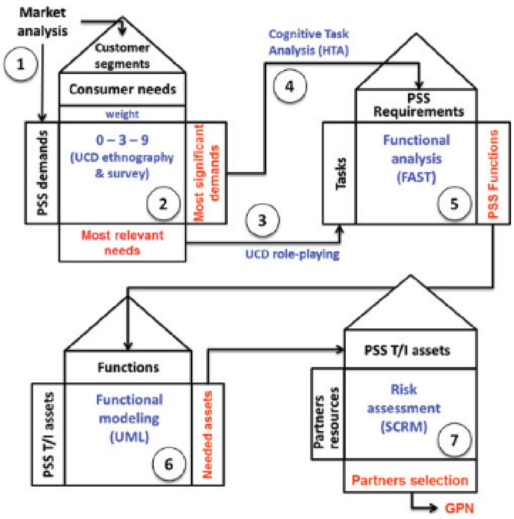


Figure 4.4: A methodology for PSS design, from Marilungo et al. (2015)

<u>Limitations of the methodology for PSS Design</u>

Prone to market research deficiencies

Because no domain support is provided during the elicitation stage, customer needs that have not been identified in the market research phase may never be identified in the subsequent stages.

4.3.5 Design Knowledge Reuse (DKR)

Neelamkavil and Kernahan (2003) embraced the TIPS (or TRIZ) methodology to find customer requirements based on previous solutions and infer new designs. The concept behind this philosophy is that most designs are variations of existing designs. The aim of Neelamkavil and Kernahan's work is to retain and organise requirements, knowledge and lessons learnt into a central system which can be inferred to new designs.

<u>Strengths of DNR</u>

Prescriptive and descriptive approach

Search for end-user FRs

Cross references domain knowledge

The implementation of Neelamkavil and Kernahan's approach consists of a database populated with past knowledge. A successful 'function' search will inform the designer how such a function was implemented in existing products, which components it is related to, and its specifications. This knowledge drives the following design stages, especially the concept design stage, which accelerates the design process. Furthermore, designers may be inspired to implement a functional requirement from a different domain.

Limitations of DNR

Stakeholders' consideration is limited to the pool of knowledge

This tool urges designers to elicit solutions from a large pool of knowledge. Thus, it requires various repositories and a considerable amount of generic data to be useful. No reference is made on whether customer needs are formalised or not.

4.4 Ontology-based approach

An ontology is the formal representation of the concepts and categories related to a domain that can characterise and classify expert knowledge (Uschold and Gruninger, 1996; W. Wong et al., 2012). It can be seen as a taxonomy of classes with various hierarchies and their related properties. Thus, an ontology provides a structure to formalise and construct reusable domain knowledge into models. For this reason, ontologies are referred to as knowledge models (Sanya and Shehab, 2014) for knowledge bases (Wong et al., 2012). Darlington and Culley (2008) explain that ontologies are useful for "*information organisation, knowledge-based development, communication, software development and problem solving*". Therefore, ontologies can be used to formalise requirements or form the basis of software tools (Zheng et al., 2021). Figure 4.5 shows that ontologies can vary from informal to formal representations. Wong et al. (2012) suggest using lightweight ontologies first and then moving to a more formal ontology structure once all the relations within a model are understood. A problem may be seen from different viewpoints and, therefore, different ontologies can be used to represent it. Thus, their size and reusability may be affected.

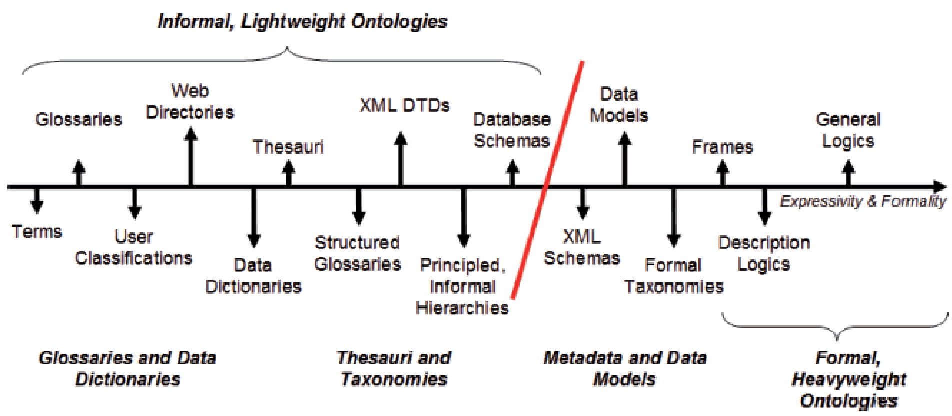


Figure 4.5: A spectrum of ontologies kinds, from Wong et al. (2012)

4.4.1 Value-based requirements elicitation (VBRE)

Taxonomies provide a controlled method of gathering requirements. These are generally constructed from a pre-established set of conditions that guide the elicitation and analysis processes (Darlington and Culley, 2002).

To deal with socio-political issues in requirements engineering, Thew and Sutcliffe (2018) define a taxonomy for values, motivations, and emotions (VME) that are normally associated with products. This approach analyses raw data, collected from end users, to capture functional and non-functional requirements and their implications. Novice or expert analysts can review transcriptions of interviews, observations or meetings, such that the most frequent categories are used to identify requirements and ones that conflict.

<u>Strengths of VBRE</u>

Prescriptive and descriptive, human-centric approach

Discovery of functional and non-functional requirements

The VBRE method takes a human-centric approach to establish requirements of the end users. Therefore, this method can be applied with any stakeholder or user of the product, allowing insightful functional and non-functional requirements to be elicited when one becomes used to the terms within the taxonomy.

Limitations of VBRE

Domain is independent, given that the taxonomy is generic

This procedure can be applied in any domain as long as the domain remains valid to the concerned product. As with thematic analyses in qualitative research, one may find it difficult to manually code the transcriptions of all the terms within the taxonomy.

4.4.2 A taxonomic framework for contextual considerations

Aranda-Jan et al. (2016) provide a taxonomy that advises designers about contextual factors affecting the design of medical devices in low-resource settings, highlighting requirements which have higher priority. For instance, in poorer countries, the affordability and serviceability are more critical than the technology used. Their taxonomy concerns four overarching themes: the physical environment, the institutional systems and structure, technology, and peoples' personal factors.

Strengths of contextual categories

Descriptive approach

Focusing on the use-phase lifecycle

Generic constraints but limited to statements

This contribution provides a descriptive, context- and user-centric approach which highlights constraints influencing the required solution. Such context considerations affect the priority of the customer needs and implementation of the artefact. It is also useful to inform the later design stages when validating the design requirements.

Limitations of contextual categories

High-level considerations, specific to undeveloped countries

Although the most important contextual factors are highlighted, no weighting factor is provided to support the way the designer evaluates their effects. Because contextual requirements describe the limitations of the artefacts, this framework does not provide knowledge or requirements to support product design. Moreover, they cannot be applied in other non-medical domains.

4.4.3 Cognitive Maps

In Dias et al. (2016), after transcribing interviews manually, cognitive maps were used to elucidate customer problems and needs. As can be seen from Figure 4.6, the cognitive map is made from a hierarchy of primary elements linked by connections that describe means and ends. Primary elements can represent objectives, actions, alternatives, and emotions, among others. These are grouped based on a strategic value system that the interpreter decides to be the fundamental objective at the top of the hierarchy. Clusters of concepts are then formed to identify common requirements and reduce the complexity of the map.

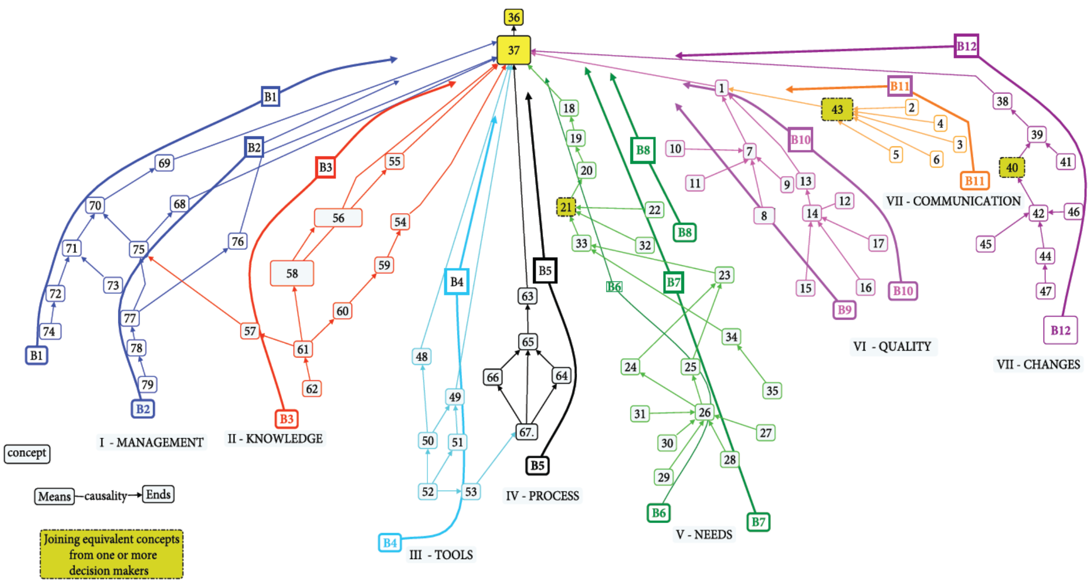


Figure 4.6: A cognitive map showing clusters of requirements, from Dias et al. (2016)

<u>Strengths of cognitive maps</u>

A prescriptive approach that elicits important concepts

Different types of requirements can be captured within any domain

Cognitive maps can visually show interlinked requirements whilst retaining the use of the natural language, making them useful for comprehending different types of user requirements. Moreover, this generic tool allows problems within any domain to be organised, communicate knowledge or construct an ontology.

<u>Limitations of cognitive maps</u>

Depends upon the stakeholders from whom data was collected

Any stakeholder can be considered in the elicitation of requirements, but one must keep in mind the exhaustiveness of this process. The construction of cognitive maps is subjective. For this reason, a team of analysts can build the cognitive map together to avoid biases and resolve conflicts at an early stage.

4.4.4 Engineering Design Requirement (EDR) Ontology

The engineering design requirements ontology

Darlington and Culley (2008) developed three ontologies: the engineering design requirements, product finish, and machine motion ontologies. The first ontology, shown in Figure 4.7, provides means by which the implicit elements that direct the design are made explicit. The content and structure of this ontology provide a blueprint for structuring any new PD project.

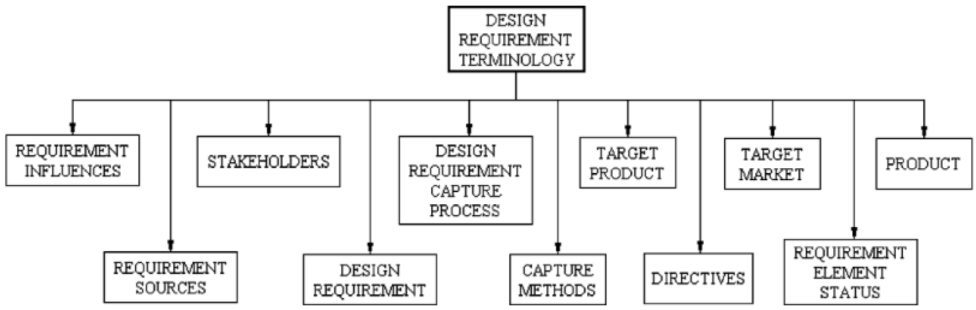


Figure 4.7: A high-level view of the Engineering Design Requirement Ontology, from Darlington and Culley (2008)

The product finish ontology

Apart from the aesthetic aspects, this ontology looks at the product's lifecycle by listing usability, function, safety, and lifespan considerations, among others. This ontology allows designers to have specifications ready for the implementation phase and serves as a checklist.

The machine motion ontology

In contrast to the previous two ontologies, which are quite generic, the machine motion ontology looks at the purpose, function, and possible attributes that a manufacturing machine can have. This ontology was implemented in a software called CaDRes, which allows designers to generate a formalised list of engineering specifications for a machine.

<u>Strengths of EDR Ontology and CaDRes</u>

Descriptive (and Prescriptive)

An ontology on its own can be categorised as descriptive. However, once implemented in a tool, the approach becomes prescriptive because it influences

Domain-specific FRs and NFRs can be considered for all the stakeholders

how the system handles requirements. The presented ontologies reflect all the stakeholders' FRs and NFRs for mechanical artefacts.

<u>Limitation of EDR ontology and CaDRes</u>

To construct an ontology, domain expertise, time and effort are required, as they can be very complex. Furthermore, other ontologies are required for different artefacts.

4.4.5 A user-centred information model for medical devices

In Hagedorn et al. (2016), five ontologies are used to implement a design support tool that considers stakeholders' requirements, end-users ergonomics, design and design process data, and relevant documentation. Figure 4.11 shows a partial representation of the model and the different relationships between entities.

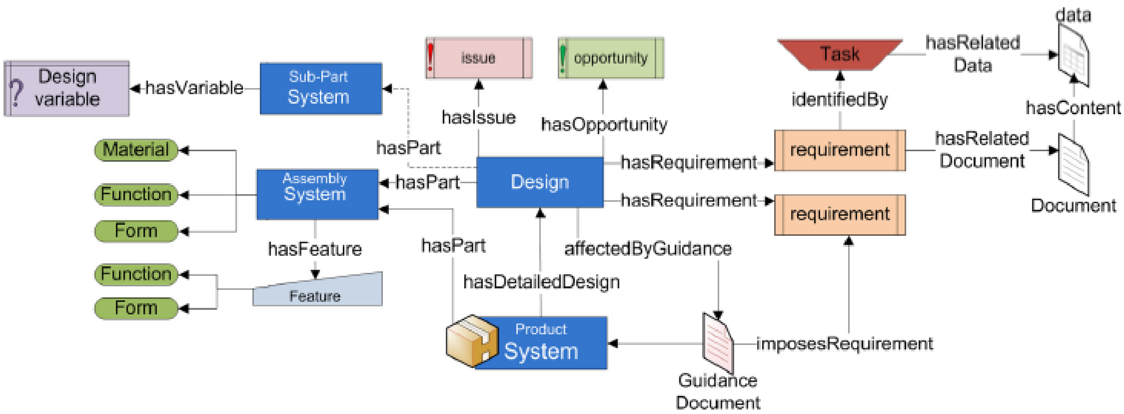


Figure 4.8: A partial representation of the Design and Design Process ontology discussed in Hagedorn et al. (2016)

<u>Strengths of the Design and Design Process ontology</u>

FRs and NFRs

This information model provides a systematic and integrated perspective of key usability information that drives design decisions. By considering existing product issues, FRs and NFRs for improvements can be generated whilst facilitating the reuse of design knowledge and, potentially, faster informed ergonomic decision-making (Hagedorn et al., 2016). Through this implementation, all stakeholders' requirements can be considered.

All stakeholders of the product are modelled

Limitations of the Design and Design Process ontology

Descriptive approach towards generic mechanical products

Due to the fact that this ontology is based on a basic model of generic product characteristics, it can only be used to improve generic aspects. Furthermore, the designer still needs to do research for requirements elicitation before manually linking the gathered knowledge to specific aspects of a design at a conceptual or embodiment design level. As with any complex information model, adding entries and link relationships requires extensive effort. For this reason, it makes more sense to be used on a product line rather than on a single product.

In Mukhopadhyay and Ameri (2016), the ReqOn ontology for generic requirements was proposed as part of a system that measures the information content within a requirement statement and ranks requirements. In contrast to Hagedorn et al. (2016), differences between FRs and NFRs are made explicit. A prototype software implementation of this ontology permits users to input requirements manually by filling a form corresponding to the properties and attributes of the ontology. The strengths and weaknesses of ReqOn are summarised in Table 4.2.

4.4.6 Ontology-driven and scenario-based requirements elicitation

The product finish ontology

A three-step, ontology-driven requirements elicitation framework based on scenario modelling (discussed in Section 4.6.2) is proposed in Fan and Jiang (2012). In the first step, the ontologies of the product and scenario with predefined relationships are established to form the domain ontology database. In the second step, rules will determine how requirements inferences are created. In the third step, product requirements are elicited through a data-mining approach, based on specific scenarios. The framework and the scenario and product ontologies are shown in Figure 4.9 (a), (b) and (c) respectively.

Strengths of the ontology-driven requirements

Descriptive approach

End-users' FRs and NFRs are automatically established

This descriptive support system allows requirements to be elicited quickly if rules are known and correctly defined. Additionally, the framework provides designers with a thorough understanding of the end-users needs by mapping specific scenarios to customers' FRs and NFRs.

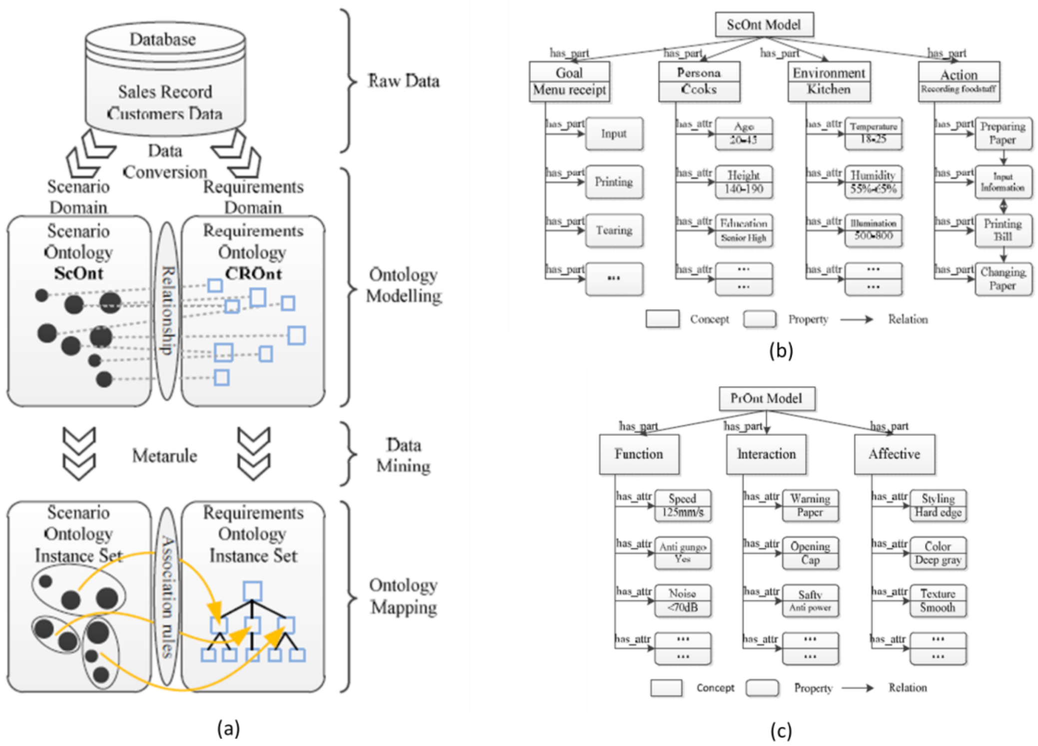


Figure 4.9: (a) Framework of ontology-driven requirements elicitation based on scenario, (b) Scenario ontology model, (c) Requirement ontology model, from Fan and Jiang (2012)

Limitations of the ontology-driven requirements

Suitable in generic or matured markets

Setting up the rules and requirements requires existing products and sales records. As discussed in Section 4.5, data-mining techniques require a large amount of data to draw clusters. Thus, they are unsuitable in immature markets.

4.4.7 Goal-Oriented Requirements Modelling

Braun et al. (2015) adopted a goal-oriented requirements modelling approach to define an ontology for requirements. As can be seen in Figure 4.10, requirements are determined by: the nature of the problem that defines feature-related, functional, theory-based and adapted requirements; the stakeholders (domain expert, researcher, developer and the end user) who generate user-related requirements; and the context or domain of the problem, which cause contextual requirements or constraints. Design-related assumptions may also cause requirements to be formulated.

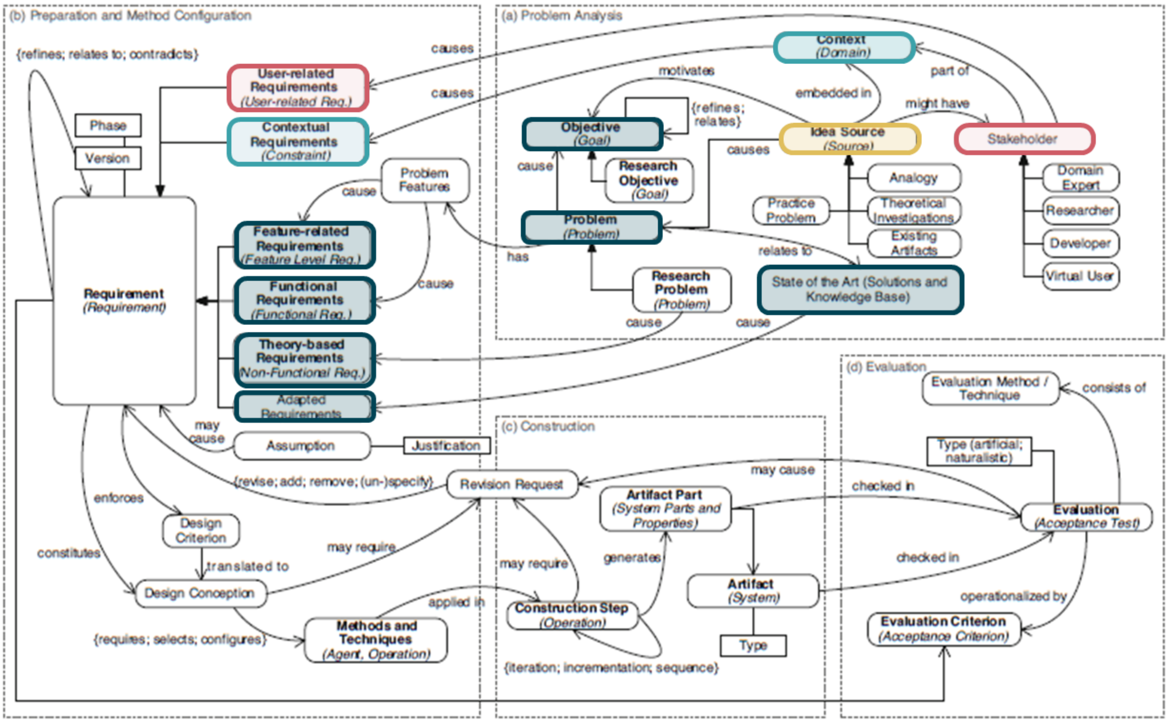


Figure 4.10: Requirements ontology, adapted from Braun et al. (2015)

<u>Strengths of Requirements ontology</u>

Prescriptive approach

Requirements stem from the domain problem

Requirements are clearly separated

This categorisation of requirements provides a descriptive approach to elicit various types of requirements, which also facilitate the communication of the design problem. Whilst some requirements need to be evaluated, functional requirements provide a starting point for detailed specification and configuration of the design in later stages. Additionally, different types of users are taken into account, which provide user requirements that describe the intended solution.

<u>Limitations of Requirements ontology</u>

Requirements lack formalisation

This ontology does not formalise the requirements statements and, so, the problem of informality is still present.

4.4.8 Computer-Aided Requirements Elicitation (CARE)

Similar to the work of Wang and Zeng (2009), Becattini and Cascini (2013), developed a dialogue-based web application to guide the designer to input the end-user needs and specify the product characteristics. The requirements elicitation stage is supported by criteria (like an ontology) for three sets of requirements: Useful Functions, Harmful Functions and Resources Consumptions. Requirements are created through a question-and-answer technique, as shown in Figure 4.11. Using a second tool, after all the requirements have been inputted, the designers specify the design variables that satisfy the requirements or that affect the system. This leads to the identification of the cause-and-effect relationships between the design variables and the requirements. Design variables are processed computationally using algorithms that help designers see a prioritised list of conflicting requirements.

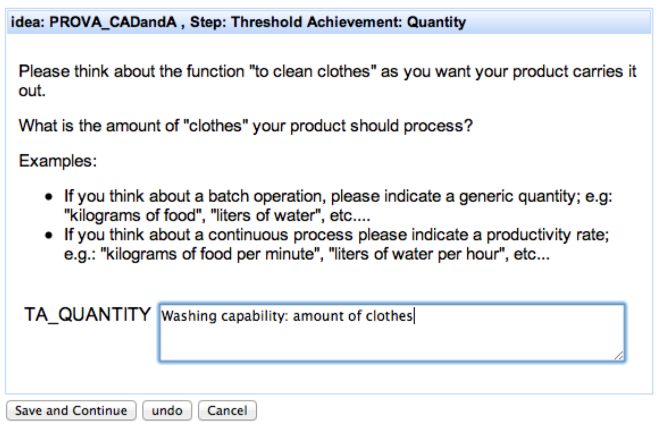


Figure 4.11: Computer-Aided Requirements Elicitation tool, from Becattini and Cascini (2013)

<u>Strengths of CARE</u>

Prescriptive-Descriptive approach

FRs and NFRs

CARE was implemented as a prescriptive, web-based tool, allowing multiple designers to work on the requirements elicitation phase. The criteria within the Useful Functions, Harmful Functions and Resources Consumptions model, coupled with the CARE tool, allow designers to elicit detailed FRs and NFRs in a descriptive approach.

<u>Limitations of CARE</u>

Considerations of end-user requirements

Requirements elicitation is domain independent but the designer needs to be experienced on the cause and effects of requirements

The criteria cover requirements belonging to the use-phase of the product, meaning that requirements belong to the end users. The second module of the proposed tool requires the designer to already have an idea of the proposed solution or at least be familiar with the main components of the system to be designed. Therefore, it may be more useful in projects to improve existing products rather than new products. Although CARE is domain-independent, because the criteria can be applied to any system, it does not provide the domain of the product.

4.5 Data-driven approaches

Operate on the natural language

A lot of research nowadays focuses on automatic information extraction from written or transcribed texts (Han et al., 2019). This language-based elicitation approach recognises the importance of gathering end-users needs in an efficient manner, especially in markets where big data is accessible. Progress in this domain has focused on improving the quality and reliability of requirements extraction from large data sources by training computers to identify requirements based on the rules that govern the natural language.

4.5.1 Heterogeneous requirements gathering

Zheng et al. (2021) explain that current project management software allows designers to specify unstructured requirements in the natural language. However, they point out that modelling and programming languages such as UML, CML, SysML and JSON can provide a unified syntax for the formalism of requirements. Nonetheless, semantic differences in the representation of requirements can still lead to misunderstanding and non-homogeneity. In their work, ontologies were used to resolve ambiguities by automating the gathering process from stakeholders and data (sensors, logs, and ICT devices). Generative design principles were then applied to suggest modular components for manufacturing robotic systems, as shown in Figure 4.12.

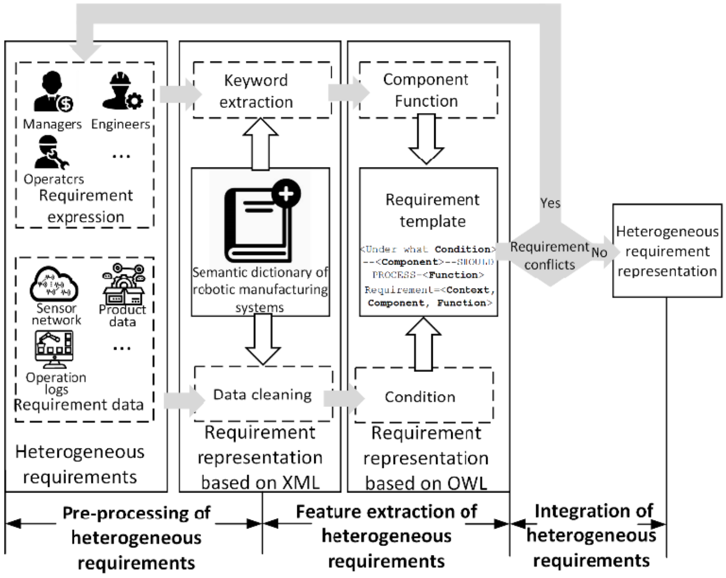


Figure 4.12: Heterogeneous requirements gathering, from Zheng et al. (2021)

Strengths of Heterogeneous requirements gathering

Heterogeneous FRs and NFRs are considered from PD stakeholders

Descriptive approach

A semantic dictionary is used to process PD stakeholders' FRs, NFRs and manufacturing data. An ontology model is used to formalise heterogeneous requirements, allowing both designers and machines to understand them and resolve requirement conflicts.

Limitations of Heterogeneous requirements gathering

Domain specific

Requirements from stakeholders need to be elicited manually. Furthermore, the proposed system depends on existing modular systems that have been already produced for the domain, such that robotic configurations are to be suggested automatically. A common disadvantage of data-driven methods is that they rely on big data and, therefore, they are more suitable in established markets.

Similarly, in Yu and Wang (2010), a Pareto-based genetic algorithm was used to determine association rules that reflect the mapping between user needs and product design specifications. This approach requires customer feedback and previous requirements on already existing products such that associated functions and translated new FRs are used to develop new products based on existing modular product families.

4.5.2 Dynamic requirements elicitation

The dynamic requirements elicitation framework shown in Figure 4.18 was proposed in Han et al. (2019) to continuously extract user requirements from social networks at a predetermined time interval. The framework makes use of a dictionary containing domain knowledge and known requirements to filter out relevant opinions. Data from the previous extraction are used to refine the data processing of the next iteration. In the data analysis stage, clusters of high-frequency words or phrases are assigned into topics if they match words from the dictionary. If not, topics are assigned manually.

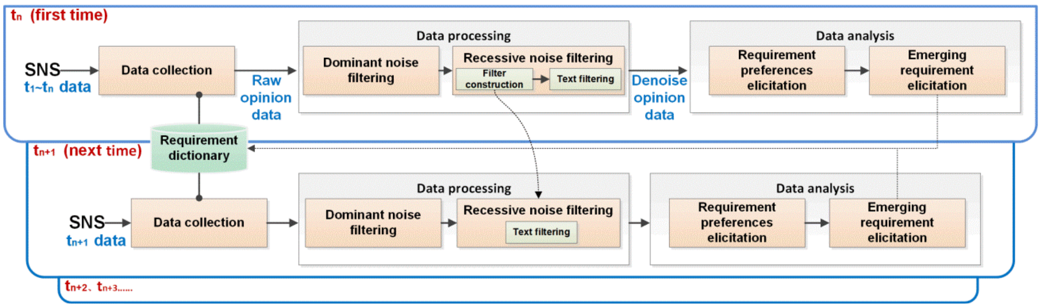


Figure 4.13: Dynamic elicitation framework of user requirements from social media, as depicted in Han et al. (2019)

<u>Strengths of Dynamic requirements elicitation framework</u>

Prescriptive approach

Type of requirements elicited dependent on the dictionary

Dictionary determines domain

This technique is advantageous over the other data-mining approaches because it keeps on eliciting requirements over time. Although the first data-mining iteration requires processing a large volume of data, the next iteration will be less intensive and has the advantage of using an improved filter. The data analysis module permits new requirements to be discovered in almost real-time and, therefore, designers can react faster to new requirements. Moreover, a well-defined dictionary allows the system to specify different requirements, such that it can be used within any domain.

Limitations of Dynamic requirements elicitation framework

Only end-users requirements are elicited

Recessive noise is always a disadvantage in data-mining techniques and, therefore, systems require supervision initially. However, the aim of artificial intelligence (AI) and machine learning (ML) is to make this process more efficient and effective by using several filters to denoise the collected data. Moreover, social media channels consider end users' or buyers' opinions rather than domain experts.

4.5.3 Extraction of customer needs from reviews on social media

Lindemann et al. (2020) propose a methodology in which customer feedback from online reviews is collected and refined iteratively. In the beginning, the sources are selected and pre-processed to clean the data from outliers or missing data. Data are then translated into general needs during the actual processing of the product. In the final stage, the requirements are evaluated against a hypothesis, set during data selection. The information can be used to deduce possible changes to the next cycle of data-mining.

Strengths of automated requirements extraction

FRs and NFRs for end users

End-users' FRs and NFRs are compiled automatically through data-mining, where informal and impartial opinions are evaluated. These are obtained from complaints, recommendations, and personal life interactions. This approach saves the time of doing empirical studies. Moreover, because the contribution proposes a methodology, this approach has a prescriptive element.

Prescriptive approach

Limitations of automated requirements extraction

Domain dependent and reviews concern end users

Data-mining techniques need supervision to ensure that the collected data are reliable. Basic needs on misleading reviews can offset the needs of customers.

Furthermore, large amount of data must be available to rely on data-mining, meaning that such an approach is more suitable in established domains.

A similar framework is discussed in Chen et al. (2019), where various AI and ML techniques are used to analyse customer reviews in the form of opinions, images and videos. Their prototype implementation leverages Google Cloud Platform services to do data-mining.

4.5.4 Co-evolving Traceable Requirements and Architecture Network

A team-based, data-mining approach, called COTRAN, was proposed in Cotran (2013) to elicit requirements for existing product lines. After the market research is performed, transcribed data is tagged automatically using a predefined dictionary of words created by the team of designers. Matched terms are marked as the required artefact's potential functions, capabilities, or behaviours. Afterwards, the design team must review the tagged phrases and collaboratively elicit requirements.

Strengths of COTRAN

Descriptive and prescriptive approach

Requirements and user independent

The proposed framework can hasten the conventional requirements elicitation process, but it is not entirely autonomous. The elicited requirements can be of any type, and these can be obtained from different users who would encounter the artefact during the lifecycle.

Limitations of COTRAN

Ambiguous requirement statements

Can be used in any domain

COTRAN does not formalise the structure of requirements, but each statement must be expressed using the word ‘shall’. This is against the requirement specification guidelines specified in Chapter 2. Although this approach can be used within any domain, the designers must have knowledge and experience with similar products or know what knowledge needs to be captured.

4.5.5 Kansei Mining System

In Jiao et al. (2006), a Kansei mining system was proposed to support future design work. By analysing sales records and product specifications, Kansei mapping patterns were created through the mining system shown in Figure 4.14, which allows rules to be stored in a knowledge base. When customers communicate new affective needs, designers are able to generate designs that reflect these needs and so can start the design work based on past design work.

Strengths of the Kansei mining system

Descriptive (and Prescriptive)

NFRs from end-users can be captured

This approach promotes designer and end-user interactions. Kansei engineering uses adjective words that can help end-users express their emotional needs. With such a system, end users can visually understand how products affect their affective needs whilst designers can grasp and better explore these needs.

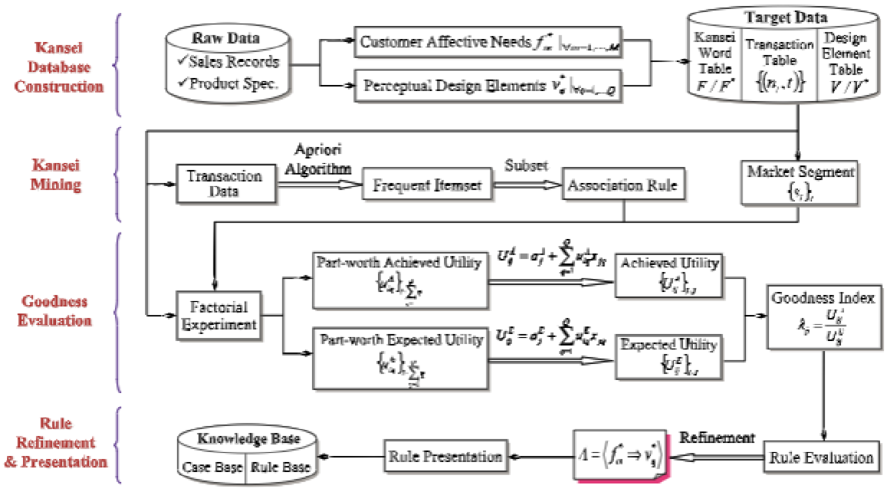


Figure 4.14: Kansei mining system architecture, from Jiao et al. (2006)

Limitations of the Kansei mining system

Suitable for similar existing products

The challenging aspect of Kansei Engineering is the translation of people's subjective affective needs into verbal descriptions. Differences in semantics add to the challenge. This approach also requires a well-defined market from which information about existing or similar products can be attributed to different features of the new product.

4.6 Model-driven approaches

The goal of Model-Driven Engineering (MDE) is to describe a system using a variety of graphical models that designers and computers can easily understand. Modelling approaches are prevalent in software applications, as they are useful in transforming abstract models of complex systems into more concrete models without losing information. The literature discussed in this section shows how such an approach is being used in the early design phases of product development.

4.6.1 Model-based systems engineering (MBSE)

The first set of literature has been grouped under MBSE because they use modelling languages to describe a system. These are Unified Modelling Language (UML) and Systems Modelling Language (SysML). SysML reuses and extends seven diagrams from UML, mainly use-case diagrams, sequence diagrams and state diagrams, among others. One of the exclusive diagrams in SysML is the *requirements diagram* which allows requirements to be formally modelled (Kruse, 2017). An example of a requirements diagram is provided in Figure 4.15.

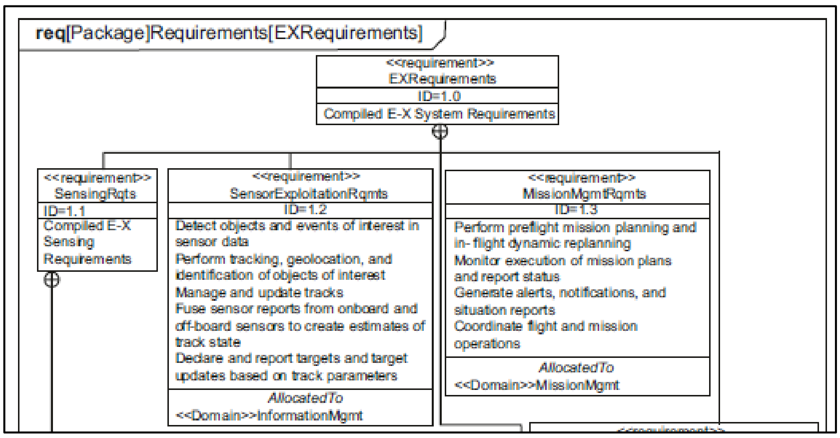


Figure 4.15: A partial top-level SysML requirements diagram, from Borky and Bradley (2019)

4.6.1.1 Modelling of requirements in SysML

Nonsiri (2015) uses SysML's requirement diagrams to model textual requirements and their relationships with parts of a system, as the level of detail increases from stakeholders, to functional, to system, to subsystem and up to components requirements. The framework shown in Figure 4.16 was proposed to explain how project managers or designers can derive tasks from requirements diagrams and then automatically optimise the sequence of tasks using the Design Structure Matrix. By decomposing requirements and establishing their dependencies, one can detail all the customer needs and reflect them in engineering specifications. Moreover, mathematical models can be assigned to each requirement to perform simulations from an early design stage, allowing designers to make informed decisions.

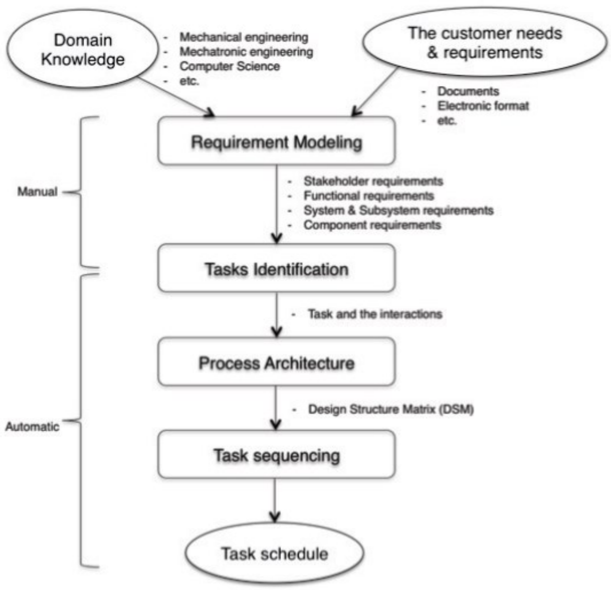


Figure 4.16: Integrated framework, from Nonsiri (2015)

<u>Strengths of Requirements Diagrams</u>

Prescriptive approach

The requirements modelling approach can be exploited in product design, especially when combined with other software applications. End-users and PD stakeholders' FRs and NFRs can be represented through requirements diagrams.

All stakeholders' needs can be modelled

Another benefit is that the diagrams can be referenced at any time during the

All requirements can be modelled

design process, making it easier to manage and trace their detailed level. Further, relationships between users and components in the system can be easily communicated.

Limitations of Requirements Diagrams

No support on domain knowledge

Because the requirements diagram is independent of any domain, the elicitation stage is not supported. Hence, problems associated with requirements completeness are created. Even though they are easy to construct, modelling has to be done manually, and no formal statements are used to write requirements. As with ontologies, creating a whole map of needs and their relationships to functions, components, and processes can be lengthy.

4.6.1.2 Use-cases models with UML and SysML

In Amaechi and Counsell (2012), use-case diagrams are modelled in UML to illustrate how users will interact with a system. A use-case model involves actors, such as users or objects interacting with the main artefact; use-cases, that is, actions or functions intended by the artefact; relationships between actors and use-cases, and a system boundary that confines the artefact or system being modelled. An example of a use-case model is given in Chapter 9 (see Figure 9.4). Use-cases are prevalent in software applications. However, Amaechi and Counsell (2012) report that use-case models are mostly useful in small systems or sub-components of larger sub-systems.

Brace and Ekman (2014) propose a framework called CORAMOD, built on SysML, to support the requirements elicitation, analysis and validation activities. Coupled with a checklist, CORAMOD ensures that critical requirements are derived from the customers' statements and facilitates the systematic decomposition of requirements. As in UML, use-case diagrams in SysML can model FRs through black-box and transparent-box analyses.

Strengths of use-case diagrams

A communicative prescriptive tool that describes possible actions

Domain and user independent

Use-cases can be easily drawn with chart maker software tools that allow elements to be dragged and dropped. Unlike scenarios, a use-case diagram can treat a system as a black-box and cannot model the context. However, in Brace and Ekman (2014), the generic checklist allows CORAMOD to model both the FRs and NFRs of systems, reducing the possibility of errors or missing requirements.

Limitations of use-case diagrams

Useful for modelling of FRs only

Designers need to use conventional methods such as interviews and focus groups to elicit requirements. Use-case diagrams can only model functional requirements, and therefore, other needs may not be identified. However, in Brace and Ekman (2014), this deficiency was eliminated by using other methods to analyse NFRs, allowing dependencies and boundaries between requirements to be defined.

Because both UML and SysML cannot execute the models after requirements have been appropriately defined, the output from such tools can be used with other engineering software to run simulations.

4.6.2 Scenario-based approach

Scenarios describe end users, their needs and the contexts in which the artefact will operate into models, as shown in Figure 4.17. A scenario helps designers working in a team to establish a shared understanding of the requirements (Blanco et al., 2014). Users are described as *personas* in scenarios. These are fictitious user profiles representing actual users and their characteristics, goals and needs to portray a picture of who is going to use the artefact. Personas can be used on their own with respect to the needs and goals of the artefact, or augmented with scenario consideration (Blanco et al., 2014).

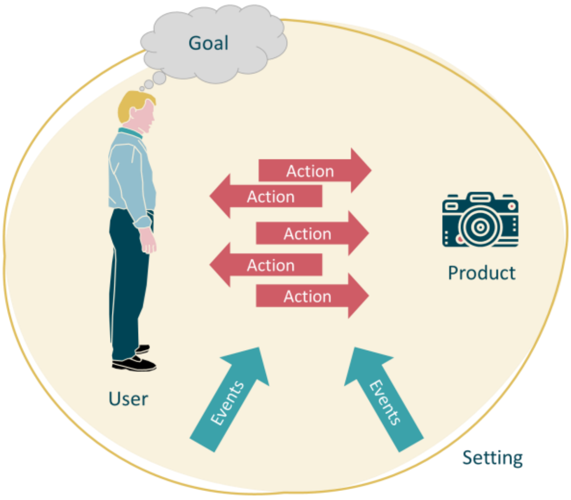


Figure 4.17: The elements within a scenario, adapted from Anggreeni (2010)

Within a scenario, situations are represented as stories, expressed in the natural language, pictures or videos, or as models, such as use-cases, storyboards, or flow charts. Scenarios can be either descriptive or prescriptive, meaning they can be based on real-world situations or envisaged situations. Scenarios can also be used later in the design process to help justify certain decisions made about the artefact or validate the design (Carroll, 2000).

4.6.2.1 Scenario-Based Product Development (SBPD)

Anggreeni (2010) developed a scenario-building tool based on a configurable content-management system (CMS) that allows users to create individual profiles for actors, goals, artefacts, settings, and events, and then define the relationships between these elements. Figure 4.18 shows a typical screenshot from the SBPD tool during the creation of a scenario. Requirements can be created either while the designer is creating the scenario or reviewing it. Thus, it allows needs to be discovered by inspiration.

<u>Strengths of SBPD</u>

Descriptive and Prescriptive approach to generate FRs and NFRs

The goal of the SBPD tool is to be simple, domain independent and allow users to build scenarios quickly. The CMS gives users the flexibility to reuse elements (e.g. actors or artefacts) in other scenarios, given that their purpose has not changed.

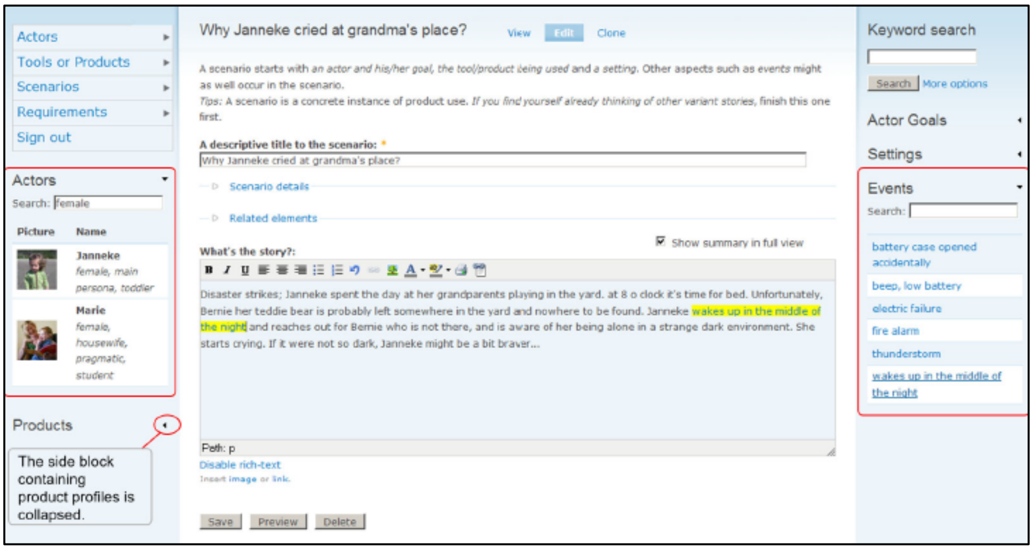


Figure 4.18: The creation of a scenario in SBPD, from Anggreeni (2010)

Can be used to model any lifecycle phase within any domain

Scenarios are appealing because they allow textual information to be represented graphically. The SBPD can be used as a brainstorming tool to elicit FR, NFRs and affordances.

<u>Limitations of SPBD</u>

Does not support the elicitation of formalised requirements

Although requirements can be assigned a category, the tool does not provide any structure on how to define requirements. It also does not guide which elements the artefact must have. Further, the SBPD tool does not capture the knowledge support required by designers to evaluate and develop requirements.

DIF-based scenario modelling

Lim and Sato (2006) constructed scenarios using the Design Information Framework (DIF). DIF uses elements and primitives (entity, attribute, state, act and time) that can be translated into analytical aspect models, narrative scenarios or specifications. Like object-oriented programming, in DIF, aspect models are built from objects with attributes and specific actions that can be performed (at a particular time) to achieve particular states. An action is defined by a timestamp, user, act, target object/user and the tool. Relations between these elements are defined through rules within the aspect models. A collection of actions builds a scenario, describing how a user will interact with the surroundings at different timestamps, allowing designers to build detailed representations.

Strengths of DIF-based scenario modelling

A descriptive approach to generate scenarios within any domain

In theory, different user requirements can be captured using the right aspect model

With the ability to model every element within a setting and assign timestamps and relations, DIF-based scenarios support designers in problem-solving, communication, and understanding users' activities in their context. The type of requirements elicited from such an approach depends on the type of analytical aspect model. Scenarios built during the task clarification stage can be reused during the subsequent design stage to evaluate concepts or validate the design.

Limitations of DIF-based scenario modelling

Complex but can be used in any domain

A disadvantage of this approach is that scenarios need to be very detailed to provide a complete picture of the setting. For this reason, they are more suitable for explaining simple products than complex ones involving multiple users and interactions. Because user goals and intentions are set in advance, the number of requirements is also pre-determined.

4.6.3 Prototypes-driven requirements elicitation

Coulentianos (2020) proposes the systematic use of early prototypes as a social tool to engage stakeholders in dealing with the fuzziness of customer needs and to increase the chances of getting the design right the first time. Prototypes serve as an impactful communicative instrument to create shared understandings. A similar approach was adopted in Balzan et al. (2019) to elicit children's preferences for the basic product characteristics. Various representations can be used as prototypes, including sketches, flowcharts, and mock-ups made from carton or 3D printers.

Strengths of prototypes

Elicit better conversations with different users of the system

Technique can be used within any solution development domain

Prototypes can generate different requirements

Early physical or digital concepts enable more profound and productive engagements with end users, as they assist in exposing interactions between users and artefacts within actual use or simulated environments. Prototypes can be used within any product development field and support the discovery of unforeseen uses and constraints through early interactions.

Limitations of prototypes

A prescriptive approach where requirements elicitation depends on the designer

Abundant resources (mainly time, money, and personnel) need to be available to conduct interviews or workshops at different stages of the design process, given that it is a highly user-centred, prescriptive approach. However, the benefits of such efforts at the beginning of a new product development project are a better product-success rate and fewer design iterations that will have to be made later on. Furthermore, outcomes from such studies, if recorded effectively, can be reused.

4.6.4 Affordance-based Modelling

As discussed in Chapter 8, Cormier et al. (2014) proposed fundamental affordances terms to formally express customer requirements and the Desired Affordance Model (DAM) shown in the example of Figure 4.19. In Cormier and Lewis, (2015), they used affordances to define relational design specifications based on users' characteristics, by first correlating affordances with specifications and then affordances with user characteristics.

Strengths of Affordance-Based Models

Prescriptive approach

By looking at the design affordances of artefacts, one can identify contextual requirements beyond the primary function of the artefact. This approach requires designers to place the artefact in the users' perspective and characteristics to identify the specifications.

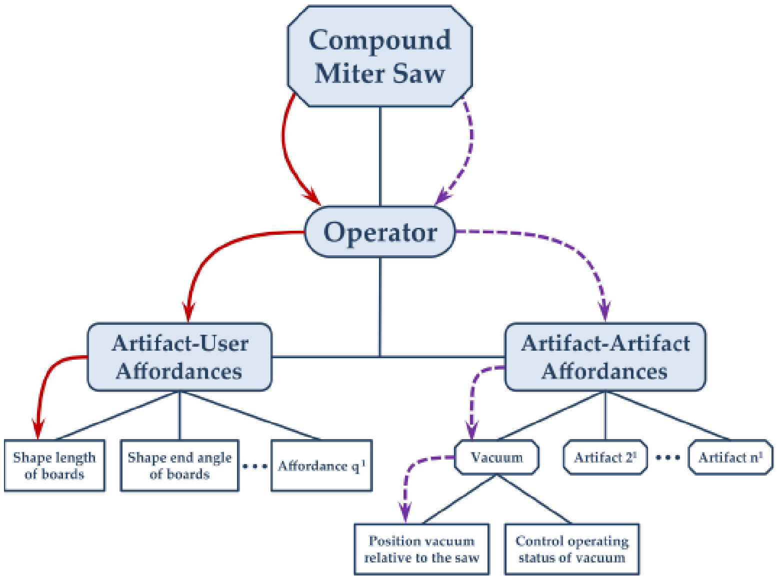


Figure 4.19: The Desired Affordance Model, from Cormier et al. (2014)

All users of the artefact

DAMs can be created for each user of the artefact, thus allowing designers to map and consider all the possible interactions during the whole lifecycle. Apart from Artefact-User Affordances (AUAs), high-level Artefact-Artefact Affordances (AAA) were also specified, allowing designers to specify requirements due to the artefacts' interactions with other systems. Low-level AAAs, that is, requirements originating from internal components, cannot be specified at the task clarification stage because they are dependent on the conceptual solution.

<u>Limitations of Affordance-Based Models</u>

Domain independent

The approach can be used within any domain, but requirements must be elicited manually. Depending on the complexity of the artefact, DAMs can overwhelm designers because a higher number of requirements can be discovered through affordances. Additionally, the generic basic affordances terms may not be suitable to represent every type of affordance, as they can be misleading.

4.7 Key characteristics and guidelines

The following studies have not been identified through the systematic scoping explained in Section 4.1 but were discovered whilst investigating the domain problem described in Chapter 3. These are listed here due to their specific key characteristics, which support the requirements elicitation process. They highlight unique elements that are instrumental for a particular user group. These studies are then collectively reviewed against the criteria specified in Section 4.2.1.

Clinicians' perspective on patients' requirements

In Abela et al. (2021), six requirements that contribute to user experience were established after interviewing clinicians working in rehabilitative therapy. Bespoke therapeutic artefacts for patients need to trigger the right motivations, generate satisfaction, meet the ergonomics and biomechanics of patients, provide real-time monitoring feedback, deliver positive emotions, and use emerging and affordable technology.

Clinicians' needs in toy-mediated therapy

On the other hand, as highlighted in Chapter 3, Fikar et al. (2018) described five design lenses for TT. These feature distinctive clinicians' needs in toy-mediated therapy. Research in such novel fields provides designers with the groundwork to establish a design direction and ensure that subtle FRs and NFRs captured from rigorous field observations are reflected.

Children's needs

Recognising that the needs of children with disabilities are different from typical children, Robins et al. (2007) list key characteristics of robotic toys for autistic children. Such toys should include familiar features with respect to aesthetics, sensory output and behaviours, such that children can relate to the toy; allow children to make choices on the way they want to play; allow children to take control of the play activity through simple, accessible features such as buttons; provide differentiating levels of challenges so that they are always motivated and interested in the artefact; offer opportunities for physical manipulations; and offer sensory stimuli control. Similar design considerations are considered in Tseng et al. (2016).

Benefits of technology to SLT

Boucenna et al. (2014), Drigas and Petrova (2014) and Mâţă et al. (2018) document the outcomes of using specific products or technologies for speech therapy. A common theme in such literature is the growing evidence that ICT-based products have positive therapeutic results in children and can support clinicians' needs.

In the field of toy design, Hinske et al. (2008), Kudrowitz and Wallace (2010) and Mertala et al. (2016) support the requirements elicitation activity by identifying elements that are needed to make toy products more usable and attractive. Jadi (2019) proposes an architecture for smart toys for autistic children with speech disorders, arguing that smart toys should have a computer process, internet connectivity, a camera, speakers and sensors, and a behaviour-notification system that alerts caregivers.

Common strengths and weaknesses among key characteristics approaches

<u>Strengths of key characteristics</u>

Focus on the end users

Although requirements elicitation should capture multiple stakeholders' needs, the use phase is critical because the artefact needs to serve the end users. Focusing on how products are used makes it possible to capture principles that users look to or have trouble with during certain situations, thus recommending FRs and NFRs that increase usability. Due to the nature of academic research studies, principles are identified through intensive empirical observations and systematic analysis. User-domain knowledge is generated through empathetic approaches to understand the social context rather than investigated from a business perspective. A key strength of guidelines and checklists is that they do

Various requirements can be captured through comprehensive user studies not influence how the customer requirements should be implemented but remind designers of aspects that may be overlooked.

Limitations of key characteristics

Descriptive guidelines

The disadvantage with guidelines and broad requirement statements is that they may not be understood well and may be implemented differently. This can be solved through early prototype testing with end users. Further, because academic studies focus on specific problems, principles may not be transferrable across different fields, but further experimental evidence may be required to adapt them to new contexts.

Applicable to specific domains

4.8 Summary of the review findings

Table 4.2 summarises the requirements elicitation support systems reviewed in this chapter. This literature review was motivated by the challenges that designers encounter during the early phase of the design process, that is, the lack of support in understanding domain requirements. This results in further challenges in translating requirements into design specifications or features that satisfy the voice of the customer.

Lack of support within the field of SALTT

Whilst the significance of the task clarification stage's activities is highly recognised among researchers, limited support is available within the SALTT domain. Several generic or domain-specific design support tools or frameworks have been proposed, but these lack the knowledge required to handle the needs for SALTT artefacts.

Lack of support for multiple end-user groups

An overall common observation across the reviewed literature and the case studies that they discussed was that none of them dealt with multiple end-user groups of the same artefact. Figure 4.20 depicts how the use-phase requirements for artefacts with multiple end-user groups are intertwined, making end-users needs more difficult to capture and manage. The ontology- and model-based literature reviewed in this chapter discusses the relationships with users, objects and target entities, but does not consider how the target entities can also be the end user.

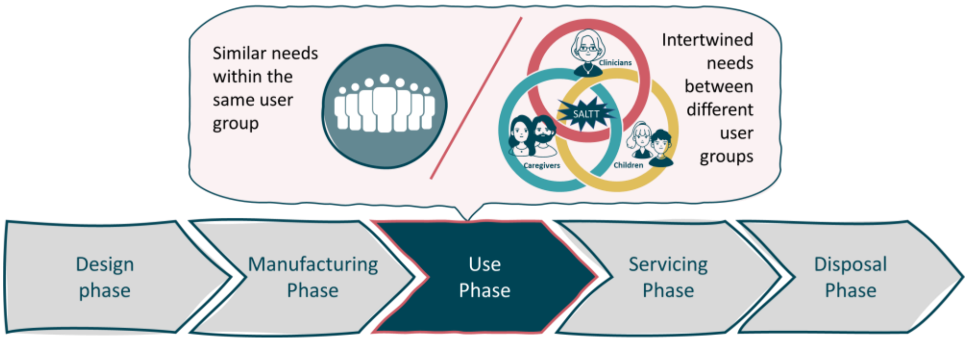


Figure 4.20: Differences in the use-phase needs between SALTT and conventional artefacts

<u>Limited support on requirements elicitation beyond functionality</u>

Theory-based approaches assume that customers' requirements can be identified entirely by understanding the function required from the product. On the other hand, checklists provide a sound framework in domains for which artefacts are generic. The QFD method was used in various approaches because it is useful in translating requirements into measurable specifications. However, Ericson (2007) argues that the need-finding activity should not focus on solution-finding. Needs are made from goals, behaviours, the context, and actions, which can be difficult to be expressed in technical specifications. Whilst designers are trained in analysing quantitative customer requirements, from a technical point of view, finding and interpreting customer needs requires them to take a user-centred design approach or rely on knowledge derived from such principles.

Ontology- and model-based approaches address this problem by capturing domain-related knowledge and mapping it into a schema that both human beings and computers can understand. Dialogue-based approaches use a question-answer approach, permitting the decomposition of the main problem and identifying further requirements.

All approaches value the importance of semantics in requirements because it is how requirements and constraints can be communicated to designers. Data-driven methods rely on a posteriori knowledge to infer results. Knowledge-based support systems built from ontologies (Milton, 2008) assist data-mining tools in extracting different requirements. However, data-mining techniques are data-dependent and so are less viable in emerging markets. Furthermore, the extraction of requirements tends to separate the needs from the context in which they are said, and are prone to misinterpretation.

Model-based approaches suffer from a labour-intensive procedure due to the numerous links between actors, objects, actions, and events. This translates into a benefit because once a model is complete, end-users contexts are better explained, and requirements beyond the main functionality can be seen.

The type of requirements that can be captured depends on the knowledge being processed and outputted to the designer. An affordance-based approach communicates needs beyond the function required from the artefact. Literature such as (Cormier et al., 2014) shows that affordances are appropriate to express requirements. Figure 4.21 illustrates how a more extensive set of requirements can be identified when considering the context, and how the artefact will be used by various users rather than how the product can be of use to the user.

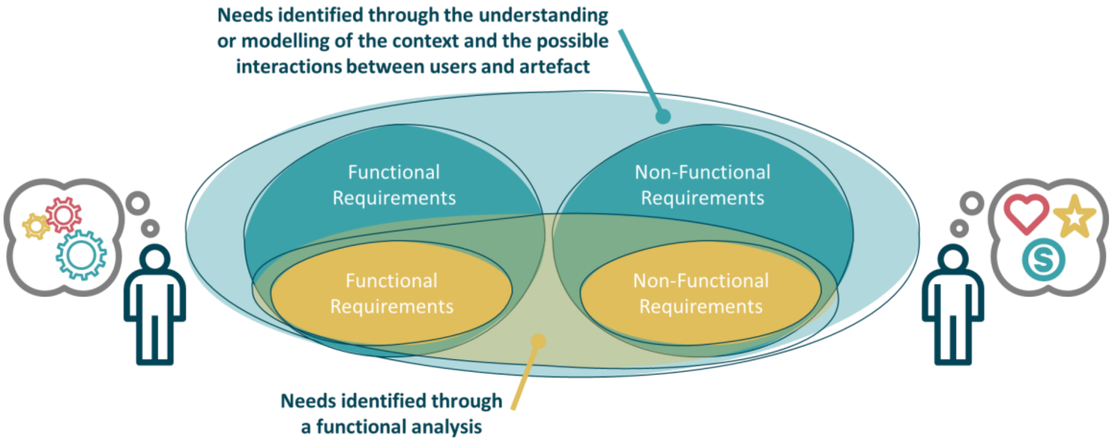


Figure 4.21: Needs identified when considering the function of the product and the interactions with the product

Descriptive vs Prescriptive support

Descriptive approaches such as checklists, ontology-based methods, key characteristics, and scenarios focus their efforts on providing knowledge support that designers need to gain a detailed insight into the actual needs of the users. On the other hand, prescriptive research, such as methodologies and model-driven methods, defines new ways to execute or support the early design tasks. Studies such as Neelamkavil and Kernahan (2003) referred to existing products to elicit requirements similar to reverse engineering. Cotran (2013) stated that "*requirements for engineering systems cannot be created by a single approach*", due to the complexity of requirements and domain specificity. In fact, studies such as Anggreeni and Van Der Voort (2009) and Darlington and Culley (2008), took a prescriptive and descriptive approach to provide holistic support. This suggests that designers must follow procedures and use appropriate knowledge to ensure that requirements are entirely drawn and understood.

4.9 Chapter Conclusions

This chapter provided a detailed literature review of the existing design support systems available for the initial design activities of the task clarification stage. Based on the review criteria chosen at the beginning of this chapter, none of the systems collectively meet the four criteria. This leads to the conclusion that, currently, there is a gap in the literature to support the generation of requirements for speech and language therapeutic toys. A graphical representation of this gap is provided in Figure 4.22. The research problem for this gap will be formulated in the next chapter and addressed successively through the chapters of Part B.

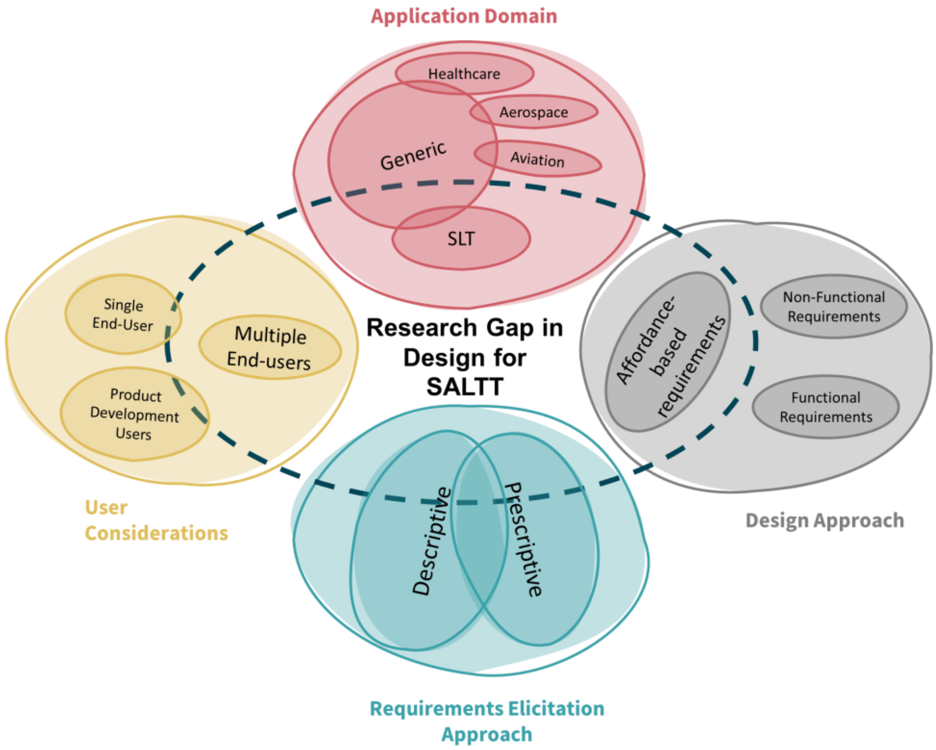


Figure 4.22: Gap in the field of requirements development for SALTT

Table 4.2: Summary of the reviewed literature

Year	System name / Authors	**Approach Classification**	**Whether a prescriptive or descriptive approach is taken**	**The type of requirements that were or can be considered**	**Whether generic or domain specific support is provided**	**The users considered during the requirements elicitation process**	Other strengths / limitations	Validation evidence
2020	Wearables in Health4.0 (Bause et al.)	Methodology	Prescriptive	FRs + NFRs (+ Emotional factors)	Wearable medical devices	All stakeholders	+ Uses existing design methodologies to cater for both users and stakeholder needs. - Framework not yet develop (no additional literature available from the author)	Not specified
2020	(Nerambali et al.)	Methodology	Prescriptive	Functional and Non-Functional Requirements	Generic, focusing on environment impact at each product's lifecycle stage	End-users (and indirectly all the other stakeholders)	+ Considers environmental impart early in the design process + Prioritise requirements based on their importance and impact + Facilitates collaboration between stakeholders - Designer is not well supported on the product - It is based on several weighting methods which could generate systematic bias.	1 case study
2019	(Gogineni et al)	Methodology (Checklist)	Descriptive (and Prescriptive)	Functional and Non-Functional Requirements	IoT devices	All Stakeholders	+ The product configurator is able to propose the product architecture which reduces the workload on designers engineers and configuration errors + The aim is to save development time, cost and improve quality of products - Applicable to specific domain	Not specified
2015	Methodology for PSS design (Marilungo et al.)	Methodology	Prescriptive	Functional Requirements	PSS design	End-users (indirectly all the other stakeholders)	+ Compare users' needs with the resources available. + Can be adopted in any domain - Manual - Only functional requirements are considered	1 industrial case Study
2010	Checklist for PSS (Muller, Schultz and Stark)	Checklist	Descriptive	Functional and Non-Functional Requirements	Generic requirements for PSSs	All stakeholders, and providers	+ Easy to use and helps discovering precise requirements quickly + Well-structured and supports task clarification - Paper based	2 workshops 1 project
2003	Design Knowledge Reuse (Neelamkavil and Kernahan)	KBD	Descriptive	Functional Requirements	Any domain if information is available	End-users (and indirectly all the other stakeholders)	+ Accelerates the design process + Maps modified customer requirements from a database of similar existing products + Turns requirements into product structure + Allows gap analysis - Requirements need to be already formalised - Does not discuss how customer needs are formalised. - May only be applicable to a chosen product family. - Requires repositories to store knowledge	1 case study
2016	(Thew and Sutcliffe)	Taxonomy	Descriptive	Functional and Non-Functional Requirements	Any domain (generic requirements)	Can be used with all stakeholders	+ human-centric approach - time consuming and demanding	3 case studies
2016	(Aranda-Jan et al.)	Taxonomy	Descriptive	Functional and Non-Functional Requirements	Health-related products in low resources countries	All stakeholders	+ Highlights contextual needs for special markets	Examples provided

Year	System name / Authors	**Approach Classification**	**Whether a prescriptive or descriptive approach is taken**	**The type of requirements that were or can be considered**	**Whether generic or domain specific support is provided**	**The users considered during the requirements elicitation process**	Other strengths / limitations	Validation evidence
2016	Cognitive Maps (Dias et al.)	Cognitive Maps	Prescriptive	Functional and Non-Functional Requirements	Any domain	Can be used with all stakeholders	+ can be easily read once the map is generated - prone to subjective bias if not conducted - time consuming and demanding	1 case study
2008	EDR Ontology / CaDRes (Darlington and Culley)	Ontology	Descriptive (and Prescriptive)	Functional and Non-Functional Requirements	Generic	All stakeholders	+ Ontologies for generic requirements can be reused in any domain - Requires time and effort to construct a detailed ontology	1 case study
2016	Design and Design Process Ontology (Hagedorn, Krishnamurty, and Grosse)	Ontology	Descriptive	Functional and Non-Functional Requirements	Generic, but example provided for medical stapler devices.	Only end users were discussed but PD stakeholders can be modelled as well	+ Provides key usability information that drive design decisions + Leads to cost-efficient optimal designs based on customers and business needs which are considered in parallel + Retains contextualized knowledge + User-centred approach + Allows for direct impact assessment of a design choice when coupled with automated reasoning capabilities - Useful at improving existing products only since needs need to be modelled. - Requirements elicitation needs to be done by the designer - Very labour-intensive to manually set links with different knowledge -Makes more sense to use the approach on a product line rather than on a single product. - No user interface was implemented.	1 case study
2016	ReqOn (Mukhopadhyay and Ameri)	Ontology	Descriptive	Functional and Non-Functional Requirements	Generic	All Stakeholders	+ Formalises functional and non-functional requirements + Domain independent and can be used with all users + The implemented tool can provide a measure on the information content of a single requirement statement or whole requirements list + Facilitates the retrieval and reuse of the requirements of similar design artefacts through a descriptive approach - Specifying individual requirements is labour intensive - No domain support for the elicitation of requirements.	Not specified
2012	Ontology driven and scenario-based requirements elicitation (Fan and Jiang)	Ontology + Scenario-based modelling	Descriptive	Functional and Non-Functional Requirements	Any - depends on ontology	End-users	+ Provides designers with a thorough understanding of the needs. - It requires existing products and sales record to set the rules and requirements	1 case study
2015	Goal-oriented Ontology for Requirements (Braun et al.)	Ontology	Descriptive	Functional and Non-Functional Requirements	Generic	All stakeholders	+ The entire design process can be presented comprehensively + Pushes for common concept within product development + Facilitates communication within the research community - Does not cater for domain specific needs	Not specified

Year	System name / Authors	**Approach Classification**	Whether a prescriptive or descriptive approach is taken	The type of requirements that were or can be considered	Whether generic or domain specific support is provided	The users considered during the requirements elicitation process	Other strengths / limitations	Validation evidence
2009	Question Generation tool (Wang and Zeng)	Dialogue-based tool	Prescriptive	Functional and Non-Functional Requirements	Generic (depends on knowledge bases)	All stakeholders	+ Dialogue-based approaches help generate a lot of information - Predefined knowledge need to be used - Specific needs may never be captured without seeing users interacting with the system	1 case study
2013	Computer Aided Requirements Elicitation (Bacetti and Cascini)	Ontology / Dialogue-based tool	Descriptive (and Prescriptive)	Functional and Non-Functional Requirements	Generic	All stakeholders	+ Dialogue-based approaches help generate a lot of information + Questions are based on an ontology - Specific needs may never be captured if ontology does not cater for them.	1 case study
2021	Heterogeneous Requirements Gathering (Zheng et al.)	Ontology	Descriptive	Functional and Non-Functional Requirements	Robotic Manufacturing Systems	PD Stakeholders	+ Modular and reconfigurable systems are quick to setup and easy to replace. - Approach depends on already produced modular systems for the domain, thus not suitable for new markets.	1 Case study
2022	Dynamic Requirements elicitation of complex products (Han et al.)	Data-mining	Prescriptive	Functional and Non-Functional Requirements	Any - depends on dictionary	End-users	+ automatic and continuous requirements elicitation + saves time in analysing end-users opinion + elicit emergent requirements in real time - noisy data - computer intensive in the beginning	1 case study
2020	(Lindemann et al.)	Methodology based on Data-mining	Prescriptive and Descriptive	Requirements related to complaints, recommendations, and interactions	Generic consumer goods	End-users	+ Saves time from doing empirical studies + Deeper and wider catchment of the population + Makes use of already available data + Captures customer "needs" and "anticipation" + Data-mining allows the identification of clusters and homogeneous requirements + Suitable to capture unconscious needs. + Saves time in interpreting a significant amount of data - Reviews may not be reliable - Cannot be a new market since it depends on existing reviews - Data can be highly unstructured - Information can be lost in the conversion process - Data requires pre-processing to clean errors, missing data, outliers, irrelevant data, etc. - System needs existing knowledge of the subject - Reviews must use the same terminology - Need to make use of various modules such as, natural language process and part of speech tagging.	Not specified
2019	(Chen et al.)	Data-mining	Descriptive	Any requirements	Any domain	End-users	Similar to other data-mining approaches	1 case study
2013	**COTRAN** (Cotran)	Tagging-Based	Descritptive (and Prescriptive)	Functional and Non-Functional Requirements	Any domain	All stakeholders	+ Promote real-time discussions + Designers are in control of which requirements to include and results are more clean than automated data-mining systems - Ambiguous requirement statements	2 Case studies (industrial

Year	System name / Authors	**Approach Classification**	Whether a prescriptive or descriptive approach is taken	The type of requirements that were or can be considered	Whether generic or domain specific support is provided	The users considered during the requirements elicitation process	Other strengths / limitations	Validation evidence
								and academic)
2010	Data-mining with Genetic Algorithms (Yu and Wang)	Data-mining	Descriptive	Any requirements	Any domain	End-users	+ Automatic mapping of requirements to specifications - Requires pre-existing knowledge of the product to be designed - Requirements need to be already collected from customers.	1 case study
2006	Kansei Mining System for affective design (Jiao, Zhang, and Helander)	Data-mining	Descriptive (and Prescriptive)	Non-Functional requirements	Any - depends on raw data	End-users	+ Reuses past knowledge + Discovery of data patterns related to affective design - It is challenging to capture people's affective needs and translate them into verbal needs - Requires a well-defined market of existing or similar products	1 case study (mobile phones)
2015	Modelling and Simulation at the early stages using SysML (Nonsiri)	Modelling	Descriptive (and Prescriptive)	Functional and Non-Functional Requirements	Any domain	Can be used with all stakeholders	+ improves communication between + Requirements diagrams can be understood by both humans and machines + Requirements can be traced - Defining diagrams is labour intensive - No support for eliciting requirements because it is just a modelling language	2 case studies
2012	**Use-Case Diagrams** *(Amaechi and Counsell)*	MBSE: Use-case modelling	Prescriptive	Functional Requirements	Any domain	Can be used with all stakeholders	+ Powerful communicative tool + Easy to illustrate interactions with artifacts through the functions offered by the artefact.	N/A - review of studies
2011	Coramod (Brace and Ekman)	Checklist	Prescriptive and Descriptive	Functional and Non-Functional Requirements	Any domain but limited to generic requirements	All stakeholders	+ Provides a systematic and reliable approach to establish the needed requirements. + It eliminates the possibility of errors or missing tackling requirements due to checklist. + Makes requirements documentation and validation easier. - It is very complex and time-consuming to model requirements and their relationships. - Designers need training on how to input and analyse requirements. - Cannot be used in specific domains as it only includes generic aspects of products - Difficult to model complex products.	Case study

Year	System name / Authors	**Approach Classification**	Whether a prescriptive or descriptive approach is taken	The type of requirements that were or can be considered	Whether generic or domain specific support is provided	The users considered during the requirements elicitation process	Other strengths / limitations	Validation evidence
2010	Supporting Scenario Use in Product Design (Anggreeni)	Scenario Modelling	Descriptive / Prescriptive	Functional and Non-Functional Requirements	Any domain	End-users	+ Simple and easy to use and build scenarios + New requirements can be defined easily. + Visually appealing since it has a graphical user interface + Can be used as a brainstorming tool - Minor flexibility restrictions because it was built on a CMS - The tool does not provide any structure to define requirements. - Does not provide guidance on the needed elements. - Does not capture the knowledge support required by designers to evaluate and develop requirements.	1 Case study (through many prototypes)
2006	Scenarios with (DIF) (Lim and Sato)	Scenario Modelling	Descriptive	Functional and Non-Functional Requirements	Any domain	Can be used with all stakeholders	+ Able to produce a detailed scenario + Provide an environment for the evaluation of early stage synthesised solutions + Can be understood by people from different backgrounds. + Boost communication among development team. - Requirements need to be pre-determined - Only useful when designers do not need a deep insight about the problem - Suitable to explain simple products with a few entities.	1 case study
2020	Eliciting requirements with Prototypes (Coulentianos)	Prototypes	Prescriptive	Functional and Non-Functional Requirements	Any domain	Can be used with all stakeholders	+ Effective communication tool that permits end users to comprehend the intention of an artefact whilst allowing designers to better understand their needs. + permits user-centred design - Require designers to have a real understanding of the setting before modelling - modelling is time consuming but once performed that information can be reused	1 case study
2014	Cormier et al.	Affordance-based modelling	Prescriptive	Affordances	Any known domain	All stakeholders	+ Formal way of expressing affordances statements + Considers different users' needs + Correlated design specifications with affordances statements - No support to the elicitation stage	1 case study
Various	Various	Guidelines	Descriptive	Any. Depends on the interpretation of the guideline	Domain specific	End-users	+ User-centred studies focus on the special needs of specific end users - Lack detail and does not	Empirical studies

5. RESEARCH PROBLEM FORMULATION

The Art and Science of Asking Questions
is the Source of All Knowledge.

Thomas Berger, 1924-2014

Based on the outcomes of the literature review and the characterisation of the problem in the previous chapters, this chapter discusses the research problem that was formulated. Section 5.1 recapitulates the reality of requirements elicitation and the lack of support in considering the uses of a SALTT artefact. Here, the research problem is disclosed along with the research questions that will be investigate the problem. The research boundary is disclosed in Section 5.2 whereas conclusion will be made in Section 5.3.

5.1 Requirements Elicitation Reality

Chapter 1 highlighted the importance of providing design support to designers in new industries, mainly where their experience is limited to comprehend how the end users will interact with the artefact. Challenges associated with an ill-defined or poorly understood problem and lack of experience within the context of the problem will lead to unsuccessful products.

In Chapter 2, different systematic design approaches were highlighted, including affordance-based design. The latter brings the functional and human implications together in design which invites behaviour rather than causing it. The study presented at the end of the chapter elucidated that the most significant challenges that designers encounter are in the task clarification stage, specifically those caused by the lack of insight into the customer needs.

Commercial therapeutic toy products designed specifically to collectively aid the clinicians, caregivers and children within the speech and language domain are not available. Chapter 3 discussed two studies. One focused on discovering the challenges and needs associated with speech and language therapy (SLT) from a clinical perspective. The other study which was conducted with children showed that particular product affordances promote longer attention spans and engagement levels. Based on the results, needs communicated in terms of affordances can provide designers with a better understanding of the end-users interactions.

The literature review described in Chapter 4 shows that designers are not supported in eliciting affordance-based requirements for multiple end users within the SLT context through the evaluated descriptive or prescriptive approaches. This gap in the literature was used to formulate the research problem that this dissertation is concerned with, that is,

The development of a prescriptive framework that supports designers with descriptive knowledge in the elicitation of affordance-based requirements for speech and language therapy from a multi-user perspective.

5.1.1 Research challenges

For designers to be supported in decomposing the customer need(s) and generate relevant requirements for the development of SALTT artefacts, a number of challenges exists for the development of a supporting means.

Challenges in eliciting affordance-based requirements

1. Although the theory of affordances has gained a lot of attention in the past decades, limited support is available in eliciting requirement in terms of affordances. The supporting means needs to be based on a framework that translates customer needs into affordances.

Challenges in communicating affordances-based requirements

2. Users' needs must be communicated in a clear format to the designers. Apart from the challenge that designers need to comprehend the users'

needs, requirements in the form of affordances must capture what the user is required to do and capable of doing with the artefact within a context whilst keeping an abstract view of the desired solution.

Challenges in considering the needs of three end users for SLT

3. Moreover, SALTTs' requirements concern the needs of different users within the SLT context. Expressing their intertwined needs requires a structure that does not overwhelm the designer's capacity to generate and manage requirements.

5.1.2 Research Questions

Based on these challenges and expectations, the following research questions need to be addressed in the second part of this dissertation.

Research Question 1

What components shall characterise the information model of the framework such that affordance-based requirements are generated for the customer needs?

Research Question 2

What are the SALTT considerations that need to be considered within a knowledge model utilised by the framework's information model?

Research Question 3

How can end-users therapeutic needs be communicated to, and understood by, the designer?

Research Question 4

How can designers be facilitated to generate unforeseen affordance-based requirements?

Research Question 5

To what extent are designers willing to use such a framework in their practice, and why?

5.2 Research Boundary

To limit the research problem and to focus efforts on developing a framework that uses affordances, the following research boundaries (RB) were applied:

RB1: Requirements elicitation

Given that the designers need specific support during the task clarification stage, this dissertation will focus on the requirements elicitation activity. This scope is to develop a support system that aids designers in identifying relevant requirements. The analysis of requirements to prioritise between requirements will not be performed.

RB2: Specific domain

As discussed in Chapter 1, artefacts designed specifically for all the key players of SLT are not commercially available. For this reason, the focus will be placed on this domain to supply designers with a means that support the creation of SALTTs.

RB3: End-users

SALTT artefacts can be based on existing technologies for which support already exist. Thus, the manufacturing, servicing, and disposal lifecycle phases should be similar to other consumer products. As shown in Chapter 4, due to the extensive literature available on generic artefacts, the experienced designer will not gain from such support if generic support is provided. For this reason, this contribution will focus on the diverse end-users needs during the use phase.

RB4: Pre-school children

It should be noted that toys in SLT are mainly used with preschoolers. Nonetheless, depending on children's interest and their development age (see Chapter 6), SALTT products may be suitable for older children. Moreover, although there is a whole spectrum of gender, in this research only male and female children are considered.

5.3 Part A Conclusion

Requirements elicitation problem

In the first part of this dissertation, various studies were carried out to recognise the challenges that designers have during the task clarification stage and the problem associated with SLT. These findings permitted the research problem and the research questions to be formulated. Currently, designers lack adequate support to understand end-users requirements, specifically for SALTT products. To support this activity, affordance-based requirements will be used.

Dissertation checkpoint 1

Figure 5.1 showed the computer-based support tools development framework proposed by Duffy and O'Donnell (1998). Chapter 2 described the designer's reality. Chapter 3 provided background to the customer problem and provided the research direction and at the end of the chapter, the phenomena model was highlighted in Figure 3.15. In Part B of this dissertation, the focus will be on the information and computer models. Chapter 6 models the knowledge gathered in Chapter 3. Chapter 8 presents a user-centred framework that takes the modelled end-users needs into formalised affordance-based requirements. The implementation of the information models into a computer-based support tool is disclosed in Chapter 9.

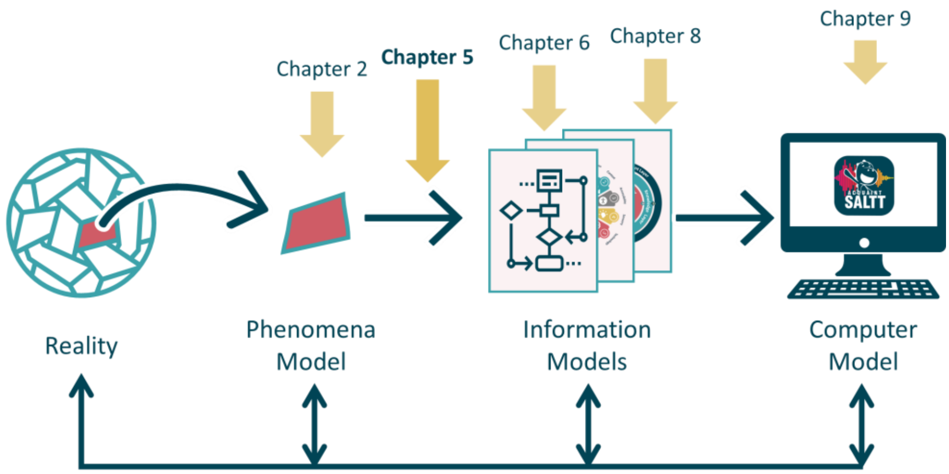


Figure 5.1: Computer-based support tools development framework, adapted from Duffy and O'Donnell (1998)

PART B

Development of the *D-SALTT* Framework Architecture

6. THE SPEECH AND LANGUAGE THERAPY POTENTIAL MODEL (SALT-PM)

If all my possessions were taken from me with one exception,
I would choose to keep the power of communication,
for by it I would soon regain all the rest.

Daniel Webster, 1800's

This chapter builds upon the findings discussed in Chapter 3. The aim is to disclose the considerations designers need to make when designing SALTT artefacts. The term Speech and Language Therapy Potential Model (SALT-PM) was coined to reflect the capacity to which an artefact serves the end users in speech and language therapy. An overview of the SALT-PM ontology is provided in Section 6.1. Section 6.2 details each element within the SALT-PM ontology. Chapter conclusions are made in Section 6.3.

6.1 The SALT-PM

The speech and language therapy considerations

Rather than proposing a set of broad guidelines or high-level lenses such as (Fikar et al., 2018; Hinske et al., 2008), a similar approach to Mertala et al.'s (2016) FMP model was taken to represent the SALTT design considerations as an ontology composed of 12 elements. Table 6.1 tabulates the requirements identified in Chapter 3 and their corresponding element.

Table 6.1: The adaptation of requirements into elements

Requirement	Element
SR1: The TT can be associated with a toy.	*Representation*
SR2: The TT considers the context in which it will be used.	*Context*
SR3: The TT is accessible to enhance usability and interactions.	*Accessibility*
SR4: The TT can provide appropriate sensory stimulation to draw interest.	*Sensory*
SR5: The TT can be low-tech or hi-tech.	*Technology*
SR6: The TT provides a variety of playful opportunities.	*Play*
SR7: The TT considers aspects of language.	*Language*
SR8: The TT can aid the planning of intervention through assessments.	*Assessment*
SR9: The TT provides adjustable intervention activities.	*Intervention*
SR10: The TT offers rewards for prolonged cooperation and motivation.	*Reward*
SR11: The TT can facilitate administrative tasks.	*Administration*
SR12: The TT is safe to be used with all the end users.	*Safety*

6.1.1 The SALTT potential

The SALTT-PM

Every element is essential for a SALTT. The absence of a component impacts the usefulness or potential of an artefact for therapy. A high-level depiction of these elements is provided in Figure 6.1, which is referred to as the speech and language therapy potential model (SALT-PM).

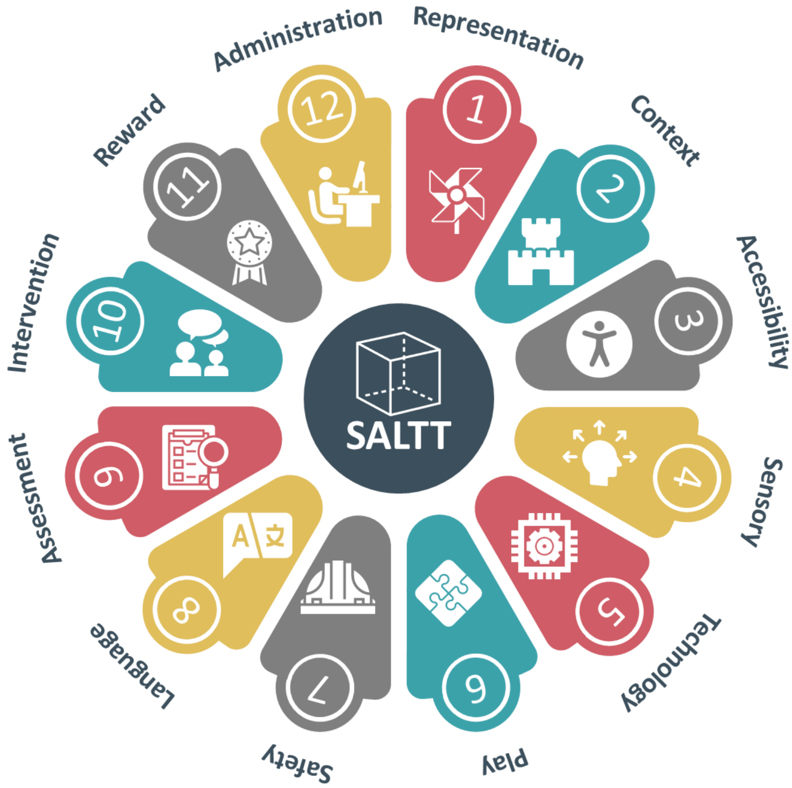


Figure 6.1:The speech and language therapy potential model (SALT-PM)

As detailed in the following sub-sections, each element addresses features requested by the end users. The SALT-PM suggests that the maximum SALTT artefact potential (SAP_{max}) is mainly determined by the number of factors (sub-elements) realised during the design process. This is referred to as the *intrinsic potential* of the artefact (SAP_i). Mainstream toys can also be used during therapy. However, their intrinsic potential is lower than a SALTT as the latter has been designed specifically for SLT.

However, a SALTT's usefulness depends also on the end users. For instance, a SALTT product designed for DLD might not be appropriate for a child with cerebral palsy if the accessibility element has not been considered. Also, a child who has outgrown DLD might still find the SALTT attractive due to its rewarding features. The relevance of a SALTT is described by the *extrinsic potential* (SAP_e) and is illustrated in Figure 6.2.

A SALTT product can offer a potential for therapy when the designed features meet the needs of the end users. Additionally, the extrinsic SAP can vary between users depending on the relevant affordances. For instance, the SAP_e for a clinician will always be higher or equal to the SAP_e for a child because the SALTT can be used with different children. The SAP_e for parents would be low if it does not offer carry-over activities.

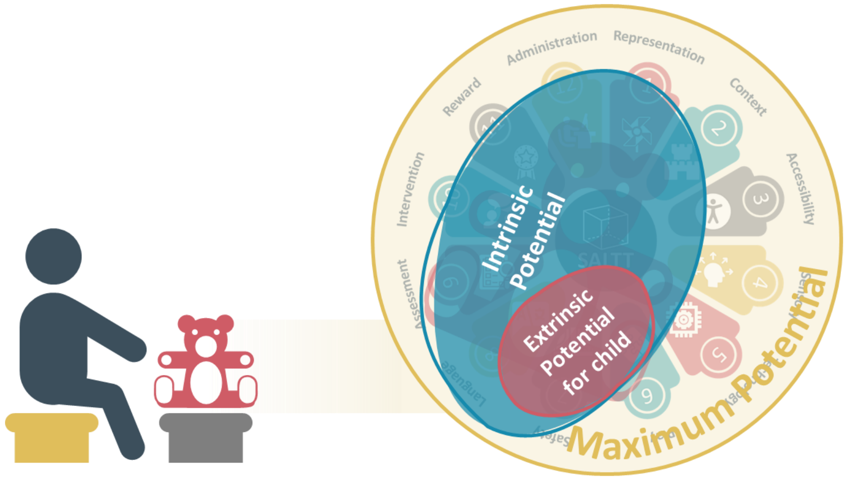


Figure 6.2: An example of the speech and language therapy potential of a SALTT to a child

6.1.2 The SALT-PM Ontology

Ontologies

Because each element is composed of further sub-elements the SALT-PM is being proposed as an ontology for SALTT artefacts. As discussed in Chapter 4, ontologies allow designers to have a shared understanding of the problem and serve as the basis for the requirements of a system (Uschold and Gruninger, 1996).

Cormier et al. (2014) point out that problem formalisation should capture the needs of all the stakeholders involved. As discussed in Chapter 5, this dissertation focuses on the actual end users, that is, the individuals who will be using the artefact during its use-life phase. Cormier et al. (2014) explain that the identified needs can be translated into a set of system requirements or a value model. The latter is a mathematical representation of the artefact's potential. As described in Chapter 7, the generation of a high-level mathematical model for the SALT-PM ontology was pursued.

6.2 SALT-PM Elements

The SALT-PM considers play and SLT factors such that the SALTT artefact is helpful within the different therapy contexts (scenarios) described in Chapter 3. The following sub-sections describe the final versions of the sub-elements within the SALT-PM, including three factors which were added to the model after the validation detailed in Chapter 7 (Section 7.1.4). Morever, a detailed description of the rationale of the chosen sub-elements is detailed in Balzan (2022c).

6.2.1 Representation element

Figure 6.3 summarises the considerations for the Representaion element.

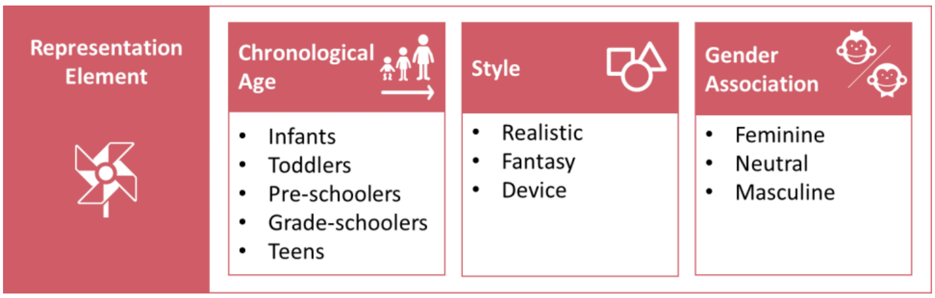


Figure 6.3: Representation element

Chronological age of children
(Infants, Toddlers, Preschoolers, School-aged children, Adolescents)

In various studies (Hinske et al., 2008; Mertala et al., 2016) representation of the toy artefact takes priority over the other elements since a toy must be appealing, communicate its purpose and look age-appropriate. Age consideration also imply ergonomics and children's anthropometric characteristics, specifically, the range of values for children's body parts sizes (Gielen, 2010). Kail (2001) uses the following taxonomy for the chronological age of children: *infants* (0–18 months), *toddlers* (12 months – 3 years), *preschoolers* (3 – 5 years), *school-aged children* (6–13 years) and *adolescents* (14–19 years).

Style of toy *(Realistic, Fantasy, Device)*

This research has highlighted the imporatance of creating a SALTT artefact that looks like regular toys to avoid stigmatism. According to Gielen (2010) and Mertala et al. (2016), children's play behaviour is partly determined by how the toy looks, whether it has a *realistic* or an imaginative/*fantasy* form. Mertala et al. refer to realistic forms as toys that "*replicate real-life archetypes*", such as toy dogs and dolls which represent real dogs and people. Within the medical context, the term devices is used to refer to assistive tools such as alternative and augmentative communication or speech-generating devices (Agius and Vance, 2016). Therefore, the term *devices* is being proposed as a third form of representation to properly distinguish between toys representing natural organisms and objects similar to computers, tablets, or hospital monitoring equipment.

Gender association of the toy *(Masculine, Feminine, Neutral)*

Differences in gender-typed toy preferences among preschool children remain significant in developmental psychology (Weisgram et al., 2014). *Masculine* toys are likely to represent vehicles, sports equipment and tools, whilst the most common *feminine* toys are dolls and domestic items (Auster and Mansbach, 2012; Weisgram et al., 2014). The latter type of toys is associated with symbolic play (Bathiche, 1993), a form of play that clinicians and child experts (Ariel, 2002; Besio et al., 2016; Pellegrini and Jones, 1994; etc.) claim to be very important for a child's language development. Research (Cherney and Dempsey, 2010; Mertala et al., 2016; Shutts et al., 2010) also shows that children will avoid toys that are associated with the other gender. Technological toys are often designed to be *gender-neutral* (Heljakka and Ihamäki, 2019b; Mascheroni and Holloway, 2017). Designers need to consider that SALTTs can be used by both genders, especially if such artefacts are shared in clinics.

6.2.2 Context element

Figure 6.4 portrays the considerations that need to be made within the context element.

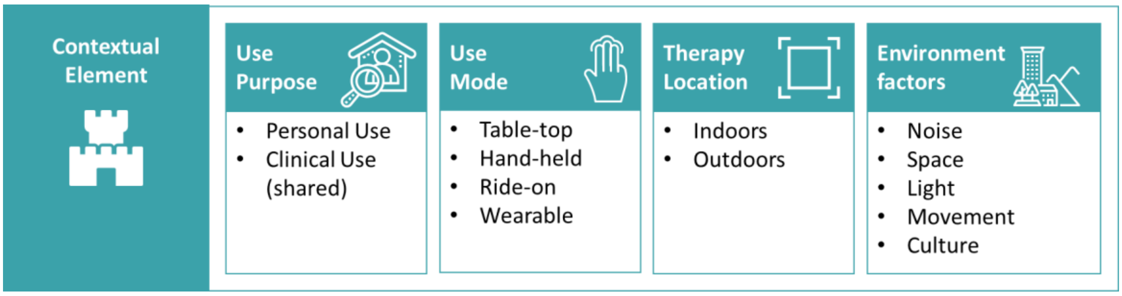


Figure 6.4: Context element

Use purpose *(Personal use, Clinical use)*

The Context element looks at how and where the SALTT artefact will be used so that the designer knows the SLT related needs. Insight about therapy sessions has been gained through the focus groups and lengthy discussions with SLPs. As detailed in Chapter 3, therapy carries over from the clinic to the home.

Mode of Use

(Hand-held, Table-top, Ride-on, Wearable)

Designers must consider how the end users will interact with the SALTT artefact during therapy. Like other products, including toys, possible modes of use are *hand-held*, *table-top*, *ride-on* or *wearable*. Portability aspects may also be considered through this sub-element.

Therapy location *(Indoors, Outdoors)*

Conventionally, therapy is carried out *indoors*, typically in clinics, schools or homes. Although it is not yet the case that therapy sessions are conducted *outdoors*, research reported in (Norling and Sandberg, 2015; Richardson, 2014) highlights the benefit of children's speech and language development when children are exposed to the outdoor environment. Caregivers are free to take the SALTT artefact outdoors or during a holiday.

Environment factors

(Noise, Space, Light, Movement, Culture)

Westby (2007) states that planning of assessment and intervention activities should be made in the light of contextual factors to reduce or eliminate barriers to children's participation in such activities. Environment factors are aspects that would negatively impact the usefulness and usability of the product. For example, background *noise* may disturb or prohibit a therapy session. Similarly, *space* issues may determine the dimensions of the artefact (and its accessories). Excessive or limited *light* conditions within the operational environment of the SALTT may interfere with therapy. The *movement* factor lets the designer ponder how the SALTT can still be used in such conditions. Finally, the location's *culture* should be considered because cultural differences in religious beliefs, languages, traditions, and behaviours vary between groups of different ethnicity, race or identity (Gopalkrishnan, 2019).

6.2.3 Accessibility element

Figure 6.5 presents the levels of impairment for each disability category as detailed in Costa et al. (2018).

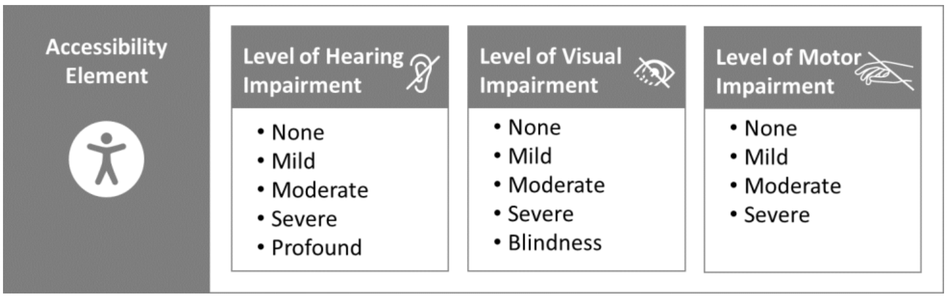


Figure 6.5: Accessibility element

Accessibility *(Hearing, Visual and Motor impairment)*

SLT should not be limited because of other impairments that a child might have. The concept of universal design was introduced back in the 1990s when the philosophy of making artefacts and environments usable for everyone without requiring modification was conceived (Ruffino et al., 2006). More recently, researchers within the European Cost Action "LUDI – Play for Children with Disabilities" developed a similar tool, called Toys and games Usability Evaluation

Tool (TUET), that assesses the usability of a toy or game for *hearing*, *visual* and *motor-impaired* children (Costa et al., 2018). Different levels of impairments were defined for each category, with impairments varying from mild to severe.

6.2.4 Sensory element

Figure 6.6 condenses the sensory elements that designers may consider during requirements elicitation.

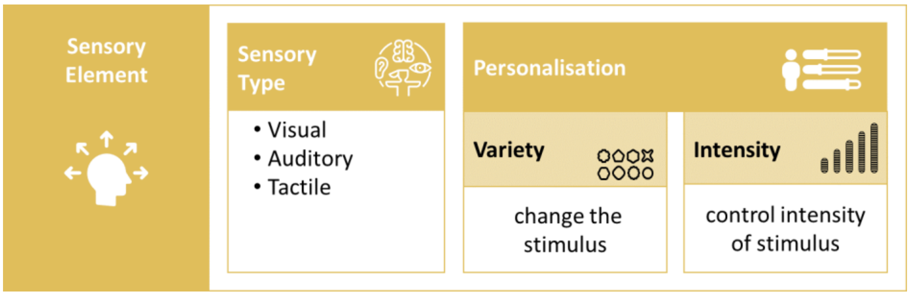


Figure 6.6: Sensory element

Sensory stimulus *(Visual, Auditory, Tactile)*

The Sensory element extends the Representation element by reminding designers about the stimuli that toys should provide as part of their attractive and pragmatic characteristics (Mertala et al., 2016). These are separate stimuli from the Reward element discussed in Section 6.2.11. Moreover, as explained in the Play element (Section 6.2.6), sensory stimulation is the bases of the first stage of play. The majority of sensory features found in toy products usually are *auditory*, *visual* and *tactile*. A small range of toys offers gustatory and olfactory stimuli which involve actual cooking and toy makeup. Dicarlo (2004) explains that children seek to stimulate their senses, and by embedding children's preferred sensory properties in toys, it will increase the time they interact with toys and the chance of developing new skills due to enhanced self-motivation.

Personalisation *(Variety, Intensity)*

Designers have to realise ways of providing a *variety* of sensory stimuli with variable *intensities* to deal with particular moods, especially in children with ASD (Besio et al., 2016; Sartorato et al., 2017) or sensory processing disorder (SPD)

(Rossi et al., 2019). Hinske (2008) suggests that the "*physical appearance should be consistent and meet the children's perceptual abilities and mental models*" but does not elaborate on whether control should be provided to match intra- and inter-user variation. Personalisation can be achieved through modifiers which are physical or digital elements of the artefact that can be controlled or interchanged such as by swapping skin covers or integrating modular add ons.

6.2.5 Technology element

Figure 6.7 lists the considerations for the Technology element.

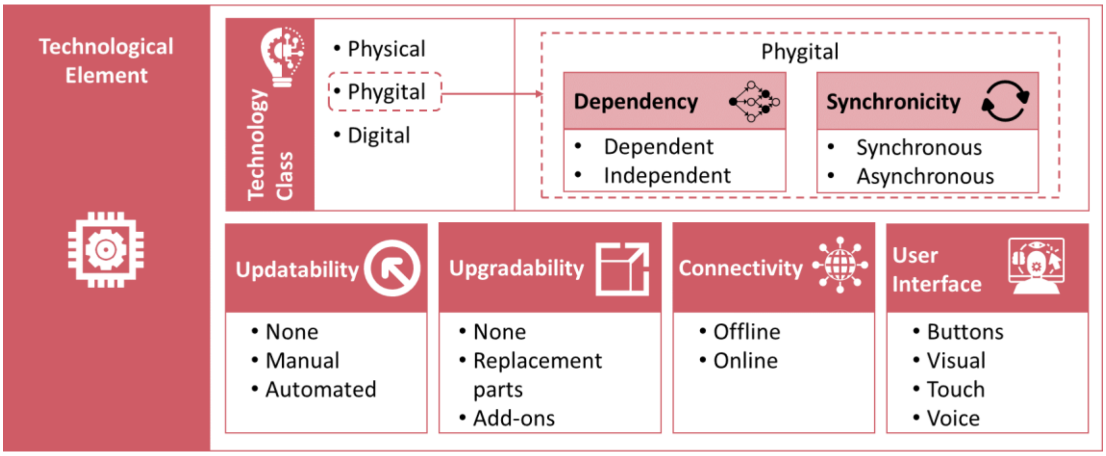


Figure 6.7: Technology element

Technology Class *(Physical, Digital, Phygital)*

As discussed in Chapter 3, play artefacts can be low-tech or high-tech. Low-tech toys do not have any electronics integrated, and their function is purely physical (mechanical). They may be 'upgraded' or enhanced if accessories can be added to increase their usefulness or playability.

Digital games

On the opposite end of the spectrum, play is enabled through digital mediums such as video games on gaming consoles, portable devices, or extended reality (XR), a term used to encapsulate VR, augmented reality, and mixed reality (Sharma, 2021). Digital mediums nowadays run on internet-enabled platforms allowing them to be easily updated.

Phygitals

The market is witnessing a new era of toys and games, the highly-popular and ever-expanding field of smart toys, hybrid toys (Heljakka and Ihamäki, 2019a), Internet of Toys (Mascheroni and Holloway, 2017) or as recently termed, *phygitals.* These can provide varied multimodal feedback (sensory stimuli) and extended play functionalities when connected to digital devices through Wi-Fi, Bluetooth or Near-Field Communication (Albuquerque, 2021; McReynolds et al., 2017).

The dimensions of hybrid in playful products

Typical examples of phygitals are Skylanders[9], Hello Barbie[10] and Cognitoy Dino[11]. The latter two toys, which are similar to Amazon's Echo (voice-controlled intelligent personal assistant), allow children to have conversations when connected to the internet. When it comes to SALTT, this technology class provides a lot of potential because therapy-related solutions can be automated and mediated through intelligent artefacts. Tyni et al. (2013) propose two dimensions for the phygital class: *dependency* and *synchronicity*, which regulate how much the physical affordances of the product influence the digital affordances and vice-versa. These two dimensions are graphically represented in Figure 6.8 for a hypothetical phygital toy.

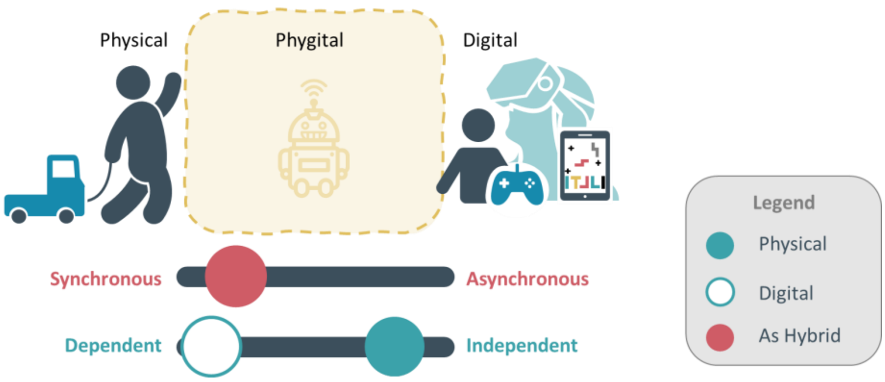


Figure 6.8: Dimensions of hybrid toys

[9] https://www.activision.com/games/skylanders/skylanders-imaginators
[10] http://hellobarbiefaq.mattel.com/
[11] https://www.kickstarter.com/projects/cognitoys/cognitoys-internet-connected-smart-toys-that-learn

Synchronicity

The synchronicity dimension refers to the sequence in which the physical and digital experiences are felt. Thus, a phygital can either be asynchronously or synchronously hybrid (Tyni et al., 2013). In the example of Figure 6.8 , the child is likely to experience the physical and digital aspect of the toy at the same time since the indicator is closer to the synchronous side.

Dependency

Phygitals allow the physical and digital play experiences to be separated depending on the intended play behaviour. For the example in Figure 6.8, the digital aspect is dependent on the physical dimension of the toy. Therefore, the user must interact with the physical object to control the digital experience. In contrast, since the physical toy is relatively independent of the digital game, the toy can be used as a traditional toy.

Updatability, Upgradability, Connectivity** and **User Interface

Upgradability concerns the hardware of the artefact, and *updatability* is related to the software. The designer must establish whether future updates/upgrades should be available to the same model. Strongly related is the aspect of *connectivity* and the type of technology that will be used. Finally, related to the Accessibility element is the type of user interface offered to the user. Multiple *user interfaces* can be included in a single SALTT, and these can vary between physical buttons, computer vision (facial expression), touch, and voice control.

6.2.6 Play element

The sub-elements of the Play elements are shown in Figure 6.9. The models of previous research in the field of toy products and play have been considered.

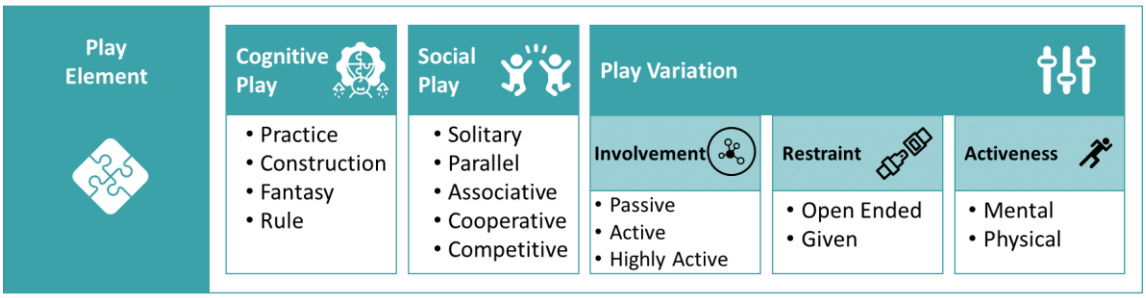


Figure 6.9: Play element

Cognitive Play *(Practice, Construction, Fantasy and Rule play)*

Besio et al. (2016) classified play into the cognitive and social dimensions. The *cognitive dimension* includes *practice*, *symbolic*, *constructive*, and *rule-based*, whereas the *social dimension* includes *solitary*, *parallel*, *associative*, and *cooperative* play. This taxonomy of play matches other studies (Kudrowitz and Wallace, 2010; Mertala et al., 2016) as they are based on the cognitive development theories of Piaget (1970) and Smilansky (1968).

Social Play *(Solitary, Parallel, Associative, Cooperative and Competitive play)*

Play Variation

(Involvement, Restraint and Activeness)

In Kudrowitz and Wallace (2010), the sliding scales of play were proposed as a toy ideation tool. Three of these scales have been grouped under the play variation sub-element within the SALTT-PM, as shown in Figure 6.9. The *level of* involvement indicates the amount of physical effort the child will be doing in the play activity, which can vary from a passive standpoint to a highly active role. Similar to the productive element of Mertala et al.'s (2016) FMP model, the *level of restraint* represents the number of rules that will restrict free play. For instance, both building blocks and puzzles fall under the category of construction play but the possibilities of play in puzzles is limited. The *level of activeness* determines whether the playful nature of the SALTT will be primarily mental, mostly physical or mixed. The Play element consideration may apply either to the play value that the SALTT artefact will have as a toy or the intervention activities it will support.

6.2.7 Safety element

Manufacturers must abide by toys safety standards to prevent end users from getting harmed. These include lacerations due to sharp edges or broken parts, suffocation due to small components, allergic reactions due to chemicals or materials used, accidental falls from ride-on toys, burns or electric shocks, drowning and death. Figure 6.10 illustrates essential factors designers need to consider at the task clarification stage.

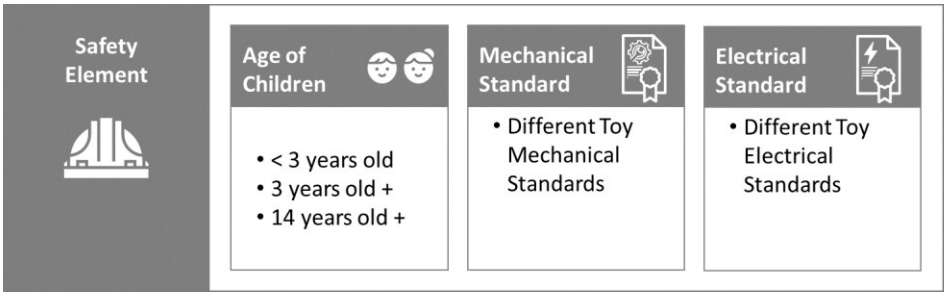


Figure 6.10: Safety element

Age of Children *(<36 months old, ≥36months old, ≥14 years old)*

Almost 200,000 toy-related injuries were reported in the US in 2020 (Qin, 2021). Toy safety standards are updated regularly to ensure accidents are reduced. Toy manufacturers and designers must abide to these standadards which vary according to the target age group. For instance, toy products for children under 36 months have stricter regulations.

Mechanical Safety Standards

Electrical Safety Standards

To avoid design changes when the product design has advanced, designers should be familiar with the respective safety standards. Different countries have different safety specifications for both mechanical and electrical factors. Although one of the purposes of ISO standards is to align different toy standards, each market has its own regualtions. This causes variation in the level of safety and quality of toys. For instance, a toy produced for a specific country (e.g., Chinese market) may not be suitable for another country (e.g. in the EU). In other words, compliance with the regulations of one country does not automatically ensure compliance in another country.

Standards for cybersecurity will need to be drawn to make connected toys and children's data safe from potential hackers. In the Administration element (Section 6.2.12), cybersecurity is mentioned again in the context of the available software tools. Furthermore, new safety requirements may be specified in safety standards due to the COVID-19 pandemic. The Toy Safety Directive stipulates that designers must consider hygiene and cleanliness requirements, especially for toys to be used by babies and toddlers and ensure that cleaning does not deteriorate the products' safety levels (European Commission, 2016).

6.2.8 Language element

The Language element is the first element that sets SALTTs apart from other toys. Figure 6.11 depicts the sub-elements that designers should consider when tackling the Language element of a SALTT.

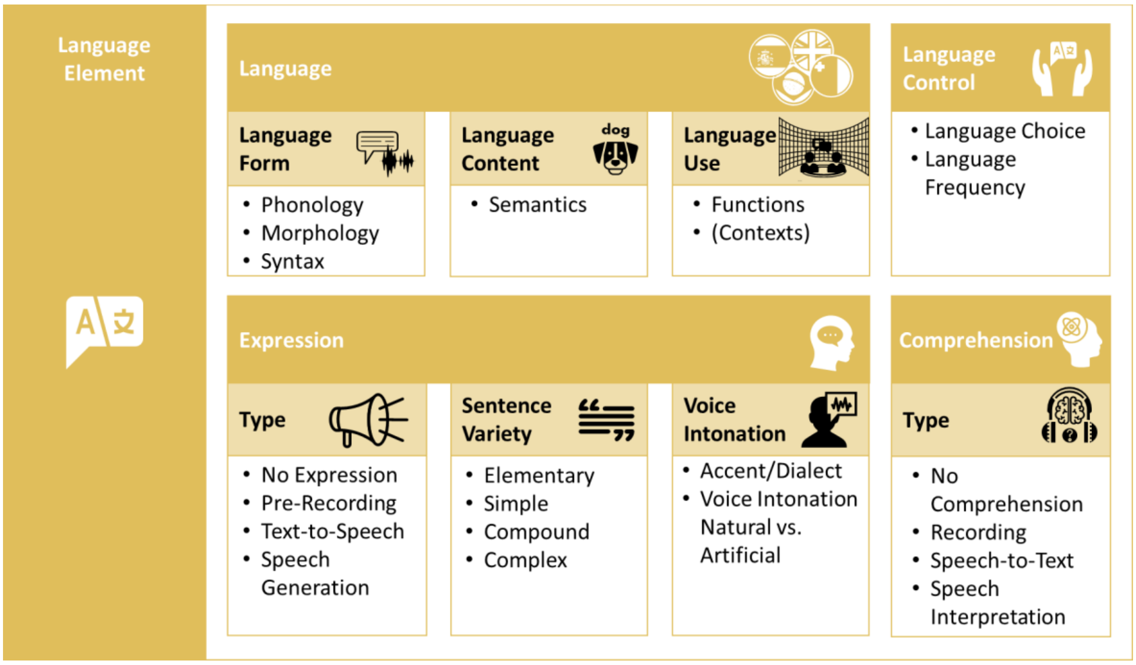


Figure 6.11: Language element

Language

The country where the SALTT artefact will be sold and the official language(s) spoken in that country is critical. Wirth (2020) reports that languages vary drastically from each other in both form and meaning. Essentially, every language is related to four basic communication skills: listening, speaking, reading, and writing. For a language to make sense, one must be familiar with the rules or components that it is made from. As depicted in Figure 6.12, these are the *form*, *content* and *use* (functions) of language (American Speech Language Hearing Association, 2014; Bloom, 1980). When a person/child is struggling with any of these domains, the SLPs diagnoses the language problem and determines the nature of the required intervention.

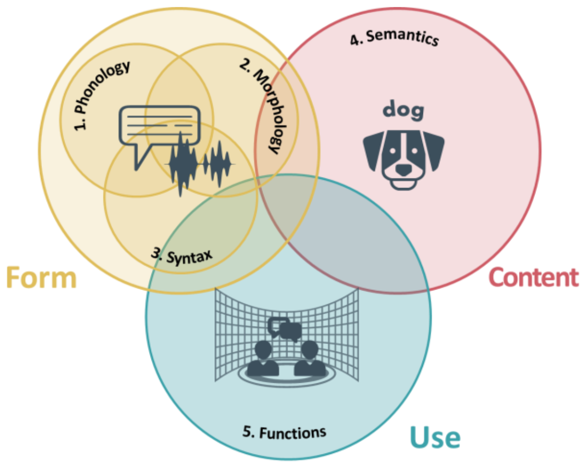


Figure 6.12: Components of Language, adapted from Bloom (1980)

Language Form

(Phonology, Morphology, Syntax)

The form of language concerns the shape and configuration of sounds, words, and their combinations that a person can say, and it is divided into Phonology, Morphology and Syntax (Bloom, 1980). *Phonology* is the language's sound system that dictates how a phoneme representing a syllable (segment) should sound. This also depends on the tone (suprasegmental feature). On their own, phonemes do not mean anything. *Morphology* is the system that stipulates the structure of meaningful words (lexicon) and their forms (inflection). For example, different forms of the word 'play' are 'player' and 'playing', among others. On the other hand, *syntax* is the system that governs the order of words combinations to form sentences and how different elements within a sentence relate to each other.

Language Content

(Semantics)

Language content is about the actual meaning of words, phrases and sentences. This is called the *semantics* (meaning) of messages, where combinations of words provide further insight into the message (Bloom, 1980).

Language Functions

(Functions)

Language use is about how language *functions* in social situations (contexts). Language is used when reasoning about a problem or talking to oneself, initiating a conversation with others, gaining attention, or requesting information.

Language Expression

Language is about expression and comprehension – two-way communication. Ideally, a SALTT artefact can do both for the maximum benefits on speech and language therapy.

Expression Type

(Pre-recorded, Text-to-Speech, Speech generation)

The talking aspect of the SALTT can be achieved in various degrees by playing pre-recorded messages through a text-to-speech (TTS) system that reads out text or by using speech generation technology such as Amazon's Alexa and Apple's Siri. Speech generation makes use of the components mentioned under the Language Comprehension sub-element (Kepuska and Bohouta, 2018).

Sentence variety

(Elementary, Simple, Compound, Complex)

A variety of sentences in different levels of complexity can be provided to expose the child to a variety of language functions. However, hearing the same praises and comments will possibly make the SALTT artefact boring for the user.

Communication Variation

(Dialects, Voice Intonations)

Variations in the same language or dialects exist due to the slightly different phonology (and lexicon) that individuals use in a language within shared regional, cultural or social factors (American Speech Language Hearing Association, 2014). The intonation of TTS technology has dramatically improved in recent years for English and other commonly spoken languages, making computer-read text sound natural (Nwakanma et al., 2014). Within the local context, an effort to generate the first TTS for the Maltese language has started (Camilleri, 2021).

Language Comprehension

(Recording, Speech-to-Text, Speech interpretation)

In language comprehension, the aim is to acquire the child's verbal input. At the most basic level, a SALTT artefact should be able to capture and record the child's utterances through a voice recording mechanism. A recorded voice clip could be used during the analysis of an assessment, during the intervention, and as a reward. Speech-to-text or automatic speech recognition (ASR) software would allow the SALTT to transcribe an audio file into text. In Attard (2018), a speech recognition software was developed for the local Maltese-English Speech Assessment (MESA) (Grech et al., 2015).

Language Control

(Language Choice, Language Frequency)

SALTT artefacts operating in bilingual or multilingual countries should allow the end users to activate multiple languages and specify when different languages should be triggered within a single activity. For instance, during an intervention session, separate questions may be asked in three different languages to test the proficiency in all the languages.

6.2.9 Assessment element

Figure 6.13 summarises the considerations for the Assessment element when reflecting upon the needs of clinicians when children undergo assessments. Although these sub-elements indicate the system requirements for such features, guidance from field experts are needed in their realisation in a SALTT.

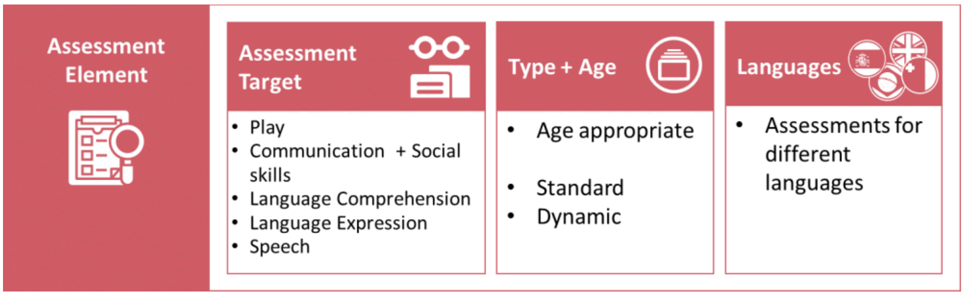


Figure 6.13: Assessment element

Language

Assessments determine the presence, nature and severity of speech and language disorders in individuals (Koch, 2018). Appropriate standards based on the language(s) being assessed must be used for proper screening.

Assessment target

(Attention and Listening, Social and Play, Receptive Language, Expressive Language, Speech)

Figure 6.14 illustrates the building blocks of language (Spooner and Woodcock, 2010), also known as the communication development pyramid. Morgan and Dipper (2018) explain that speech and language skills develop alongside each other. This pyramid (and variations of it, including the communication development tree) explain how communication is supported by other skills.

Figure 6.14: The building blocks of language, adapted from Spooner and Woodcock (2010)

The diagram is used to explain to caregivers the complexity of language development (Morgan and Dipper, 2018). Based on this reasoning, this diagram can help the designers understand the speech, language, and communication development stages and classify the assessments' targets.

Attention and listening skills

Children develop attention skills by paying attention to people and objects around them. This is accompanied by other pre-verbal skills such as eye contact, cause and effect and pointing. Jackie Cooke and Williams (1985) detail how children's attention span increases as they grow older. Assessments in this regard should capture the cause of attention and listening problems, such as hearing impairments, neurological problems, autism and learning difficulties, among others (Law et al., 2012).

Social and play skills

As detailed in the Play element, as children's cognitive play dimension develops, they are learning that words can be used to represent objects, food, and people. When children play with others, they learn to take turns, share, co-operate and negotiate depending on the social play dimension. These are skills necessary in effective communication. Assessments for this developmental target can be verbal and non-verbal.

Understanding or receptive language

The understanding of words occurs before children master how to use them. Receptive language assessments analyse how the child understands and interprets language. For instance, within the local context, lexical assessments have been used to assess conceptual and semantic skills in the Maltese and English languages (Gatt, 2017; Wirth, 2020).

Expression of language

Expressive language assessments look at how a child communicates when using language and how it is being understood. Children first learn how to say single words in their infant years and then progressively learn how to combine words until they form sentences.

Speech sounds

Speech is about the articulation and phonology aspects of language, which refer to how sound is produced. Examples of articulation problems are when the child cannot produce the sound of a word due to hearing acuity, cognitive impairment, or oro-motor structures and functions such as the movements of lips (Koch, 2018). For example, the child may say 'wabbit' instead of 'rabbit'. Children with a phonological disorder can produce the sounds correctly but may use them in the wrong position in a word or omit them.

Assessment Target

The choice of assessment depends on which aspect of the communication pyramid is being assessed, the child's chronological age (age-appropriate), health conditions, and the language. In the case of bilingual countries, Grech and Dodd (2007) remark that in order not to misdiagnose bilingual children with language disorders, assessments in all the languages are necessary to separate between language impairment (in each language) and language difference which is attributed to weakness in one of the languages.

Assessment Type *(Standard, Dynamic)*

Assessments are mainly divided into standardised (or static) and dynamic assessments and both have benefits and limitations (Camilleri and Law, 2007). Standardised assessments are based on research and established through statistical validity and reliability. When executing such tests, SLPs need to employ a strict procedure during the test and while scoring children's performance. For example, SLPs can only use a predefined set of words, and thus may not obtain an accurate picture of the child's skills. Standardised tests are further divided into criterion-referenced and norm-referenced tests. The focus of dynamic assessments is to establish children's capability to learn new skills during evaluation, which can occur during intervention sessions. For instance, the SLP may test the child whether a skill has been acquired. If not, the skill is taught and then retested, thus ensuring that the child has been exposed to that skill.

Format

Paper-based assessments are nowadays being converted to computer-based because of the numerous benefits that technology permits in acquiring, storing, scoring, and analysing the child's input for diagnosis (Buttigieg et al., 2021). In this regard, technology relieves the lengthy and laborious evaluation of the results, making assessments more attractive and time-efficient (Buttigieg, 2019).

6.2.10 Intervention element

As reflected in Figure 6.15, the Intervention element is the most demanding factor to consider when developing a SALTT artefact, and it is divided into two main parts. The upper row of sub-elements details intervention considerations for receptive and expressive language disorders. The second row shows the Intervention Control category, composed of seven sub-elements that are intended to provide the flexibility needed by clinicians for intervention.

General speech and language intervention considerations

Development Age

(Attention and Listening, Social and Play, Receptive Language, Expressive Language, Speech)

When a new case is referred, the SLP aims to understand how many languages the child is exposed to and whether language dominance exists (Gatt, 2017; Gauthier, 1998). For instance, the language acquisition process of a child in a monolingual and bilingual/multilingual environment is different as shown in Appendix A. There is also a difference in the latter case depending on when the second or subsequent languages are learned (Hutauruk, 2015).

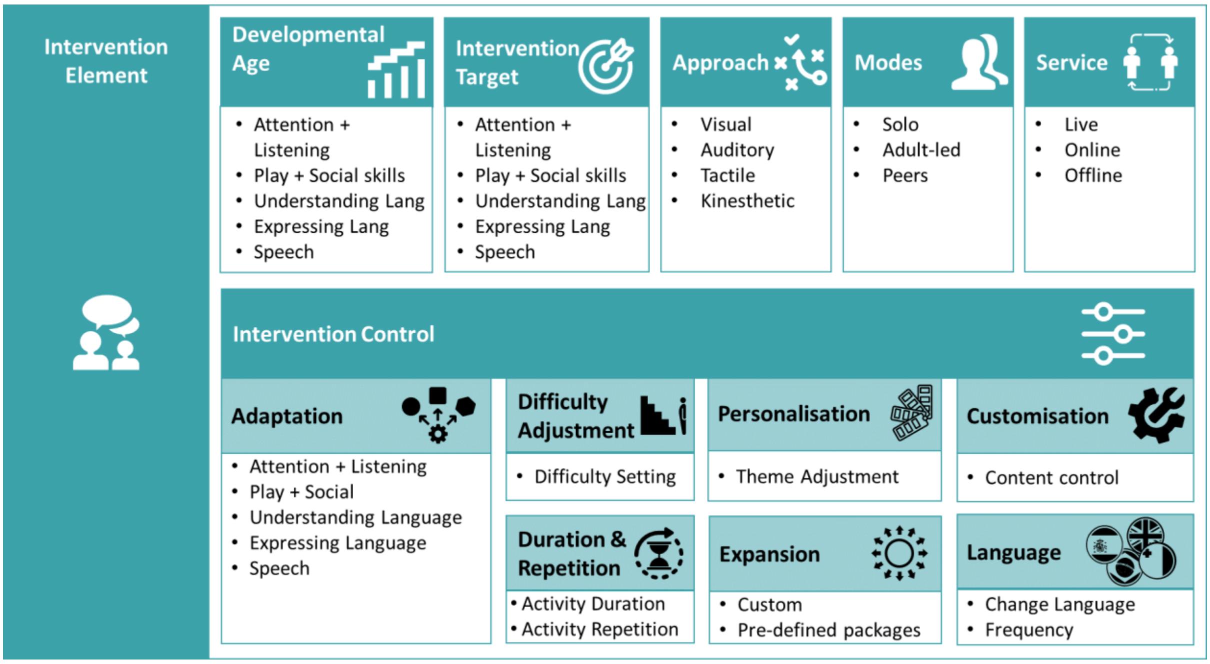


Figure 6.15: Intervention element

Development Age

(Attention and Listening, Social and Play, Receptive Language, Expressive Language, Speech)

When a new case is referred, the SLP aims to understand how many languages the child is exposed to and whether language dominance exists (Gatt, 2017; Gauthier, 1998). For instance, the language acquisition process of a child in a monolingual and bilingual/multilingual environment is different as shown in Appendix A. There is also a difference in the latter case depending on when the second or subsequent languages are learned (Hutauruk, 2015).

Children are referred to SLT if they start missing language development milestones, that is, if the child's chronological age does not match the *developmental age*. The developmental age is an indicative age bracket of when children should reach milestones. For instance, a child might be chronologically six years old but has the attention and listening skills of a three-year-old. In such a case, the developmental age would be three years old.

Intervention Target

(Attention and Listening, Social and Play, Receptive Language,

The process of how children subconsciously master a language is considered a remarkable feat (Hutauruk, 2015). Appendix A details typical speech and language development charts that provide a basis of the key areas within each building

Expressive Language, Speech)

block of language (intervention target) on which SLPs work during the intervention. These also provide the foundation for how clinicians can adopt the scaffolding technique to support children overcome challenges within their zone of proximal development and facilitate language learning. The idea behind scaffolding is that with a little bit of help, children can learn new skills, and when that is learned, support is reduced.

Approach

(Visual, Auditory, Reading/Writing, Kinaesthetic)

A learning style is the way the human being receives, processes, and internalises new information. Information is received through the sensory modalities of visual, auditory, reading/writing, and kinaesthetic/tactile (Fleming, 2001). In the context of SLT, SLPs use various modalities and combinations during intervention to adapt to the children's preferred learning style (McDaniel, 2010). The visual modality relates to the visual channel of receiving information, that is, the eyes. Visual learners learn most when they see pictures and info-graphic content.

Similarly, the auditory modality refers to the auditory channel of receiving information. An auditory learner finds it easier to learn or remember things they hear and say, such as singing a nursery rhyme. On the other hand, some learners prefer to read and write to absorb information. This is called the reading/writing modality, where printed/written words are used. Kinaesthetic/tactile learners prefer to process information when manipulating things or doing physical activities. For example, an SLP may teach prepositions by interacting with objects in the clinic, such as getting *behind* a chair or placing a book *on* a shelf. These four modalities are known as the VARK system, and it is found to support the learners' attention and motivation levels (Othman and Amiruddin, 2010).

Modes

(Solo, Adult-led, Peers)

SLPs usually deliver intervention on a one-to-one basis in the clinic. However, sometimes, they provide intervention to groups of children in the school environment. Furthermore, to support carryover at-home therapy, the designer should think of ways the child can exercise speech and language intervention activities with or without the support of others.

Service
(Live, Online, Offline)

The SLT service can be delivered face-to-face during live or online sessions. Carryover at-home therapy is considered the offline mode. The designer needs to be aware of these aspects to use the SALTT device in different situations. The aspect of online service is discussed further in the Administration element.

Intervention control

When designing intervention activities for a SALTT, designers should remember that SLPs require flexibility and control over these activities to cater to a broad spectrum of children's needs.

Language

In the case of bilingual/multilingual SALTT artefacts, intervention can be provided in different languages. The SALTT device should allow the SLP to specify the language or languages to be used during an intervention and whether an activity should combine different languages. For instance, the SLP may want an intervention activity to be conducted 40% in English, 30% in Maltese and 30% in Italian.

Adaptation
(Attention & Listening, Social & Play, Receptive Language, Expressive Language, Speech)

Adaptation is about changing an intervention activity's scope to cater to another intervention target. For example, an SLP may want to use an odd-one-out game to work on children's receptive and expressive skills.

Personalisation *(Theme Adjustment)*

A SALTT should provide ways of allowing the SLP to change the theme of the intervention activity to create a personalised activity. This is because children that have been diagnosed with the same speech and language disorder may not like the topic of the intervention activity due to different personal preferences.

Customisation *(Content Control: Randomise, Limit, Representation)*

To tailor intervention activities based on the child's abilities, the content of an intervention activity may be customised according to the therapeutic objectives. An SLP may be required to (1) *randomise* the words that appear in an activity so that the child does not get used to it; (2) *control* or limit which words appear in the activity to target specific lexical or articulation issues; and (3) or change the object’s representation (e.g., from photo to cartoon illustration) with the SALTT.

Expansion *(Custom, Predefined)*

Apart from restricting content, SLPs need to expand the available content. Linking this sub-element to the updatability/upgradability sub-elements in the Technology element, a *predefined expansion* could be a software package download or an add on. Else, mechanisms could be embedded within the SALTT for *custom expansions* where the SLP can manually design or add content.

Difficulty Adjustment *(Difficulty setting)*

Intervention activities can be based on the concept of scaffolds so that an adequate challenge is presented to the child. Changing the *difficulty setting* can make a particular task easier or harder. The SLP may need to specify the number of difficulty levels and which difficulty setting to perform the intervention activity.

Duration and Repetition

(Activity duration, Activity repetition)

The final control sub-element is the duration of the intervention activity and the number of turns it is required to be done by the child to consider it complete. For instance, for a child with a low attention span, the SLP may want to configure the activity so that the child is only asked three questions (duration) twice (repetition).

6.2.11 Reward element

Although it is impossible to design an artefact that produces an unlimited number of rewards that match all the possible interests of children, designers can provide features that allow clinicians and caregivers to customise the type of reward.

Figure 6.16 summarises the considerations (sub-elements) that need to be considered when working on the reward mechanisms offered by SALTTs.

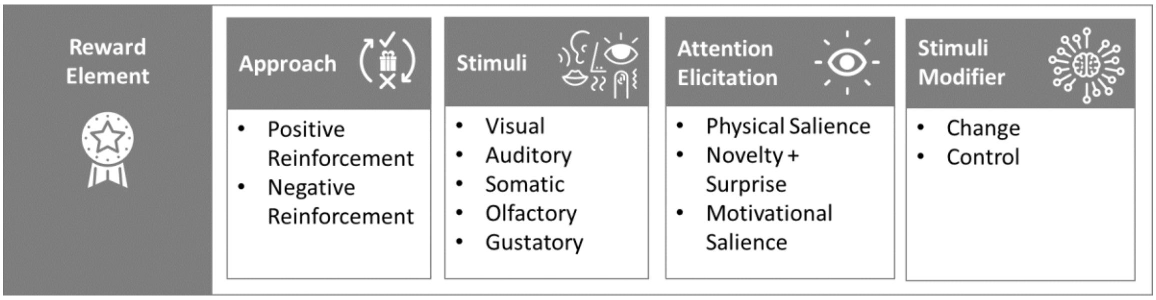


Figure 6.16: Reward element

Based on the studies carried out with SLPs, rewards are central to intervention, just as toys are tools for therapy. In the therapy context, reference is being made to *nonprimary rewards*, rewards not related to survival and reproduction (Schultz, 2015). SLPs use rewards with children to motivate them to behave appropriately and cooperate during intervention sessions (Robins et al., 2007), work towards the therapeutic goal, keep them engaged (Hinske et al., 2008) and have longer attention spans, and ultimately, to reward them for their performance. Rewards can be in the type of praises, sensory stimuli, events, objects, activities, and situations which have the potential to attract children and be consumed. Typical examples of rewards that SLPs provide are stickers, tokens such as blocks that can be used to build something, and small physical gifts. Sometimes children are also rewarded by allowing them to do a preferred activity, such as playing with their favourite toy or game on the tablet.

Michaelsen and Esch (2021) state that behaviour is either stimuli-driven or goal-directed. In the former case, human beings follow stimuli unconsciously due to their end effect on their basic emotions (affect) (Ekman et al., 1987; Kowalska and Wróbel, 2017), whereas when one cognitively processes the stimuli, these become goals. Thus, an attractive reward influences both attention (Kim et al.,

2021) and motivation (Michaelsen and Esch, 2021). This is also captured by Schultz's (2015) model for the components and functions of rewards, as depicted in Figure 6.17.

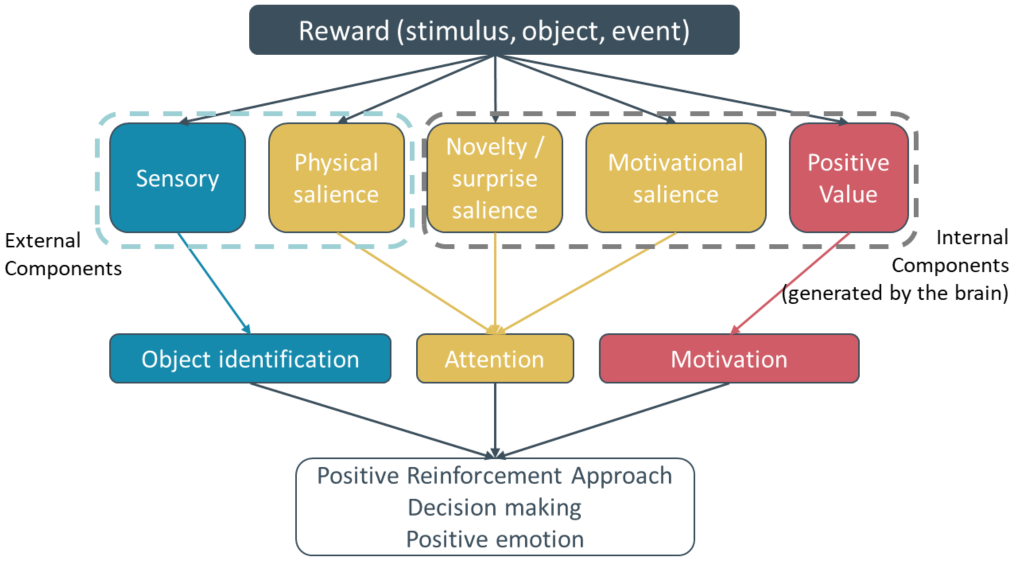


Figure 6.17: Reward components and their functions, adopted from Schultz (2015)

Stimuli (Visual, Auditory, Somatic, Olfactory, Gustatory)

The first component of rewards is sensory. Its simplest form refers to stimuli or objects with physical parameters, such as size, colour and acidity, and can be identified through the visual, auditory, somatic, gustatory and olfactory receptors. Stimuli are the source of rewards and must be translated into objects, events, situations, or activities. These allow children to discriminate between rewards.

Attention Elicitation *(Physical salience, Novelty/Surprise salience, Motivational salience)*

The second component is the salience of rewards and helps retain the child's attention. Attention is the result of three factors: the physical intensity and impact of the reward, the novelty and surprise element of the reward, and the general motivational impact to attain the desired reward.

Stimuli Modifier (Change Stimuli, Control Stimuli)

The third component of rewards is the subjective, positive value that rewards have on the individual. This translates into the motivation to execute a particular behaviour. Michaelsen and Esch (2021) divide motivation into three types:

appetitive (or incentive) motivation which leads to positive affect; aversion (avoiding) motivation, which contributes towards avoidance of negative affects, such as fear and disgust; and assertion (non-wanting) motivation. This explains why stimuli must be meaningful to the child. The aim should be to provide stimuli such that a child's motivation becomes goal-directed, allowing him/her to be more engaged. Thus, ways to adjust the provided reward must be enabled within the design of SALTT.

Reward Approach *(positive reinforcement, negative reinforcement)*

Positive reinforcement is the process by which a particular behaviour is encouraged by offering a reward. Skinner's (1965) theories on operant conditioning state that a response can also be strengthened by negative reinforcement, that is, by removing an unpleasant stimulus, such as changing an activity or not assigning practice between a session and another. This further emphasises the need to allow SLPs to use different strategies when assigning rewards based on the child's preferences.

6.2.12 Administration element

Figure 6.18 summarises the sub-elements for the Administration element. The popularity of technological devices, notably the tablet, is prevalent among SLPs both locally (Zarb, 2018) and internationally (Mâţă et al., 2018; Wiśniewska, 2020).

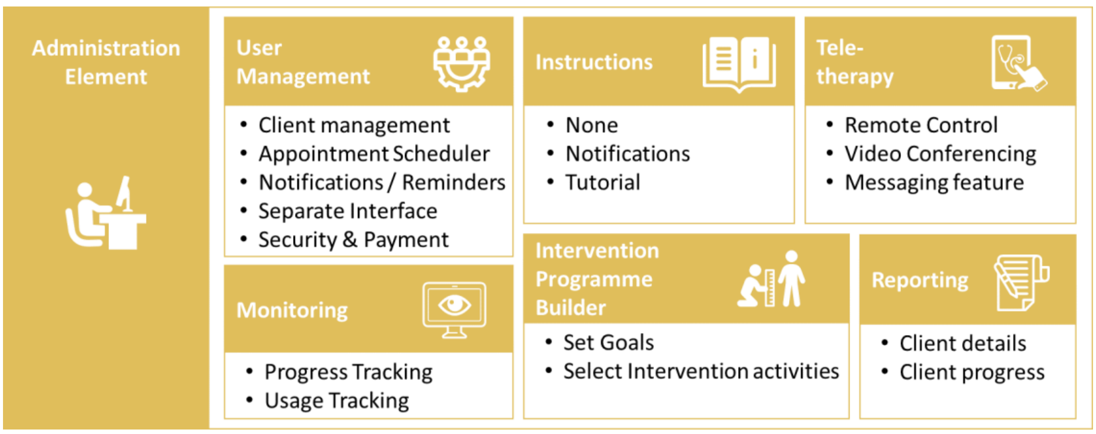


Figure 6.18: Administration element

Apart from being means that allow SLPs to perform assessments and intervention activities with children, they provide several administrative utilities that support the day-to-day job. The Administration element cannot be realised if the SALTT is not hi-tech as most of the sub-elements can only be implemented through software. The requirements for this element were mainly collected from the focus groups with SLPs and parents as described in Chapter 3. However, upon reviewing their needs, these were found to reflect existing practice management software (PMS) features.

Practice Management System

In contrast to an electronic medical record (EMR), a repository that stores patients' medical history, a PMS is a type of software used to manage day-to-day office operations (practice management), including tele-healthcare (Davey and Davey, 2015; Farber, 1989). A PMS can be used by public or private health organisations, clinics, and individual clinicians such as speech therapists. Examples of paid PMSs include MyClientsPlus[12], TherapyNotes[13] and TheraNest[14].

User (Client) Management

Section 3.4.2 presented a picture of the number of active clients SLPs have. Managing tens of clients simultaneously, all with varying speech and language problems, history, and customised intervention programmes, client management can become an overwhelming task.

Appointment scheduler, Notifications

A central appointment scheduling system can allow clinicians and caregivers to be more efficient and avoid missing appointments. If the SLT session needs to be cancelled, this can be rescheduled to the next available slot. Reminders can be sent automatically to all parties, reminding them of any pending tasks, such as preparing the assessment for the next session.

[12] https://myclientsplus.com/
[13] https://www.therapynotes.com/
[14] https://theranest.com/

Separate interfaces for different users

Since the SALTT is one device for multiple users with different uses, it must provide separate interfaces or portals. In the SLP interface, clinicians can modify settings such as the intervention control features mentioned in the Intervention element, see/schedule appointments, send reminders, emails and instructions, and track payments, among other tasks. In the parent interface, caregivers can access reports and instructional videos, post questions, read notifications, book/reschedule appointments and pay online. In contrast, the child's interface will only allow children to perform intervention activities.

Furthermore, SLPs noted that as soon as children get familiar with the technology, they quickly learn how to navigate through the software to do their preferred activities. For this reason, interfaces should be locked so that children perform the required activities.

HIPAA Compliant and secure

SLPs were concerned about the security of clients' personal and healthcare details. The three reviewed PMSs are HIPAA compliant. HIPAA stands for Health Insurance Portability and Accountability Act. Therefore, HIPAA compliance ensures that healthcare data is securely protected from abuse and that clients' identity is adequately safeguarded.

Invoicing and payment processing

In the case of private SLT sessions, payment can be facilitated through a PMS. This is also useful in providing clients with proof of payment or making them aware of pending payments.

Information Generation

A PMS may serve as a professional platform that allows SLPs to communicate with other SLPs to remain up to date in the profession or collaborate on intervention ideas.

Intervention Programme Builder

An intervention programme builder would allow the SLP to design a tailored intervention programme consisting of activities set explicitly for the needs and interests of the child. In other words, the SLPs would be allowed to select several different activities suitable for treating the disorder, where the seven control elements discussed in the Intervention element are adjusted individually for each activity. Moreover, the programme can be adjusted as the child progresses to achieve the desired therapeutic objectives. Furthermore, the SLP can be given the possibility of creating new user profiles from existing programmes, making only minor adjustments for the needs of the new clients.

Monitoring

(Progress Tracking, Usage Tracking)

With the ability to monitor the usage of the SALTT artefact and the progress rate being made, clinicians can deduce whether the intervention is working as desired or not. This allows the SLP to modify and improve the intervention programme. Automatic monitoring and scoring allow the SLPs to focus their effort on the child's input instead of tracking and worrying that they forgot to mark an answer. Monitoring can be done on both intervention activities and assessments. Furthermore, usage monitoring coupled with notifications and reminder features could nudge the children that they need to practice.

Reporting

Reports provide a means by which SLPs can communicate how the child's speech, language, and communication skills are improving, share the objectives and goals set for the child, and explain how therapeutic activities can be extended to the child's daily life. When coupling automatic monitoring with reporting, reports can detail: the scores of assessments and intervention activities; whether the child performs the assigned tasks; the frequency of practice (if tasks are repeated); skills that are yet to be acquired; and communicate progress patterns that can be insightful to both the clinician and the caregiver.

Instructions

During the focus groups, SLPs claimed that parents often complain that they do not know how to play or carry out an intervention activity with their children, even though they are present during the therapy sessions. The same comments were reported in Buttigieg (2019). As a result, carry-over at home is not performed, and therapy efficacy is low. Instructions or recorded step-by-step videos can be provided to parents through SALTT.

Remote therapy

Technological advances have enabled remote therapy, also known as tele-practice, where traditional face-to-face therapy is carried out through video conferencing. This is particularly useful in countries where distances and availability of services are impediments to therapy. Fairweather et al. (2017) report that tele-healthcare is cost and time-effective in such situations, even though face-to-face sessions are preferable.

Prior to the COVID-19 pandemic, clinicians were reluctant to provide their service online. Local SLPs reported that they would have less control over the child's attention and behaviour during tele-practice, and the session is prone to distractions within the child's home environment (Buttigieg, 2019). Nonetheless, tele-practice was the only way of continuing SLT during the global lockdowns due to the viral pandemic. Both local (Wirth, 2020) and foreign (Aggarwal et al., 2020) studies suggest that SLPs' opinions about tele-practice changed during COVID-19.

Although more research is required on the lasting influence of remote therapy, Aggarwal et al. (2020) found that SLPs will still seek tele-practice due to the benefits it provides to both clinicians and caregivers.

6.3 Chapter Conclusions

Considerations for SALTTs

This chapter has detailed the SALT-PM lightweight ontology for SALTT artefacts based on the end-users therapeutic use-phase needs. It was shown how characteristics from play artefacts could be integrated within a product that clinicians, caregivers and children need for speech and language therapy. The 12 elements of the SALT-PM detail the necessary therapeutic factors that designers must consider when designing SALTTs. Technology plays a central role in realising the full potential that SALTT products can reach.

SALT-PM elements are not orthogonal

For this reason, the SALT-PM elements are not completely independent of each other. For instance, the mode of use sub-element in the Context element considers whether the SALTT will be for personal or clinical use. If the SALTT artefact is required for personal use, then not all considerations of the user management sub-element in the Administration element are be considered.

The potential of a speech and language therapeutic toy

The potential of a SALTT is a measure that determines the artefact's suitability for SLT from an end-users perspective, with a special focus on the child user because the child may outgrow the artefact. A SALTT artefact with a high potential for SLT is one that 'grows with the child', that is, continues to be useful as the child's speech, language and communication needs improve. The following chapter will discuss the validation of the SALT-PM.

7. VALIDATION OF THE SALT-PM

The logic of validation allows us to move between the two limits of dogmatism and scepticism.

Paul Ricoeur, From Text to Action: Essays in Hermeneutics II, 2006

The SALT-PM is the combined result of research conducted in this doctoral work and the inclusion of models and theories found in the literature. This chapter aims to validate the soundness of the SALT-PM to ensure that designers are provided with reliable knowledge about the end-users requirements for SALTT artefacts. A two-stage validation of the SALT-PM is provided in Sections 7.1 and 7.2. Chapter takeaways are made in Section 6.3.

7.1 Validation of the SALT-PM

The aim of this section is to validate the current form of the SALT-PM with SLPs so that it can be used as an lightweight ontology in the framework architecture discussed in Chapter 8 and implemented in the prototype tool as described in Chapter 9. The truthfulness of the SALT-PM ensures that the designer is provided with reliable knowledge.

7.1.1 Validation objectives and criterion

SALT-PM Validation Objective #1

The first validation objective (VO1) (see Figure 7.1) is to confirm that the elements and sub-elements of the SALT-PM capture the needs of SLPs. Instead of evaluating the model with caregivers and children, the SLPs' perspective will be used because they are the leading therapy providers.

Validation Objective #2

The second validation objective (VO2) is to gain an initial understanding of each SALT-PM element's potential for a SALTT from the clinicians' point of view.

Validation Criterion

The focus of this study is VO1 because it will determine the completeness of the SALT-PM. Thus, the criterion to assess the SALT-PM is to determine the completeness of each element.

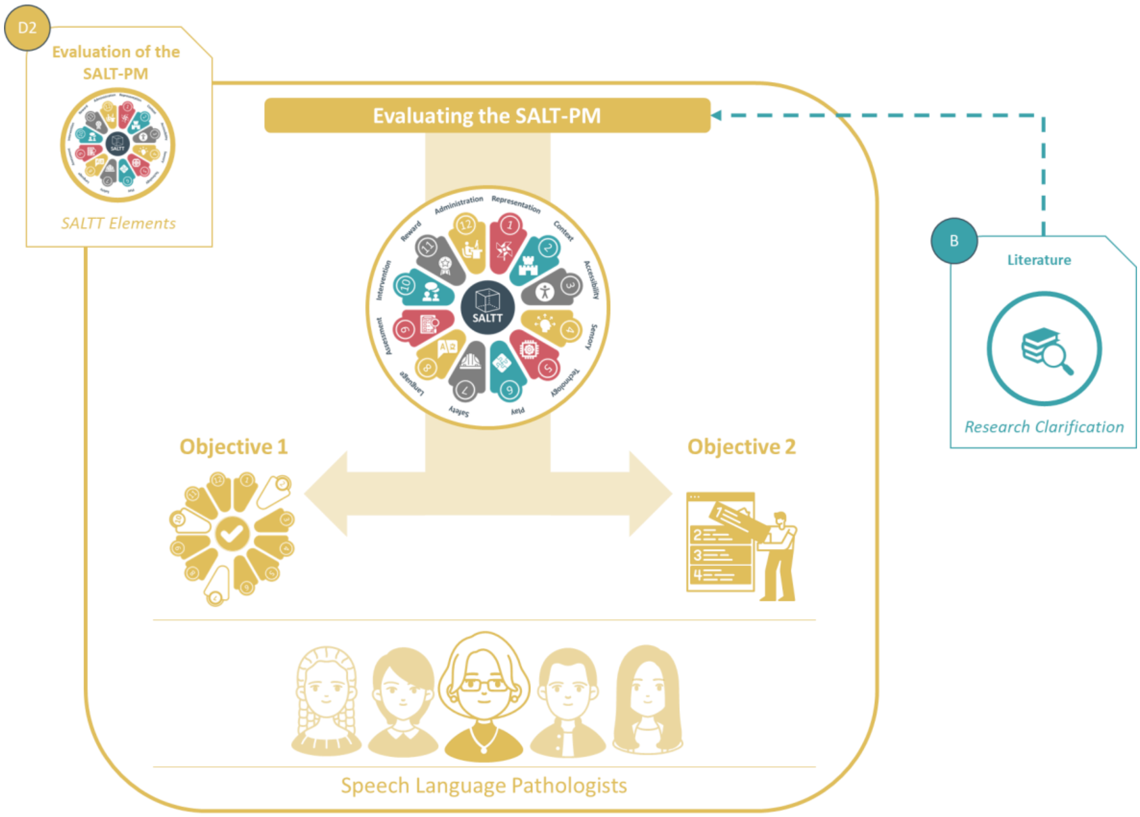


Figure 7.1: Structure of SALT-PM evaluation study

7.1.2 Participants of the validation study (VS)

Ethics consideration

Before the recruitment process started, ethics approval was sought from the Faculty of Engineering research ethics committee at the University of Malta (application number 8550-26012021). Further permissions to conduct this study were granted by the Data Protection Officer (DPO), the Manager of the Speech-Language Department (SLD) and the President of the Association of Speech-Language Pathologists (ASLP) of Malta.

Recruitment

The information letters and consent forms for this study were sent to the Manager of the SLD, who is responsible for SLPs working with the public sector, and the President of the ASLP, who has access to contact details of members working in the private and public sectors. Both organisations were asked to circulate the information letter and consent form to their members twice because participation remained low.

Participants

Nine practising and one non-practising SLPs have agreed to participate in this study. By signing the consent form, participants agreed to allow the researcher to record the online SALT-PM validation session. Table 7.1 lists the participants' information, including their level of education. Their years of experience (YOE) varied between 5 and 30 years (Mean = 11.1 years, Std. Dev. = 9.4 years).

Limitations of study

Although the sample size is small, it must be noted that half of the participants had more than ten years of experience working in the field, and seven participants had more than one degree related to communication therapy. Another limitation of this evaluation is that only local SLPs participated in the study. It is also noted that only one participant is male. This conforms with the prevalence of male SLPs as discussed in Byrne (2016) and Dias et al. (2016).

*Table 7.1: Participants' details (*YOE: Years of Experience)*

Participant	Gender	YOE*	Current Role	Education
VS01	F	26	Academic	Ph.D.
VS02	F	4	Practising SLP	B.Sc.
VS03	F	1	Practising SLP	B.Sc.
VS04	F	13	Practising SLP	M. Sc.
VS05	F	18	Practising SLP	M. Sc.
VS06	F	3	Practising SLP	M. Sc.
VS07	F	6	Practising SLP	M. Sc.
VS08	F	25	Practising SLP and Academic	Ph.D.
VS09	F	2	Practising SLP	B.Sc.
VS10	M	13	Practising SLP	M. Sc.

7.1.3 Procedure for the SALT-PM validation study

Procedure

Participants were first provided with a background of this doctoral research and its main objective: creating a framework that would support the development of a requirement generation tool for SALTT artefacts. Then, an overview of each SALT-PM element and sub-elements was provided except for the Safety element. Even though participants were made aware of the Safety element, they were not asked to validate it because safety is considered an essential part of every product. Each explanation was followed by questions that asked the SLP how important it is for a designer to consider each sub-element, as shown in Figure 7.2 through Figure 7.17. Before progressing to the next element, SLPs were asked whether they had additional comments to add to an element. In the final part of the study, participants were asked to rate the elements and whether these reflect the needs of the end users. Each interview lasted between 40mins to 90mins.

7.1.4 Results and discussion

Statistical analysis was not performed because of the small number of participants. However, a percentage is provided to compare the participants' feedback. Qualitative feedback is included to provide insight into the reasoning of the SLPs.

Representation element

Both the chronological age and overall form were rated positive as shown in Figure 7.2. Only two participants (VS03 and VS08) said that it is "Important" for the designer to consider the gender of the target end users. Most participants believe that gender association has a relatively lower importance because irrespective of the gender associated with the toy, children will show the SLP what they want to play with. VS10 said that:

> *"This ties in with the chronological age of children… between the age of 12- and 24-months boys and girls may play with the same things. It's only later that they develop gender-specific playing themes".*

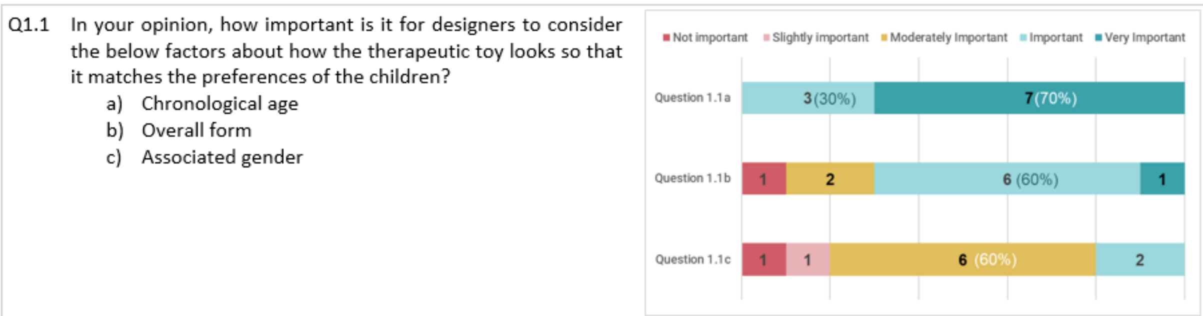


Figure 7.2: Participant's responses for the Representation sub-elements

The SLPs were asked whether they would want the SALTT artefact to look like a toy or not. As shown in Figure 7.3, the majority (70%) were in favour, whereas

VS06, VS07, and VS08 said "Maybe". Opposing feedback argued that although younger children would be more interested in a toy, "*children would not make a distinction that this tool is for therapy*" and that "*there are situations when [SLPs] need real objects to explain concepts*".

Q1.2 Should a therapeutic tool look like a toy?

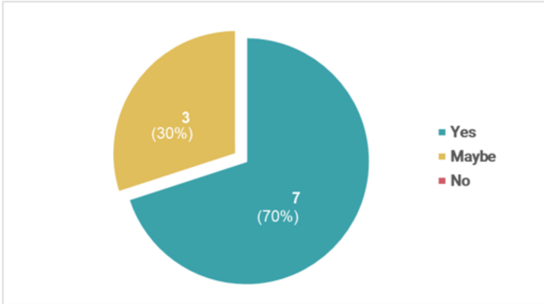


Figure 7.3: Participant's responses on whether a SALTT should look like a toy

Context element

Overall, the Context sub-elements were rated positively as portrayed in Figure 7.4, meaning that designers should consider how and where the SALTT will be used. VS10 remarked that:

> *"There is the assumption that speech therapy occurs in a clinic, but in reality, they can take the product outdoors as well or in other formats. You do not want to design something that cannot be used unless the only way to produce it is cheap".*

This stresses the importance that caregivers and children need to continue therapy between one clinical session and another.

Q2 In your opinion, how important is it for designers to be aware of the context in which speech and language therapy is performed, in terms of:

a) how the therapeutic device will be used?
b) how the therapeutic device will be handled?
c) where the therapeutic device will be used?
d) environmental factors?

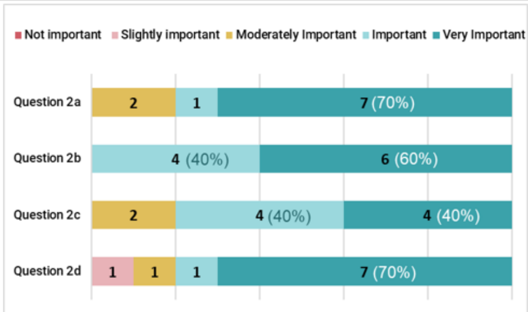


Figure 7.4: Participant's responses for the Context sub-elements

Accessibility element

Figure 7.5 shows the feedback received on the Accessibility element. The majority (70%) of the participants said that it is "Very Important" for the designer to consider the impairments that users may have. The common feedback was that the therapeutic toy should be accessible as much as possible within the limits imposed by the impairment because if the child does not have access, the therapeutic toy would be useless. Only one participant (VS04) gave a "Moderately Important" rating for the Visual Impairment. Her rating was based on the prevalence of accessibility issues she has encountered throughout her career.

Q3 In your opinion, how important is it for designers to consider accessibility factors in a therapeutic tool?

a) Level of Hearing Impairment
b) Level of Visual Impairment
c) Level of Motor Impairment

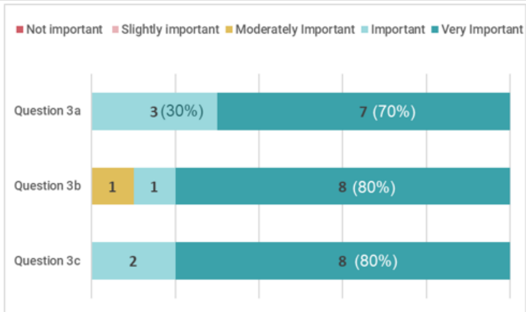


Figure 7.5: Participant's responses for the Accessibility sub-elements

Sensory element

Overall, participants agreed with the sub-elements of the Sensory element, as shown in Figure 7.6. Only VS08 provided a "Moderately Important" response when asked whether the designer should be aware of the different stimuli. She explained that:

> *"I didn't say "Strongly Agree" for any of these, because I think for the majority of kids, it's not that important, but then you know that there's a subsection of kids with disabilities that you would say: Yeah, I wish we could do this."*

Participants welcomed the idea that the SALTT would allow the SLP to vary the intensity of the stimulus because it would make it more versatile and would not bore the child. VS06, VS07 and VS10 also related this feature to children with autism by referring to variations between different children who may have hyper- or hypo- sensitivity. VS10 said that customisation would enable the SLP to change the product's features to meet a client's immediate and future needs.

Q4 In your opinion, how important is it for designers to consider:
a) the type of sensory stimulus?
b) providing the ability to vary the stimulus?
c) providing the ability to change the intensity of stimulus?

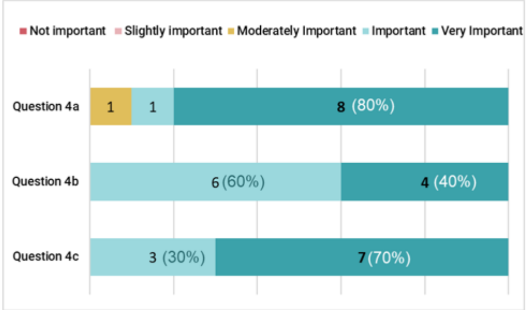


Figure 7.6: Participant's responses for the Sensory sub-elements

Technology element

Most participants rated the considerations within the Technology element as "Important" or "Very Important", as can be seen in Figure 7.7. VS04 and VS07 explained that designers do not need to be reminded which technology will be used because it depends on the marketing team's intent and consequently VS04 marked the technology class as "Moderately Important". VS03 and VS04 remarked that internet connectivity might be a limiting factor because if an SLP is in a clinic with a weak or no Wi-Fi signal, then the therapy session might be interrupted.

Q5 In your opinion, how important is it for designers to consider:
a) the class of technology?
b) the effects of technology on the way users interact with a therapeutic device?
c) connectivity?
d) user interface?
e) upgradability?
f) updateability?

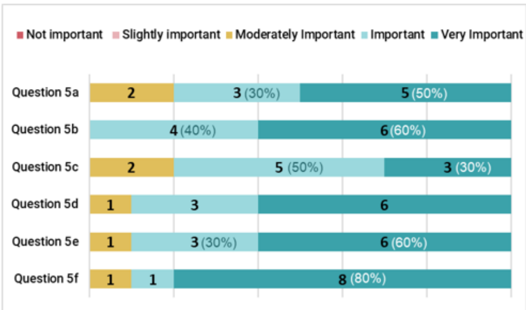


Figure 7.7: Participant's responses for the Technology sub-elements

VS10 noted that both low-tech and hi-tech devices are needed, and although upgradability and updatability increase the longevity of the product, warrantees and compatibility with software upgrades expire after some time. VS05 and VS08 also agreed with VS10, stating that for the money that parents would spend, ideally, the SALTT would have a long lifetime, at least until the child outgrows his/her condition. On the other hand, VS02 said that it is better to have a fast yet straightforward tool instead of many features.

Play element

Play's cognitive and social dimensions and the play variation sub-elements were mostly rated as "Very Important", as shown in Figure 7.8.

Q6.1 How important do you think it is for designers to be aware of:

a) the different types of Cognitive Play?
b) the different types of Social Play?
c) the level of involvement?
d) the level of restraint?
e) the level of activeness?

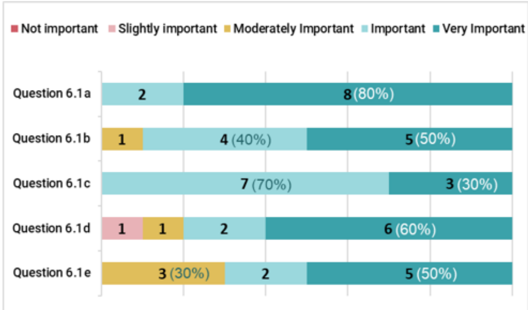


Figure 7.8: Participant's responses for the Play sub-elements

Participants were also asked whether the SALTT product should provide opportunities for play that are independent of therapy. Seven participants replied "Yes", two (VS03 and VS08) "Maybe", and one participant (VS06) disagreed (refer to Figure 7.9). Even though VS01 and VS08 expressed a positive opinion, they pointed out that the child might not want to do therapeutic activities, if the SALTT is used for both play and intervention. VS06 said that the SALTT should not be used for general play and that the designer should find ways of including play in intervention. VS04, VS07 and VS09 remarked that additional play elements within a SALTT could be used as a reward or a quick break. This can help maintain children's attention and cooperation.

Q6.2 Do you think that a Speech and Language therapeutic tool should offer play possibilities that are independent of the intervention activities?

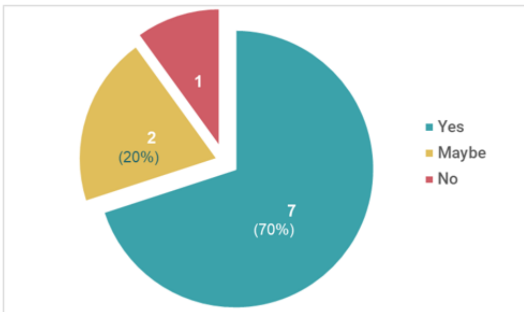


Figure 7.9: Participant's responses on whether a SALTT should offer play for the sake of fun

Language element

The participants rated the language components primarily as "Very Important", as shown in Figure 7.10. VS04 rated the ability to have control over the frequency of a language as not important but did not provide justification.

Q7.1 In your opinion, how important is it for designers to consider the following language aspects in a therapeutic tool?
a) Form of each language
b) Content of each language
c) Functions of each language
d) All official languages of a country
e) Allow selection of desired language(s)
f) Provide control over the occurrence of different languages

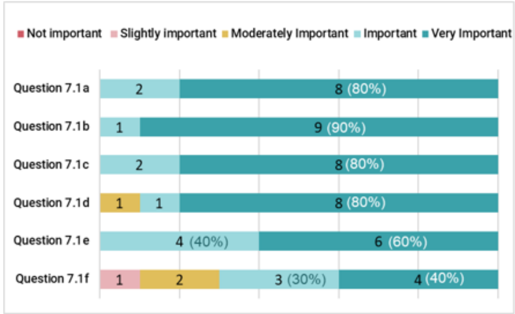


Figure 7.10: Participant's responses for the Language sub-elements

Participants were asked whether a SALTT product should include the expression sub-element only, the comprehension sub-element only, or both expression and comprehension sub-elements. Different opinions were expressed for the first two options (refer to Figure 7.11). However, all participants agreed that it is "Very Important" to consider both aspects of language because clients have different needs. VS04 pointed out that from a therapeutic aspect, if the device is an AAC device, then the types of expressive and comprehension technology are critical.

Q7.2 In your opinion, how important is it for designers to consider the following verbal communication aspects in a therapeutic tool?
a) Include expression only
b) Include comprehension only
c) Include both comprehension and expression

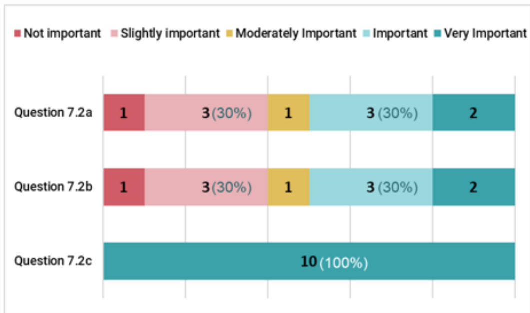


Figure 7.11: Participant's responses for the Language expression and comprehension sub-elements

Most SLPs (70%) deemed the consideration of the type of expressive technology and sentence variety as "Very Important". On the other hand, only half of the participants consider voice intonation as important. Nonetheless, all three elements were rated positively as shown in Figure 7.12. VS10 suggested including 'dialects' within the SALT-PM because this would affect the expressive aspect and integration of culture.

Q7.3 In your opinion, how important is it for designers to consider the following expressive aspects in a therapeutic tool?
a) Type of expressive technology
b) Sentence variety
c) Voice Intonation

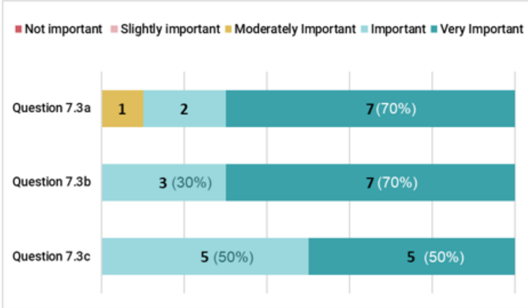


Figure 7.12: Participant's responses for the Expression sub-element

Assessment element

Overall, for the Assessment element, SLPs consider the inclusion of assessments in a SALTT essential as reflected in the results depicted in Figure 7.13. However, VS04 and VS08 said it is tough for a single product to cater for such a wide range of skills and development stages, "*but that would be amazing*". VS08 said it is "Not Important" to include a standardised assessment because "*once you put a standardised test in a toy or an app, it is not standard anymore because you changed the format. It has to be re-standardised*". This is true because a test becomes a standard when it is validated in a particular format. The participants made no particular comments about dynamic assessments, except for VS05, who said that a dynamic assessment is more critical than a standardised assessment in a therapeutic tool. This is because VS05 foresaw that a SALTT would be more beneficial for intervention.

Q8 In your opinion, how important is it for designers of therapeutic tools to include:
a) assessments that consider every stage of children's speech and language development?
b) standardised assessments?
c) dynamic assessments?
d) assessments for the right language(s)?

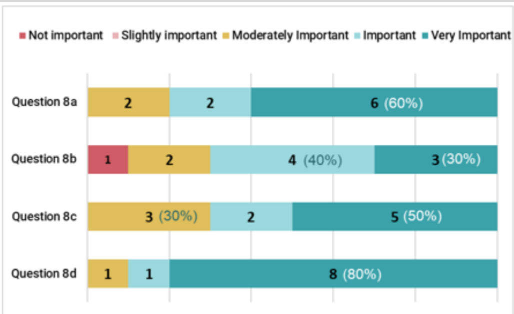


Figure 7.13: Participants' responses for the Assessment element

Intervention element

The validation of the Intervention element was divided into two parts. The first questions were about the sub-elements that concern the activities for the intervention aspect, and a second set of question was explicitly asked for the control aspect. As can be seen from Figure 7.14 and Figure 7.15, the sub-elements of the Intervention element were mostly rated as "Very Important". VS10 rated both the intervention target and the intervention approach as "Moderately Important" but did not provide any specific reasons why they are less important than the other sub-elements.

Q9.1 In your opinion, how important is it for designers to keep in mind the following aspects when developing intervention activities?

a) The developmental stages of children
b) The different targets of intervention
c) The different learning modes of children
d) The different ways intervention can be provided
e) The different ways SLP can provide the intervention service

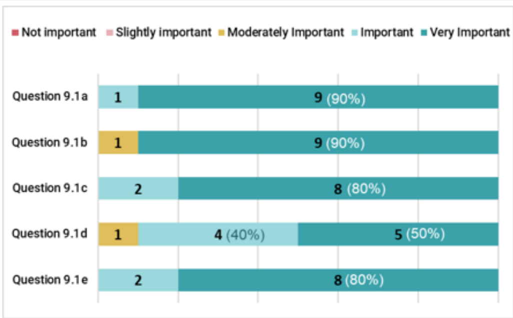


Figure 7.14: Participants' responses for the sub-elements that concern the intervention activities

Participants exhibited a very positive attitude towards the controlling considerations in the Intervention element. VS06 said that it is very important that a therapeutic toy allows the SLP to update the intervention activities based on the child's progress, whilst VS08 stated that the SLP always needs to have control over the activities used. VS08 suggested including the randomicity feature in the content control sub-element, whereas VS09 underlined the importance of representation. VS09 explained that young children would not relate a real car photo with a cartoon representation of a car: "*we start with real objects, then pictures of real objects and then illustrations*". VS09 also added that she had experienced cultural differences among her clients and providing content control would greatly support personalised intervention.

After seeing this part of the Intervention element, VS03 commented that "*I just wish that all these things existed. Not just this element but all elements*".

Q9.2 In your opinion, how important is it for designers to provide the SLP control over the intervention activity/activities?

a) Allowing adaption of the activity for different goals
b) Allowing personalisation of the theme used in an activity
c) Allowing customisation of the content in an activity
d) Allowing difficult adjustment of the activity
e) Allowing modification of the activity's duration and repetition
f) Allowing new content to be added
g) Allowing changing language of an activity

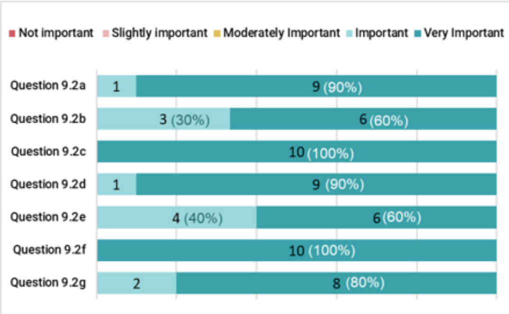


Figure 7.15: Participants' responses for the sub-elements that concern the control aspect of the intervention activities

Reward element

The Reward sub-elements were also positively rated, as displayed in Figure 7.16. VS06 stated that it is essential for the designer to see the child's perspective, the different age levels, and what reinforcers are suitable. For example, stickers are more relevant for young children. VS08 noted that "*rewards are what keep children coming back*".

Q10 In your opinion, how important is it for designers to consider the inclusion of the following aspects of rewards in a therapeutic tool?

a) Rewarding approach
b) Type of stimuli
c) Attention elicitation
d) Stimuli modification

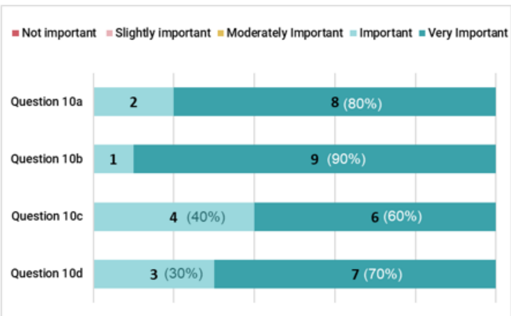


Figure 7.16: Participants' responses for the sub-elements of the Reward element

VS10 recommended differentiating between extrinsic, tangible or digital rewards that give immediate satisfaction and intrinsic rewards that are personal to the child. VS10 explained that the latter deal with the emotions such as when the child feels proud of her achievements. He compared fitness apps that use digital medals to provide a sense of achievement. This is known as persuasive technology for behavioural change (Cash et al., 2017).

Persuasive technology deals with human psychology by touching on those factors that drive human behaviour (Fogg, 2009). Behaviour change strategies are usually not coercive and can be classified on whether they take a conscious or an unconscious approach (Cash et al., 2017). The latter strategy tends to be more effective because no considerations need to be made to perform a particular behaviour. The SALT-PM was built upon this foundation by considering affordances as discussed in Chapter 3.

Administration element

The Administration element was positively received, as shown by the ratings that SLPs gave to each administration sub-element (Figure 7.17). VS10 rated the *user management* sub-element as "Moderately Important" because the other sub-elements were considered more important. All ten participants rated the *progress monitoring* sub-element as "Very Important". VS04 commented that the intervention builder feature is critical as it provides ways to make custom made intervention programmes. She added that "*the more administrative features [the SALTT] has, the more preferable it would make it for clinicians, plus it would reduce the workload*".

VS05 said that "*these are the things that I, as a clinician, look for in an application. My favourite apps can synchronise and save client's progress*". VS09 also noted that the ability to generate reports would be helpful because they can be sent to the parents and other caregivers, such as teachers, to see the child's progress. This would allow them to work on the next objective.

Q11 In your opinion, how important is it for designers to consider the inclusion of the following administrative features?
a) User management tools
b) Intervention programme builder
c) Progress monitoring tools
d) Reporting tools
e) Tele-therapy (tele-healthcare)
f) Instructions on the therapeutic tool

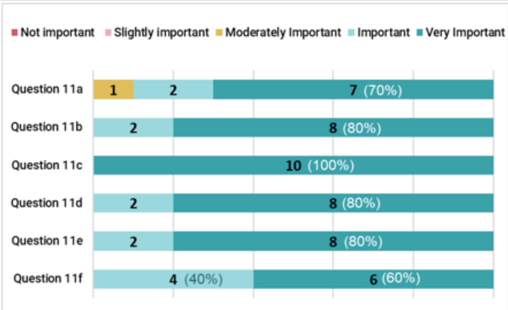


Figure 7.17: Participants' responses for the sub-elements of the Administration element

The SLP's perspective on the potential of each element

In an attempt to establish the potential of each SALT-PM element from an SLP perspective, the participants were asked to rank the 11 elements that were reviewed. Note that the Safety element was not included in the ranking because safety is considered a top priority in SALTTs. Figure 7.18 shows how the participants ranked the discussed SALT-PM element. The Rank-Order Centroid method (Kunsch, 2019) was used to generate a weighting for each rank.

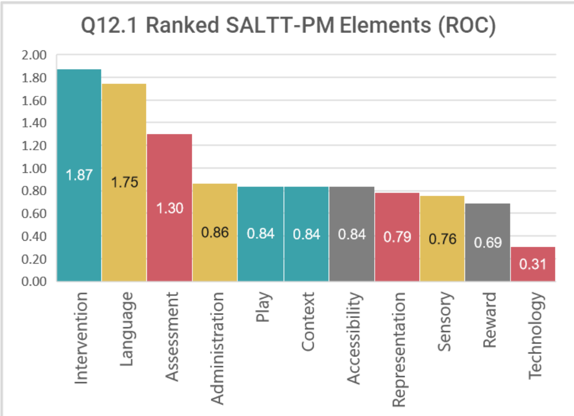


Figure 7.18: The participants' ranking for the SALT-PM element

The Intervention element was ranked as the most important element, followed by the Language and Assessment elements. This clearly distinguishes why a SALTT is different from any other toy. The other elements were similarly rated except for the Technology element, with the Administration element leading this cluster of elements. Although some elements can be implemented without using technology, the Technology element plays a central role in realising some sub-elements across the other elements. In a way, the Technology element behaves like the Safety element, that is, it cannot be compromised. On the other hand, an artefact may still have the potential for therapy. For these reasons, it is argued that the Technology element should not be assigned the lowest potential. Whilst 80% of the participants ranked the Technology element as the least or second least important SALT-PM element, VS08 and VS10 ranked it the eighth- and seventh-most important element. This difference may be due to the type of clients that VS08 and VS10 see. These two SLPs stated that they work with autistic children who have intelligible speech, which requires the use of augmentative and alternative communication (AAC) devices. To extrapolate these results, a bigger sample size of participants is required.

Participants were also asked to validate, from a clinician perspective, whether the SALT-PM addresses the needs of clinicians, caregivers, and children. As shown in Figure 7.19, most of the participants "Strongly agreed" with this.

Q12.2 In your opinion, to what extent do you agree that the Speech and Language Therapeutic Potential model considers the needs of:

a) Speech-Language Pathologists (SLPs)
b) Parents
c) Children

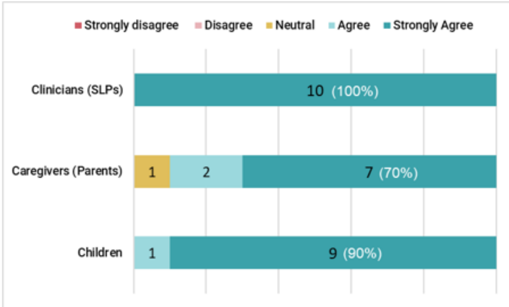


Figure 7.19: Participants' opinion on SALT-PM's consideration for the three end-user groups

VS01 commented that the SALT-PM gives detailed criteria and evidence related to the SALTT's applicability. She added that designers need to know detailed information about the different elements. VS04 claimed that "*this model is exciting for speech therapists because it takes into consideration the needs of therapists. We are used in using educational toys, but this is specifically designed for speech therapists*". VS06 explained that the SALT-PM considers the needs of clinicians, children, and parents who are "*the link between clinicians and children*". VS08, who was in neutral agreement on whether the SALT-PM addresses the needs of caregivers, believes that the design of TT should be child-driven first and then clinician-driven. VS07 said that although adults provide therapy, children's input is significant even though preschoolers are too young to understand therapy. VS06 argued that she would not want to give parents certain access to specific features.

As a final question, the participants were asked to rate the usefulness of the SALT-PM to designers. As shown in Figure 7.20, all SLPs said that the SALT-PM is "Extremely Useful". VS05 stated that the model allows the designers to consider the voice of the professionals. VS09 observed that *"these are the factors that we consider when we have a new client and need to assess the client holistically."*

Q12.3 Overall, please rate the usefulness of the SALT-PM as a reference for designers.

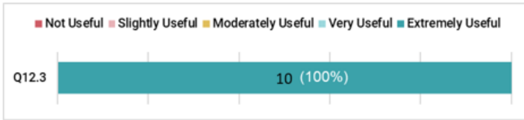


Figure 7.20: Participants' opinion on the usefulness of the SALT-PM to designers.

VS10, who has praised the structure of SALT-PM as a much-needed model, said that the SALT-PM would allow designers to develop tools that are useful for SLPs and parents. To answer this question, VS08 gave her perspective first.

> *"It certainly made me think of all the different elements that should be considered when designing a toy that is going to be used by a speech and language therapist. Like, I think a lot of us [SLPs] have experience of using toys and we are able to evaluate what we buy beforehand... [Or sometimes a toy is] tried with different children and then we start to see the features of it; what's good and not good. So definitely, I feel that you've made me very aware of all the different elements that we can consider when we're thinking about toys for children, their speech and language needs. So, I imagine if I was a designer, because I'm a speech therapist, and I know all the stuff you're talking about or a lot of them, and I have a lot of experience with toys, I could relate a lot of these aspects. But for the designer, they might not have this knowledge. This is really going to help guide them through the process of what to consider."*

The concept of making the designer aware of the problem context is discussed further in Chapter 8. VS08 raised an important point on the order in which the elements should be shown to the designer. She acknowledged that "*it would be really complicated... [because] I don't think the model is linear*".

One of the reasons the SALT-PM is depicted as a circle is because it should be left up to the designer to decide which elements to consider first. This depends on the designer's working style, whether it is the industrial designer, a design engineer, or a team of people. Then again, a number has been assigned to the elements. The first six elements can be related to toy products, whereas the second half of the elements are related to SLT. Additionally, the elements move from the physical aspect of the product to the mechanics of play and therapy and then to more abstract needs such as the rewards and administration. Realising a SALTT artefact with a high therapeutic potential requires a multidisciplinary team, where experts can focus on specific parts of the SALTT concurrently.

7.2 *Olly Speaks*: A Case Study for the SALT-PM

Olly Speaks

As part of the *SPEECHIE* project (see Chapter 1), a prototype SALTT artefact called *Olly Speaks* was designed and developed after a QFD analysis on the sub-elements of the SALT-PM was performed by the project members. *Olly Speaks*, shown in Figure 7.21, is thus a manifestation of the SALT-PM and was used as a vehicle to extend the validation of the SALT-PM with an actual case study. The actual design process of *Olly Speaks* is documented in (Balzan, 2018).

(a) *(b)*

Figure 7.21: (a) Renderings and (b) an actual picture of Olly Speaks

7.2.1 Specifications

Hardware Specifications

Five identical versions of *Olly Speaks* were built from Poly Lactic Acid (PLA) using Fused Deposition Modelling (FDM) 3D printers for the various studies conducted throughout the *SPEECHIE* project. Children's product preferences that emerged from Balzan et al. (2019) were used to enhance the overall design. *Olly Speaks* measures 360x235x270mm and weighs 1.4kg. It has a 7" TFT LCD touch screen, two 1.8" colour TFT screens as eyes, two motor actuators for the movement of the wings (hands), a main computer board, two 2W speakers residing in the headphones, a soundcard, a solenoid-based locking mechanism in the backpack, a dual microphone located in the beak area, a Wi-Fi module, and a rechargeable battery. The backpack of *Olly Speaks* was intentionally designed to create anticipation in children so that the SLP can store rewards.

Software

Olly Speaks runs on an Android operating system, and a dedicated application (app) was developed by a gaming company called Flying Squirrel Games Malta. The app consists of several sub-applications developed for the research work described in Wirth (2020). These include two lexical (receptive and expressive) assessments, which were based on the work of (Gatt, 2010), four speech games (Phonemes, Articulation, Syllable and Clapping) and four language comprehension intervention games (Categorisation, Picture Association, Odd One Out and Treasure Hunt). Both the assessments and the intervention games can be carried out in Maltese and English. Figure 7.22 portrays how *Olly Speaks* connects to a cloud to upload score results and download intervention control settings from a separate app, called the *SLP/Parent app*, installed on another mobile device. This enabled a degree of control over the intervention activities. The photos in Figure 7.22 demonstrate how the user studies (explained in Section 7.2.1) were carried out when *Olly Speaks* was used with children.

Scores for the receptive assessment and all the intervention games were automatically recorded. Words and phrases that *Olly Speaks* emitted were pre-recorded, whilst only a recording function as comprehension technology was implemented as listed in Table 7.2 of Section 7.2.2.

Rewards

A positive reinforcement approach was adopted in the intervention games, where a ‘sparkle sound’ and stars would appear around correct selections, as shown in Figure 7.23.

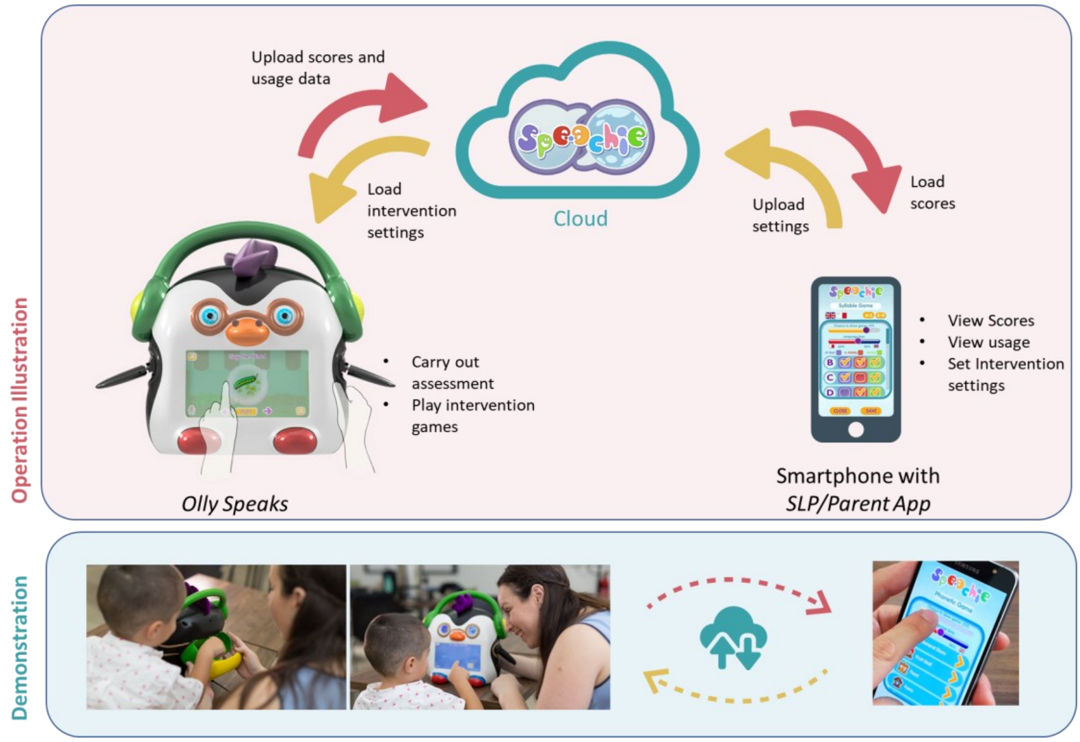


Figure 7.22: Demonstration of how Olly Speaks operates

On an incorrect response, the picture would shake. Once a whole intervention activity is completed, a pre-recorded compliment plays to motivate the child further. At the same time, *Olly Speaks'* eyes are animated, and it flaps its wings. Moreover, the backpack would automatically open at the end of the intervention activity by activating the solenoid-based lock.

Figure 7.23: Reward representation on Olly Speaks

7.2.2 Mapping *Olly Speaks* to the SALT-PM

Table 7.2 maps the implemented features within *Olly Speaks* vis-à-vis the twelve elements of SALT-PM. This mapping aims to provide the reader with an understanding of the level of implementation with respect to the various results obtained through a series of studies explained in Section 7.2.1.

Table 7.2: Analysis of Olly Speaks with respect to the SALT-PM

Representation element		**Accessibility element**	
Chronological Age:	Preschoolers (3-5 yrs)	*Hearing Impairment:*	Mild
Style:	Realistic / Fantasy	*Visual Impairment:*	Mild
Gender Association:	Neutral	*Motor Impairment:*	Mild
Context element		**Sensory element**	
Use Purpose:	Clinical use	*Sensory Type:*	Visual, Auditory, Tactile
Use Mode:	Table-top		
Therapy Location:	Indoors	*Sensory Variety:*	None
Environment factors:	Noise, Light	*Sensory Intensity:*	None
Technology element		**Play element**	
Technology Class:	Phygital	*Cognitive Dimension:*	Practice, Rule
Dependency physical (from 0 to 1):	0.8 (Mostly Dependent)	*Social Dimension:*	Solitary
Dependency digital (from 0 to 1):	0 Independent	*Level of Involvement (from 0 to 1):*	0.2 Mostly Passive
Synchronicity (from 0 to 1):	1 Synchronous	*Level of Restraint (from 0 to 1):*	1 Given
Updatability:	Yes	*Level of Activeness (from 0 to 1):*	0.3 Mostly Mental
Upgradability:	No	**Safety element**	
Connectivity:	Yes	*Age:*	> 36months
User Interface:	Visual, Touch	*Mechanical Standard:*	EN 71
		Electrical Standard:	EN62115
Language element			
Languages:	Maltese, English	*Expression Type:*	Pre-Recording
Language Choice:	Yes	*Sentence Variety:*	elementary
Language Frequency:	Yes	*Voice Intonation:*	Natural
Language Form:	Yes, limited	*Comprehension Type:*	Recording
Language Content:	Yes, limited		
Language Use:	Yes, limited		
Assessment element			
Assessment Target:	Language (and Speech)	*Assessment Type:*	Standardised
Assessment Age:	Preschoolers	*Languages:*	Bilingual Maltese-English
Intervention element			
Developmental Age		*Intervention Target*	
Attention/Listening:	Level 4 onwards	*Attention/Listening:*	Yes
Play/Social Skills:	N/A	*Play/Social Skills:*	No
Receptive Language:	3 years onwards	*Receptive Language:*	Yes
Expressive Language:	various	*Expressive Language:*	Yes
Speech:	3-5 years old	*Speech:*	Yes
Approach:	Solo, Adult-led	*Intervention Mode:*	Visual, Auditory, Tactile, Kinaesthetic
Service:	Live, Offline		
Intervention Control			
Adaptation:	No, in general but can be adapted by SLP	Language:	Maltese, English
Personalisation:	No	Difficulty Adjustment:	Yes (Language activities)
Customisation:	Yes (Speech activities)	Duration & Repetition:	No
Expansion:	No	**Administration element**	
Reward element		*User Management:*	No
Approach:	Positive Reinforcement	*Monitoring, Reporting:*	Yes
Stimuli:	Visual, Auditory, Tactile	*Instructions:*	Yes (tutorials)
Attention Elicitation:	Physical, Novelty, Motivational	*Intervention Programme Builder:*	No
Stimuli Modifier:	No	*Tele-therapy:*	No

7.2.1 Overview of the studies carried out through *Olly Speaks*

Research studies

Four Master's studies (Attard, 2018; Buttigieg, 2019; Micallef, 2019; Wirth, 2020) emerged from the *SPEECHIE* project, but the primary evaluations on *Olly Speaks* were conducted by Wirth (2020) from an efficacy perspective and Micallef (2019) from a marketing perspective.

Market potential of Olly Speaks

In Micallef (2019), a market study was conducted with ten local SLPs, eight parents of atypically developing children and eight parents of typically developing children. The unique selling points of *Olly Speaks* were used to develop a marketing strategy. Participants were informed that *Olly Speaks' would be* priced at €300. Results showed that SLPs and parents of children with DLD would purchase such a SALTT artefact.

Effectiveness and efficiency

In Wirth (2020), the potential of using *Olly Speaks* as a clinical tool for SLT in Malta was investigated through a three-component evaluation. In the first study (A), 153 three to five-year-old bilingual and typically developing Maltese children took part in a lexical assessment and intervention study using *Olly Speaks*. This study provided a performance baseline for bilingual Maltese children. In the second study (B), three bilingual, Maltese children, aged between 5 and 6 years with a DLD, participated in a six-week intervention programme where intervention was facilitated by conventional methods and *Olly Speaks*. Results from this study showed that *Olly Speaks* "*is an effective, efficient and motivating tool*" for SLT (Wirth, 2020) as children were engaged more, cooperated and performed better. In the third study (C), similar to Micallef (2019), *Olly Speaks*' potential as an effective and efficient means for therapy was evaluated with seven SLPs and three parents of children with DLD from a clinical perspective. SLPs acclaimed the benefits provided by the separate SLP/Parent app (as part of the Administration element), the ability to maintain children engaged and motivated towards therapy, and the ability to support carryover of therapy outside the clinic.

Satisfaction measures

In parallel with study A reported in Wirth (2020), the third aspect of usability (Abran et al., 2003), satisfaction, was analysed with the 153 children. Whilst efficiency and effectiveness focus on the performance of the individual, satisfaction targets aspects of the user's experience that results from the use or anticipated use of a product. Thus, satisfaction was measured both on the assessment and intervention features, and the overall design of *Olly Speaks* by using the Smileyometer technique discussed in Chapter 3. Furthermore, at four stages of the study, children were asked to indicate whether they were feeling happy or sad based on a five-point Smileyometer.

Results showed that children preferred the intervention activities over the assessment activities, particularly the Picture Association game being rated the most preferred game. Regarding the overall design of the SALTT, all children except for one were satisfied with *Olly Speaks*. Most children liked the backpack feature because the SLP was hiding rewards inside it. As shown in Figure 7.24, children's happiness levels improved at each study stage, with a significant improvement happening after the first assessment, that is, after using *Olly Speaks* for the first time.

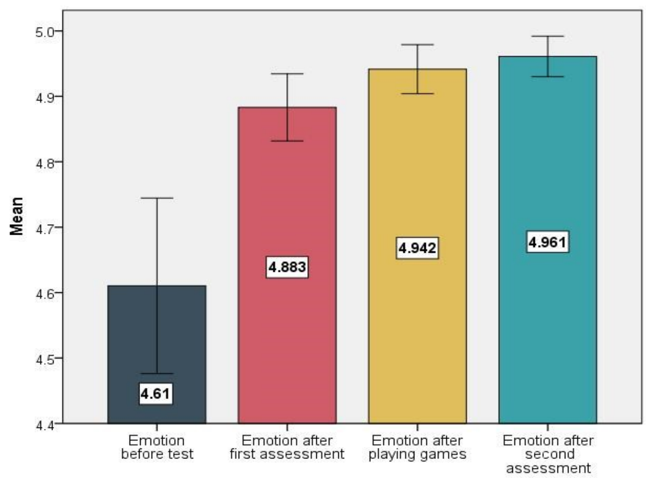


Figure 7.24: The level of happiness at different stages of the study whilst using Olly Speaks

7.2.2 Concluding comments on the evaluation of *Olly Speaks*

Through *Olly Speaks*, it was possible to validate the SALT-PM with a broader audience, specifically with atypical children whose needs were mostly captured through SLPs and parents. The highlight of the achieved results is that through *Olly Speaks*, children had longer attention spans and cooperated more with the SLP when compared to the same activities performed through low-tech, conventional means. In fact, Wirth (2020) reported that:

> *"The Intervention Study also showed favourable results for Olly Speaks with regards to maintaining and controlling the participants' attention, sitting tolerance and behaviour. These three aspects were generally rated more positively when using Olly Speaks as opposed to [conventional means] ... Olly Speaks was highly rated by the parents and SLPs who participated in the Evaluation Study in terms of being able to engage a child and maintain their attention. Furthermore, both groups gave higher ratings to the toy's design for holding children's attention than to the games found on the device…This was further emphasised by the parent feedback which regarded Olly Speaks as an interactive toy, going beyond just a screen."*

This evaluation of *Olly Speaks* revealed how the short attention span in children during SLT was addressed since longer attention spans were reported by SLPs. The second need that *Olly Speaks* addressed was providing a means to facilitate carryover at-home therapy through a dedicated SALTT. Even though not all elements of the SALT-PM were implemented in *Olly Speaks*, these results provide a degree of evidence that the SALT-PM can be used to guide the design of SALTTs.

7.3 Chapter Conclusions

Validation of the SALT-PM

The first part of the SALT-PM's validation showed that it considers the holistic needs of SLPs, children and caregivers. Furthermore, the second part revealed that one does not need to implement every sub-element specified in the SALT-PM ontology to make a SALTT a useful product for therapy. Due to the non-linearity of the model and the different number of sub-elements present in each element further research is required to determine the intrinsic potential.

8. AN AFFORDANCE-BASED REQUIREMENTS ELICITATION FRAMEWORK ARCHITECTURE FOR SALTTS

It's the knowledge derived from information that gives you a competitive edge.

Bill Gates, The New Road Ahead - Newsweek, 2005

The aim of this chapter is twofold: firstly, to disclose a framework architecture for supporting affordance-based requirements generation for SALTT, and secondly, to present a formalism of the affordances that result from the speech and language therapy potential model (SALT-PM). Figure 8.1 shows a high-level block diagram of the framework, consisting of five main layers. A detailed version of the framework architecture is provided in Section 8.1. Further insight to the SALT-PM ontology is provided in Section 8.2. The formalism of affordance-based requirements is presented in Section 8.3 whilst chapter conclusions are made in Section 8.4.

Framework overview

The architecture depicted in Figure 8.1 is the outcome of the framework requirements (FWRs) gathered during the first descriptive study discussed in Chapter 2. Because the framework was initially constructed to generate SALTT requirements, it was called *D-SALTT*, for Designing SALTT products.

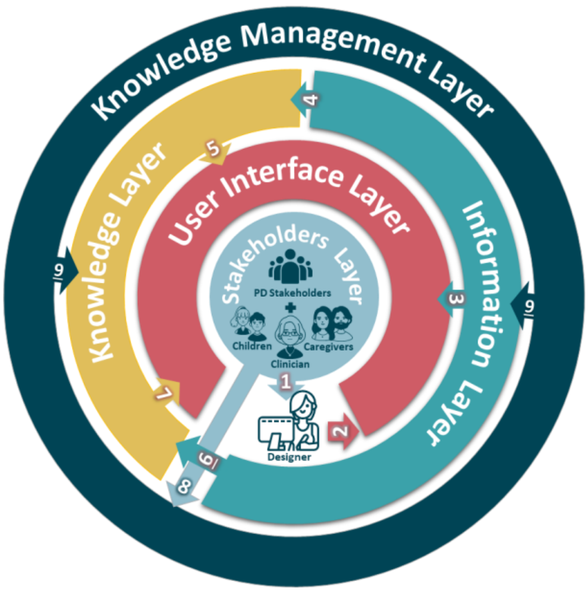
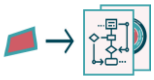


Figure 8.1: Overview of the D-SALTT Framework

Information model framework architecture



The framework is based on human-centred design principles, where the artefact's lifecycle users are placed at the core of the framework. The initial user needs are passed to the designer from the Stakeholders Layer (SL) through a design brief or established as the designer observes the respective users. On the other end, the designer interacts with a computer-based tool which essentially consists of a User Interface Layer (UIL), an Information Layer (IL), a Knowledge Layer (KL), and a Knowledge Management Layer (KML). The UIL allows the designer to access knowledge within the IL and generates requirements for SALTT products after the KL has processed the knowledge. The KML is responsible for keeping the system up to date with the latest trends, customer needs and relevant knowledge, such as for SALTT products.

8.1 The *D-SALTT* Framework Architecture

The scope of D-SALTT

As illustrated in detail in Figure 8.2, the *D-SALTT* framework consists of 9 main steps. In this research, the SALT-PM serves as one of the libraries within the IL. This will enable the designer to understand the elements of a SALTT.

In the following sub-sections, the purpose of each module within each framework layer is explained as the requirements generation process progresses when the user interacts with the UIL through stages I to IV.

8.1.1 Identifying the initial customer needs

Role of the Stakeholders layer (SL)

At the core of the *D-SALTT* framework architecture lies the SL, which considers every user the artefact will encounter during its lifecycle. As drawn in Chapter 2, the new business idea, concisely captured in the design brief compiled by the marketing analyst, is passed to the designer (*Step 1*).

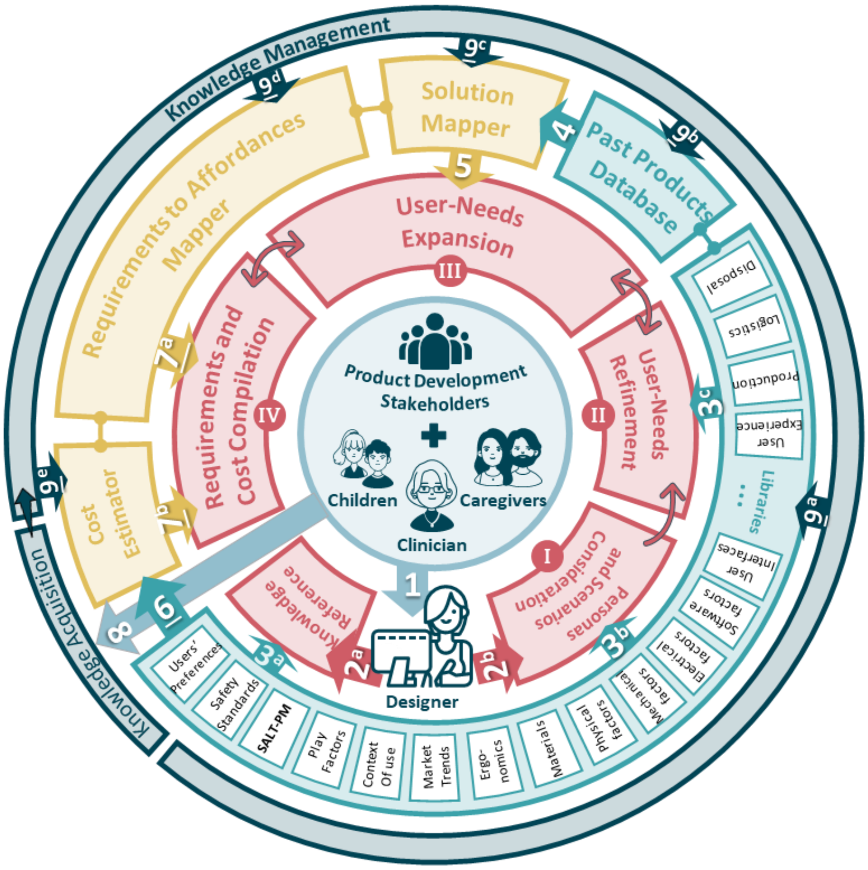


Figure 8.2: D-SALTT Framework Architecture

Because the design brief is not always available or exhaustive enough, the designers may also wish to conduct market research. This step is illustrated in Figure 8.3. Contrary to the current reality, the framework architecture proposes that the designer is allowed access to the artefact's users, regardless of the organisation's size in which he or she works.

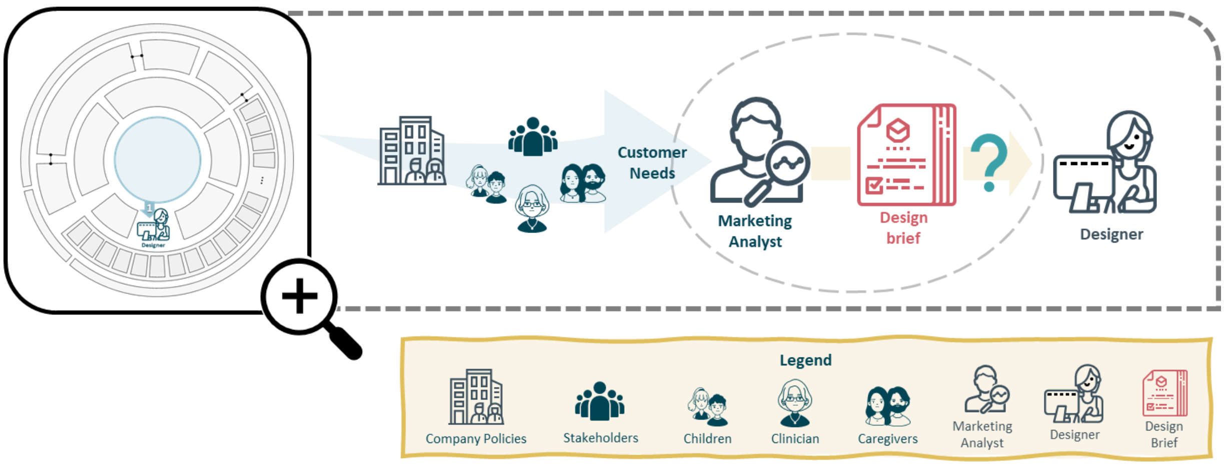


Figure 8.3: Passing the customer needs to the designer

In the case of SALTT products, the designer should capture the end-users needs from clinicians, caregivers, and children.

8.1.2 Accessing knowledge within the computer-based support tool

The role of the User Interface Layer (UIL) and the Knowledge Reference module

Once the designer has an initial idea for whom the product will be designed for and of their needs, the designer can interact with the computer tool. As will be explained in Chapter 9, computer programs consist of a *user interface* through which users can perform the various functionalities offered by the software. In the *D-SALTT* framework architecture, the features are provided through the UIL, which guides the requirements generation process or allows the designer to access the information contained in the IL (*Step 2[a])* as illustrated in Figure 8.4.

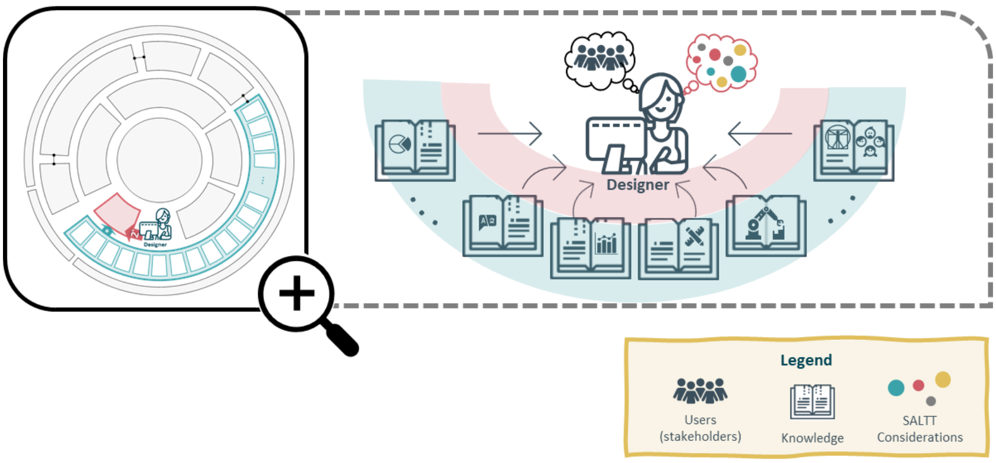


Figure 8.4: Accessing the knowledge contained in the Knowledge Layer

Accessing the knowledge libraries

Although this action is listed as Step 2[a], access to knowledge should not be confined to a particular step of the requirements generation process. Instead, the designer should consult the knowledge libraries anytime. In the study described in Chapter 2, participants disclosed that designers require insight into the product during the task clarification stage, including aspects of manufacturing, market trends, and user attributes. This information should be stored as frames or records (Milton, 2008) such that the system can access, process, or represent it to the user.

8.1.3 Generating requirements based on personas or scenarios

Personas and scenarios consideration

The framework explains how a support tool would aid the designer in identifying user needs. In step 2[b], the designer interacts with UIL to start inputting the end-users needs acquired in Step 1. Similarly, if the user needs are not available or incomplete, the designer can interact with the tool to gain insight into the design problem. Instruments such as personas (Antle, 2008; Monsalve and Maya, 2015; Müller et al., 2010) and scenarios (Sutcliffe, 2003) can automatically generate an initial list of needs based on typical users or a particular use-case. Personas or scenarios are stored in the IL and delivered to the UIL in Stage I.

Personas and scenario-based models

The attributes related to a particular persona can be linked to the requirements represented by the SALT-PM to generate basic end-users needs quickly as shown in Figure 8.5. Therefore, personas must be constructed from correct and well-researched representations of the user. A number of scenarios can be placed in the information layer among the other libraries to support designers in understanding the use context of SALTTs.

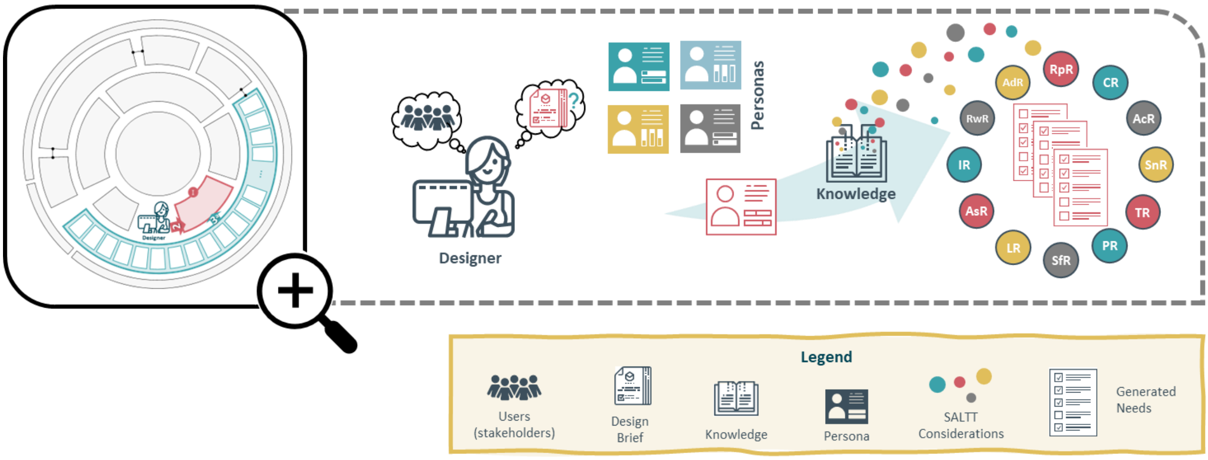


Figure 8.5: Understanding users' needs through personas

8.1.4 Generating detailed requirements

Personas and scenarios are not compulsory

The designer may choose not to be bound or influenced by personas or scenarios. Thus, Stage I can be omitted or used only as a reference. In Stage II, the designer should input or tweak the available requirements or generate new ones based on the libraries residing in the IL, as shown in Figure 8.6.

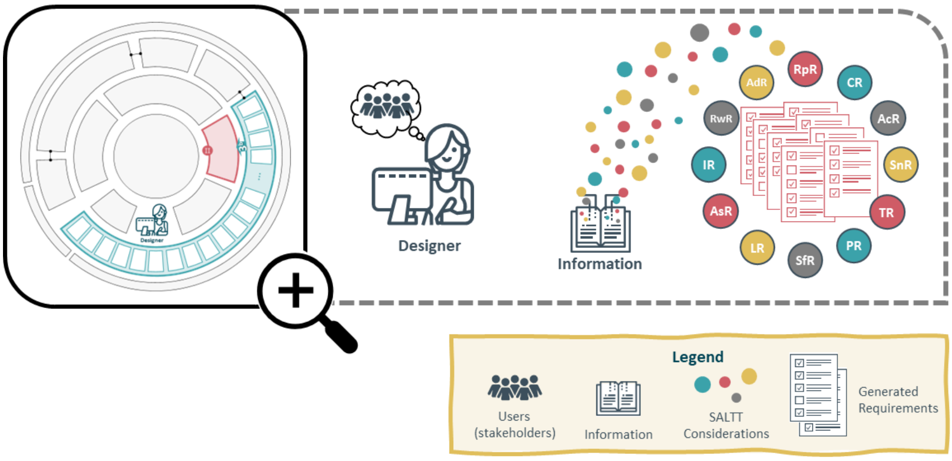


Figure 8.6: Generating user requirements based on information within the computer-based tool

User-needs refinement

This information can be presented to the tool's user interface in the form of predefined checklists that allow the designer to consider the different lifecycle phases of the artefact (Müller et al., 2010). In the case of this dissertation, the use-phase checklist can be represented by the SALT-PM, where its elements and sub-elements characterise the users' needs. Figure 8.6 shows that checklists are part of the libraries residing in the IL of the system (Stage II). Analogous to the previous step, the objective of this stage is to understand the design problem by going through every customer need that the designer must be aware of.

8.1.5 Solution exploration and requirements expansion

Dual purpose of the solution exploration stage

Based on the generated user-needs, designers may inquire about past solutions (existing products) that satisfy similar customer needs to find market gaps, start understanding how the requirements can be synthesised and extend the generated user-needs.

Finding market gaps

Stage III is illustrated in Figure 8.7, where the generated user-needs from Stage II are sent to the Solution Mapper module in the KL (Step 4). This module looks for existing artefacts within a database of past products residing in the IL that match the provided requirements. Suppose the search query matches any solutions in the database (containing all the existing mainstream or adapted toys that can be used in SLT). In that case, they are presented to the user via the UIL (Step 5). As depicted in Figure 8.7, the designer can investigate how certain user-needs have been synthesised into the existing solutions. This serves as a preparation for the next design stage, where designers may get inspired to improve upon existing solutions when developing concepts. On the other hand, if Step 5 returns no results, a market gap will be communicated to the user.

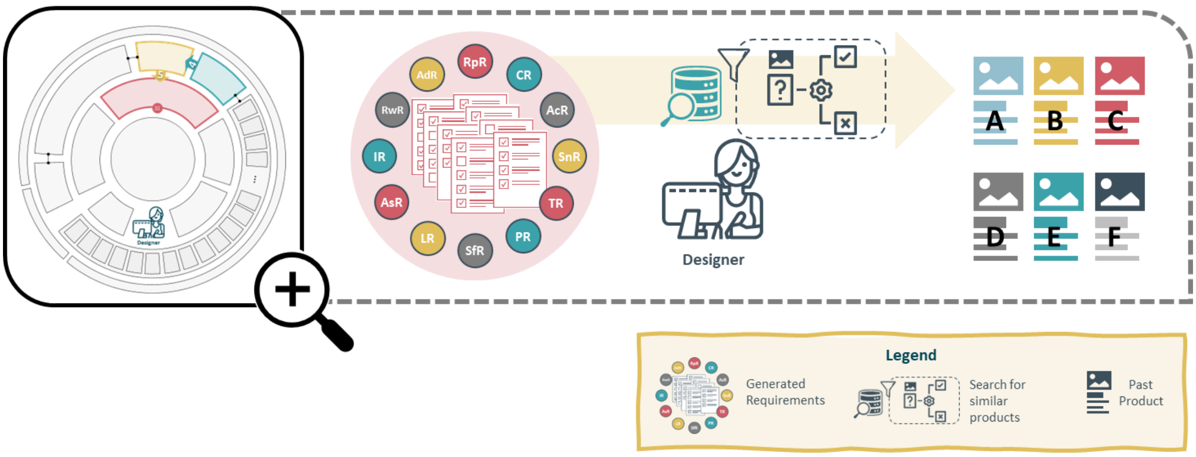


Figure 8.7: Exploring existing solutions that meet the generated requirements

Expanding user-needs

The third purpose builds upon the previous one, where the existing solutions may trigger further user-needs to be added to the generated list of requirements, as shown in Figure 8.8.

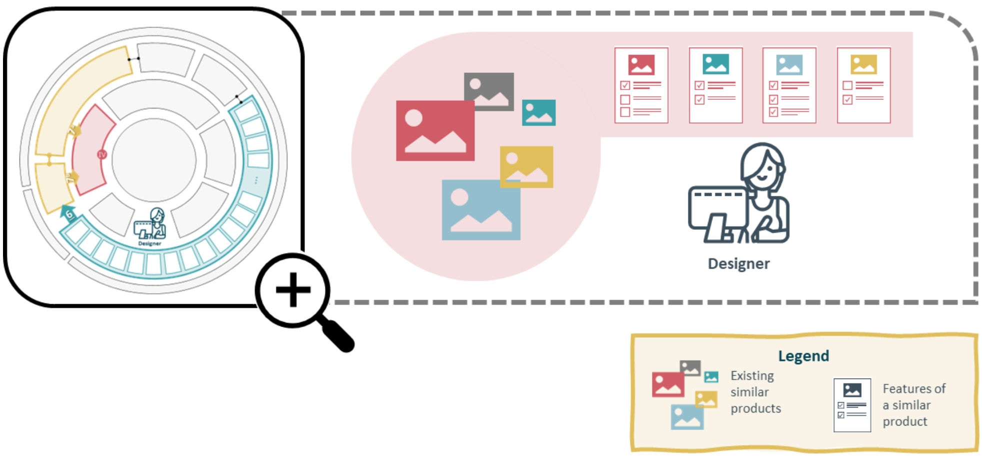


Figure 8.8: Exploring features of existing solutions to expand the user-needs

8.1.6 Mapping requirements to ABRs

Mapping the selected requirements into ABRs

Once the designer is satisfied with the elicited list of user-needs, in Stage IV, the list is taken by the KL, where information from the IL (Step 6) is used to map the selected features into affordance-based requirements (ABRs) (Step 7[a]). The formalism of the ABRs is explained in Section 8.3.

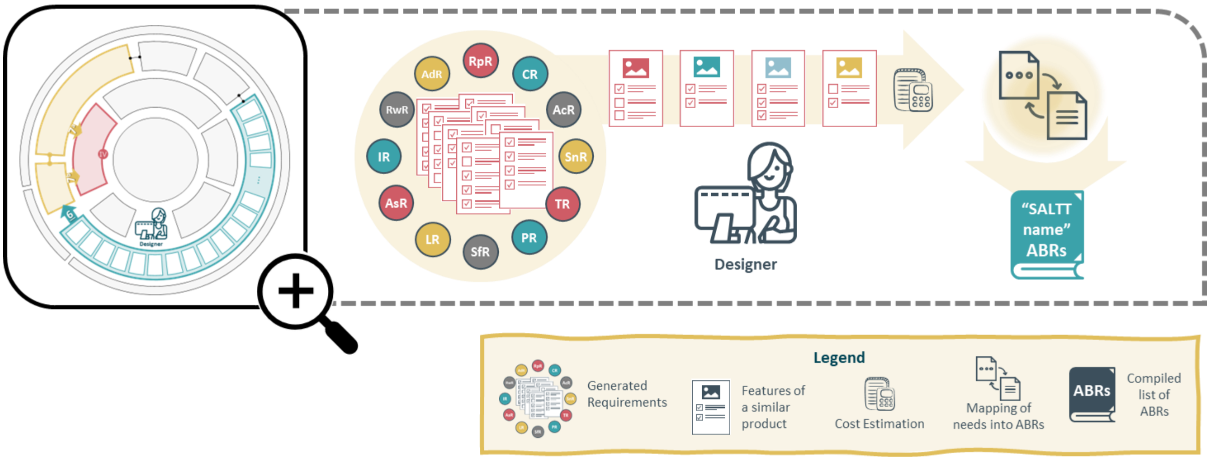


Figure 8.9: ABRs Mapping and cost estimation

Estimating artefact's

Knowledge about the implementation cost of each feature can be made available in step 7[b]. One factor determining the manufacturing cost depends on the implementation, that is, how it was designed and produced. Thus, an estimation or a range of values may be provided to calculate the total artefact's estimated cost. The cost estimator module was FWR10 identified in Chapter 2. Such information at this stage can compromise creativity as expensive design routes may not be sought. This can be beneficial if designers reject unfeasible solutions as early as possible so that design time is invested elsewhere or else act as a motivation to find ways to minimise costs by innovating over existing solutions.

8.1.7 Knowledge maintenance

Manual or automatic knowledge upkeep

Knowledge models and customer preferences may get outdated over time, whereas new products may emerge and need to be added to the database. The Knowledge Acquisition module's role within the KML is to capture changes to the available knowledge (Step 8 in Figure 8.2) and subsequently update the respective modules of the framework architecture in Steps 9a to 9e so that all information and subsequently knowledge remain updated. A representation of these steps is given in Figure 8.10 where updates may be done automatically or by an expert.

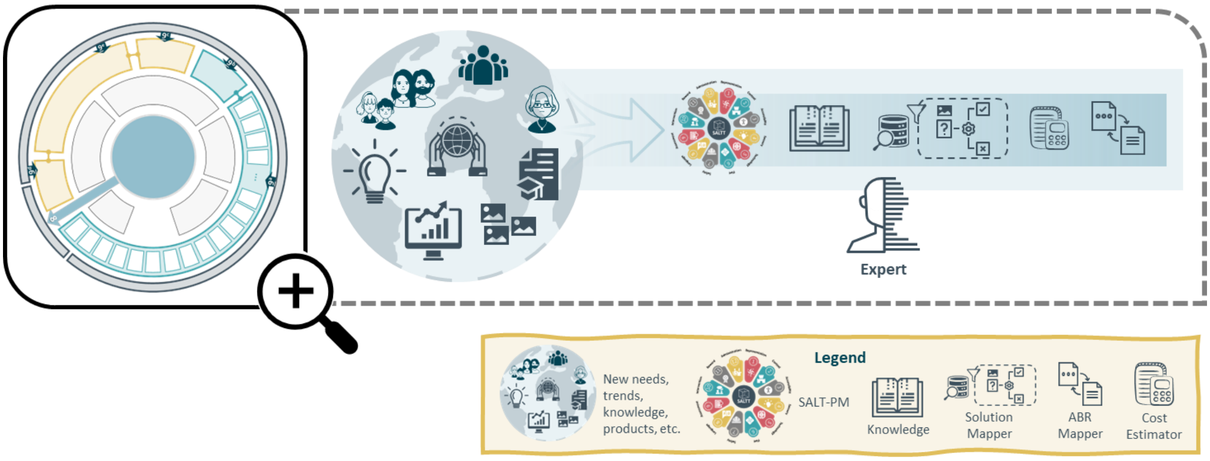


Figure 8.10: Knowledge maintenance in the D-SALTT framework architecture

Revisiting requirements

The double-sided arrows in the UIL (refer to Figure 8.2) between Stages II and III, and Stages III and IV signify that the designer can go back and forth through these steps. A limitation of the current framework architecture depiction (Figure 8.2) is that it does not show how the designer may revisit the generated requirements past the task clarification stage. For instance, the designer may want to change a customer's need in the embodiment stage. In such a case, Stage II would be the first step towards requirements modification. The next sections discuss knowledge modelling of the SALT-PM model and the Requirements to Affordances Mapper module.

8.2 The SALTT Artefact Potential (SAP)

Expressing knowledge in a computer recognised format

To develop a computer model of the framework architecture, the knowledge that will be used must be structured (Gembarski et al., 2016). In other words, design knowledge must be formalised into a format such that computational models can execute design tasks automatically and faster (Wang and Duffy, 2007).

Structuring requirements for SALTT

Because this research is about capturing requirements for SALTT artefacts, the SALT-PM plays an essential role with respect to how knowledge about SALTT requirements should be formalised.

In Chapter 6, the potential benefit of a SALTT artefact was claimed to be dependent on the intrinsic and extrinsic potential. The intrinsic potential is related to those elements (and sub-elements) of the SALT-PM, which determine the artefact's suitability for SLT. On the other hand, the extrinsic potential depends on the artefact's suitability for the end user. Therefore, establishing the correct requirements or widening the requirements will increase the SALTT artefact potential (SAP), as can be seen in equation (8.1) which models this relation in the basic notation of set theory.

(8.1) $$SAP \coloneqq RpE \cup CE \cup AcE \cup SnE \cup TE \cup PE \cup SfE \cup LE \cup AsE \cup IE \cup RwE \cup AdE$$

where,

set $A \cup B$ is referred to as the union of A and B, consisting of the elements of A and the elements of B.

(8.2) • RpE represents the set of requirements within the Representation element, given by $RpE = \{RpER_1, RpER_2, \dots, RpER_n\}$, where $n = |RpE| = 3$.

(8.3) • CE represents the set of requirements within the Context element, given by $CE = \{CER_1, CER_2, \dots, CER_o\}$, where $o = |CE| = 8$.

(8.4) • AcE represents the set of requirements within the Accessibility element, given by $AcE = \{AcER_1, AcER_2, \dots, AcER_p\}$, p = where $|AcE| = 3$.

(8.5) • SnE represents the set of requirements within the Sensory element, given by $SnE = \{SnER_1, SnER_2, \dots, SnER_q\}$, where $q = |SnE| = 5$.

(8.6) • TE represents the set of requirements within the Technology element, given by $TE = \{TER_1, TER_2, \dots, TER_r\}$, where $r = |TE| = 7$.

(8.7) • PE represents the set of requirements within the Play element, given by $PE = \{PER_1, PER_2, \dots, PER_s\}$, where $s = |PE| = 11$.

(8.8) • SfE represents the set of requirements within the Safety element, given by $SfE = \{SfER_1, SfER_2, \dots, SfER_t\}$, where $t = |SfE| = 3$.

(8.9) • LE represents the set of requirements within the Language element, given by $LE = \{LER_1, LER_2, \dots, LER_u\}$, where $u = |LE| = 10$.

(8.10) • AsE represents the set of requirements within the Assessment element, given by $AsE = \{AsER_1, AsER_2, \dots, AsER_v\}$, where $v = |AsE| = 7$.

(8.11) • IE represents the set of requirements within the Intervention element, given by $IE = \{IER_1, IER_2, \dots, IER_w\}, where\ w = |IE| = 37$.

(8.12) • RwE represents the set of requirements within the Reward element, given by $RwE = \{RwER_1, RwER_2, \dots, RwER_x\}$, where $x = |RwE| = 13$.

(8.13) • AdE represents the set of requirements within the Administration element, given by $AdE = \left\{AdER_1, AdER_2, \dots, AdER_y\right\}, where\ y = |AdE| = 16$.

Equation (8.1) reads *as: The SALTT artefact potential (SAP) is defined by the number of factors (or sub-elements) considered from the Representation, Context, Accessibility, Sensory, Technology, Play, Safety, Language, Assessment, Intervention, Reward and Administration elements.*

Cardinality of the elements (sets)

For the current version of the SALT-PM, the cardinality (size) of each element is provided in (8.2) to (8.13). These amount to 123 end-user requirements.

8.3 Formalism for Affordance-based Requirements

Requirements to be solution independent

Cormier and Lewis (2015) noted that design knowledge prior to the concept design stage must remain solution independent. However, domain knowledge aids designers in understanding the purpose(s) of the artefact, who the users are, their corresponding user characteristics, and how the product and in which environment it will be used. As concluded in Part A of this dissertation, designers find it challenging to initiate design with such information missing or unclear. Moreover, requirements identified past the concept design stage will involve changes. In contrast to functions which express the user needs from the designer's perspective, affordances allow designers to understand the same needs from a user's perspective, thus revealing unpredicted usages.

8.3.1 Affordance descriptors

Using affordances to represent requirements

The idea of representing user needs through affordances was presented by Maier and Fadel (2003) as cited in Cormier and Lewis (2015). Affordances have traditionally been expressed in a "verb + ability" format (Galvao and Sato, 2005; Gaver, 1991; Gibson, 1979; McGrenere and Ho, 2000). Hou et al. (2019) represent the affordance descriptive forms as shown in Table 8.1.

Table 8.1: Affordances description forms, adapted from Hou et al. (2019)

Form	Alternative form	Example
Verb + -ability		Grab-ability, press-ability
Verb + noun + -ability	Noun + verb + -ability	Lift handle-ability, hand hold-ability
Transitive verb + noun	Intransitive verb	Play together, play

However, as reported in Hu (2012), representation of the affordances can be complex because it depends on whether one expresses the doing or the happening manifestation (Scarantino, 2003); the operation or the behaviour (Bærentsen and Trettvik, 2002; Gibson, 1979). Further information would generally be required to express what the user requires from the artefact.

In Chapter 2, AUA and AAA were explained in relation to an existing product. Cormier et al. (2014) state that affordances of existing products are solution dependent, whereas the desired affordances for artefacts yet to be realised, need to be solution independent to properly abstract users' needs. They explain that for affordances to be effective problem abstraction means, the affordance-based statement must capture the relational benefit to its users without implying solutions. Their notation of an affordance statement is as follows:

Affordance formalism adopted from Cormier et al. (2014)

The principle artefact affords a [user] [affordance] of [target object or environmental entity] [from additional information (optional)].

Based on the affordance structure matrix (Maier, 2011) discussed in Chapter 2, Cormier et al. (2014) defined a set of 21 orthogonal affordances, referred to as the affordance basis for engineering design. These are listed in Table 8.2.

Table 8.2: List of affordances in the affordance basis as shown in Cormier et al. (2014)

Augmentation	Production	Provisioning	Transformation	Conditioning	Orientation
Shaping	Incorporation	Join	Separation	Capture	Positioning
Storage	Aestheticization	Communication	Organisation	Transportation	Cleaning
Protection	Entertainment	Control			

This list can be used as a checklist to abstract various user needs depending on the lifecycle being considered. Four examples from the affordance basis of Cormier et al. (2014) are provided in Table 8.3.

Table 8.3: Affordance basis for engineering design, from Cormier et al. (2014)

Affordance	Definition	Example
Transformation	Allow an object to change or significantly alter the state of another object or resource.	An oven affords the user to transform raw batter into cooked brownies.
Aestheticization	Make an object pleasing to the senses (relative to the user).	A laptop skin affords users the ability to aestheticize their computer's appearance.
Communication	To make information or data known to an object.	A turn signal on a car affords the user the ability to communicate their intent to turn.
Entertainment	Allow an object the ability to hold the attention of a user pleasantly or agreeably.	A portable media device affords the user entertainment.

Problems with the affordance basis

First of all, as Cormier et al. (2014) pointed out, this is not a comprehensive list of all the possible affordances offered by products. Additionally, these affordances may be too generic and awkward for the designer to understand due to the language used. For instance, play is a form of entertainment. Using entertainment as the desired affordance may create different interpretations as it can refer to various forms of entertainment, including singing, listening, watching, playing, and eating. For this reason, within this research, the intended action is used as an affordance whilst remaining solution independent. The addition of "-ability" to a verb makes affordances easy to understand and flexible in defining features of products. Similarly, Cormier et al. (2014) define aestheticization as attractive to (all) the senses when, aesthetics are only related to the sense of vision. For these reasons, the affordance basis can make affordance-based requirements unclear or difficult to understand.

8.3.2 Defining affordance-based requirements (ABRs) for SALTTs

Further to the research boundary highlighted in Chapter 5, to build upon the work of Maier (2011) and Cormier et al. (2014), the focus is placed on a specific lifecycle phase, that is, the use phase of a specific type of artefact, that is, SALTT, and on specific end users, that is, children, caregivers and clinicians. This will cater to the shortcomings of approaches that consider general artefacts in engineering design that tend to provide generic information and not in-depth domain knowledge.

Mapping requirements to affordances

For the scope of this dissertation, Cormier et al.'s (2014) affordance statement notation is initially used to translate customer needs defined by the SALT-PM. However, this was modified as detailed below. Based on the work of Maier (2011) and Cormier et al. (2014), Table 8.4 lists the definitions assigned to the different types of ABRs.

Table 8.4: Definitions for ABR, AUA-BR, AAA-BR and AUCA-BR

Term	Definition
Affordance-based requirement (ABR)	A required, relational benefit for a user to perform an action provided by the artefact.
Artefact-user affordance-based requirement (AUA-BR)	A required, relational benefit that allows the user to perform an action because of an interaction with the artefact.
Artefact-artefact affordance-based requirement (AAA-BR)	A required, relational benefit that allows the user to perform an action because of two or more artefacts interacting together.
Artefact-use context affordance-based requirement (AUCA-BR)	A required, relational benefit that allows the user to perform an action because of an interaction with the artefact within a particular context.

Note that similar to (Cormier et al., 2014), an AAA-BR is expressed at an artefact level rather than at a sub-system level as in Maier (2011), because requirements are solution independent at the task clarification stage. This implies that the required artefact may be supported, dependent, or part of the environment of other artefacts for an affordance to exist or be beneficial to the user. Moreover, through the SALT-PM, it was noted that the context or environment per se may pose particular challenges for the artefact to be used. Figure 8.11 depicts the dispositions of affordances with respect to the goal. For example, a radio may afford users the ability to listen to music in a quiet room but not when there is loud background noise.

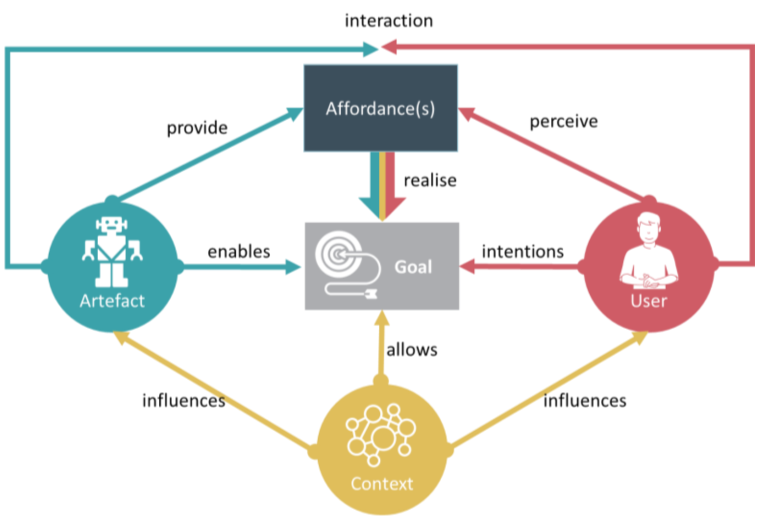


Figure 8.11: Dispositions of affordances

Artefact-User-Context Affordance (AUCA)

Consequently, a new type of affordance that considers the artefact and use context, AUCA, is proposed. In reality, all affordances should be proposed in terms of their context. However, the context becomes relevant in the disposition of an affordance when an AUA is affected by the context. Whether AAAs also depend on the context has not been investigated and is still an open research question.

Positive phrasing for ABRs

A desired affordance is expressed "*from a positive vantage point*" (Cormier et al., 2014) even though an affordance can have a positive or a negative consequence (Maier, 2011). This means that ABRs should detail the benefit they will provide to the users. Moreover, ABRs must be expressed using the requirements guidelines mentioned in Chapter 2. Twelve lists of ABR statements mapped from the SALT-PM are disclosed in Appendix B. Table 8.5 lists six examples of ABR statements to discuss the actual formalism used. For ABRs #2 and #7, an extra example has been added to demonstrate how alternative wording can change the format of ABRs.

Table 8.5: Examples of affordance-based requirement statements

ABR # + Type	Principle Artefact	User (s)	User characteristic	Affordance	Affordance modifier	Target object/entity	Other information
#1 *AUA-BR*	The product affords	clinicians, caregivers, and children		the ability to use/play		with a physical product.	
#2 *AUA-BR*	The product affords	children		the ability to play		with the product	having a fantasy representation.
				or			
	The product affords	children		the ability to play		with a fantasy-oriented toy product.	
#3 *AUA-BR*	The product affords	children	with mild hearing impairment	accessibility		to the product	
#4 *AUCA-BR*	The product affords	clinicians, caregivers, and children		improved hearing capabilities		of the product	in noisy environments.
#5 *AAA-BR*	The product affords the	clinicians, caregivers, and children		the ability to position		the product	on a tabletop or any other flat surface.
#6 *AUA-BR*	The product affords	children	aged less than 36 months	the ability to use/play	safely	with the product.	
#7 *AUA-BR*	The product affords the	clinicians		the ability to have		assessment(s) (in a particular language).	
				or			
	The product affords	children		the ability to be assessed		(in a particular language)	

Formalism of ABR statements

As can be seen from Table 8.5, Cormier et al.'s (2014) formalism for affordance statements was strengthened to indicate user characteristics and provide a better understanding of the required affordances. The following statement describes the formalism used:

The principle artefact affords a [user(s)] ***[with user characteristic (optional)]*** the [affordance] ***[+ adjunct (optional)]*** of [target object or environmental entity] [+ additional information (optional)].

ABRs #3 and #6 are examples of how the improved affordance notation can be used. The addition of [user characteristic] between the [user] and the [affordance] provides a further portrayal of who the user will be, highlighting special considerations that designer needs to be aware of. Similarly, supplementing the statement with an [affordance modifier] (as an adjunct) between the [affordance] and the [target entity] provides further relational information on the affordance with respect to the user. In the case of ABR #6, the affordance modifier specifies the need to have a safe play.

Types of affordances

A variety of ABR examples have been included in Table 8.5, mostly AUA-BRs (#1, #2, #3, #6 and #7). The reason why most ABRs are of the type artefact-user, is attributed to the fact that at the task clarification stage, requirements are normally based on the users' needs. ABR #4 is an artefact-use context affordance-based requirement (AUCA-BR) which describes how the artefact's required affordance will be affected by the environment in actual use. On the other hand, ABR #5 defines an artefact-artefact affordance-based requirement (AAA-BR) which states how the SALTT artefact will interact with another artefact.

Extension to the complementarity characteristic of affordances

In Chapter 2, the five characteristics of affordances (Maier, 2011) were described. Maier discusses one implication of the complementarity characteristic by which products afford different behaviours to different users. He argues that a door affords grownups the ability to pull the handle, but not to children who cannot reach the handle. In this example, both adults and children are meant to do the pull action. However, in this work it was found that some affordances can be expressed in terms of either the user who intends to perform the action or the user who intends to receive the action. Scarantino (2003) explains a similar situation with two classes of affordances, depending on whether the action is a doing (goal-triggered) manifestation, such as the ability to throw, or happening (result-triggered) manifestation, like the ability to be driven. In the case of SALTTs, when two different user groups use the same artefact, the doing affordance might be different, as shown in ABR #7 of Table 8.5. This is analogous to a ball which affords a human being the ability to throw and to catch it. In such events, it is best to express the ABR in both formats to ensure that the needs associated with each end user are communicated well to the designer.

Challenges in formalising ABRs

Because the formalism of ABRs is based on the natural language, as shown by ABR #2, the optional information can sometimes be omitted if the ABR statement is rephrased in such a way that it remains conforming with the rules of the statement structures. In the second example of ABR #2, the [target object] part of the alternative statement is more informative than the first one.

The same ABR can apply to different user groups

ABRs #1, #4 and #5 are examples of ABR statements that concern all users in the same way. Although this may appear to cause redundancy, Cormier et al. (2014) claim that extra ABRs allow the designer to be aware of multiple users who will require to do the same interaction with the artefact.

Degree of details in ABRs

The Language element of the SALT-PM details possible ways of implementing the language comprehension and expression requirements. The purpose of using affordances rather than functions at the task clarification stage is to keep the solution for the end-users needs independent and abstract as much as possible. However, end-users needs may detail design specifications like the weight or materials required. Such information helps designers understand what the customer truly wants. In an ABR statement, a design specification may be optionally added in the last segment of the formalism used.

8.4 Chapter Conclusions

The link between the D-SALTT framework architecture and SALT-PM

This chapter has provided a step-by-step explanation of how the *D-SALTT* framework architecture would help designers generate an extended list of ABRs for SALTTs if it had to be implemented as a computer-based support tool. Nonetheless, since the SALT-PM is a separate prescriptive knowledge model that structures which and how SALTT requirements should be considered, the *D-SALTT* framework architecture can be applied to other domains. The *D-SALTT* framework was based upon the workflow of the task clarification stage to support the early design tasks whilst leveraging the concept of affordances to bring designers closer to the end user.

The potential of SALTT elements

Further information was provided on the potential aspect of a SALTT. It was shown that not all elements contribute the same potential level, and the potential level is independent of the number of sub-elements associated with an element.

Formalism of affordances

Finally, an improved formalism approach has been proposed to define ABRs with respect to the users, taking care that the defined requirements match the abilities of the target users and the use context. A list of ABRs based on the SALT-PM was generated, which will be used by the Knowledge Layer of the prototype solution implementation as discussed in the next chapter.

9. *D-SALTT* PROTOTYPE TOOL IMPLEMENTATION

We shape our tools and thereafter our tools shape us.

Marshall McLuhan, Understanding Media: The Extensions of Man, 1964

*This chapter discloses how the D-SALTT framework architecture and SALT-PM were implemented in an **A**ffordan**c**e-based Re**qu**irements Gener**a**t**i**o**n** **T**ool for **S**peech **a**nd **L**anguage **T**herapeutic **T**oys (ACQUAINT-SALTT). In Section 9.1, the tool requirements to support the task clarification stage are disclosed. An overview of the level of implementation of ACQUAINT-SALTT is explained in Section 9.2. Section 9.3 presents the implementation of ACQUAINT-SALTT and representations of the computer model using UML diagrams. Key conclusions are made in Section 9.4.*

9.1 Tool Requirements

Objective of ACQUAINT-SALTT

The primary purpose of *ACQUAINT-SALTT* in this research is to have a means by which the *D-SALTT* framework can be evaluated. As the name of this prototype tool implies, the tool was implemented to make designers acquainted with the different aspects of SALTTs. Figure 9.1 compares the actual functionality of the prototype tool with the intended functionality of the total intended support, as discussed in Blessing and Chakrabarti (2009).

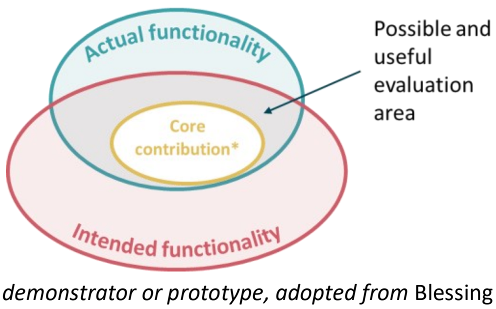


Figure 9.1: The functionality of a demonstrator or prototype, adopted from Blessing and Chakrabarti (2009)

ACQUAINT-SALTT captures this doctoral research's core contribution and includes the necessary features to allow the *D-SALTT* framework architecture to be evaluated in a descriptive study of the envisaged reality.

Overall requirements

Based on the User Interface Layer (UIL) stages highlighted in Chapter 8, the following initial requirements for the tool have been established:

- Ability to capture end-users and stakeholder requirements
- Ability to input the requirements in the tool
- Ability to use checklists, personas or scenarios
- Ability to refine requirements based on the ontology of SALTT products
- Ability to access knowledge bases related to market, end users, SLT and product development
- Ability to describe customer needs in terms of affordance-based requirements (ABRs)
- Ability to find matching existing products used in SALT
- Ability to expand requirements from matching products
- Ability to generate a list of requirements
- Ability to manage (maintain) knowledge

9.1.1 Implementing *ACQUAINT-SALTT* as a KBS

Justification for implementing the prototype tool as a Knowledge-Based System

Milton (2010) discusses a number of computer-based tools referred to as knowledge technologies through which knowledge can be collected, organised and represented effectively. These include knowledge-based systems (KBS), knowledge-based engineering (KBE) systems, ontologies, case-based reasoning (CBR), data-mining, document management systems and natural language processing. Since the design problem deals with the early design phase and the fact that the designers need to be supported with various kinds of knowledge, it was decided to implement *ACQUAINT-SALTT* as a KBS sharing aspects of the other knowledge technologies. This is because KBSs allow knowledge to be organised, but the mode of use (handling of knowledge) and the structure of how knowledge is organised determine the actual approach (Milton, 2008).

Figure 9.2 shows the basic components that make up the architecture of a KBS. Based on these components, the initial tool requirements (TR) were further formulated as explained below.

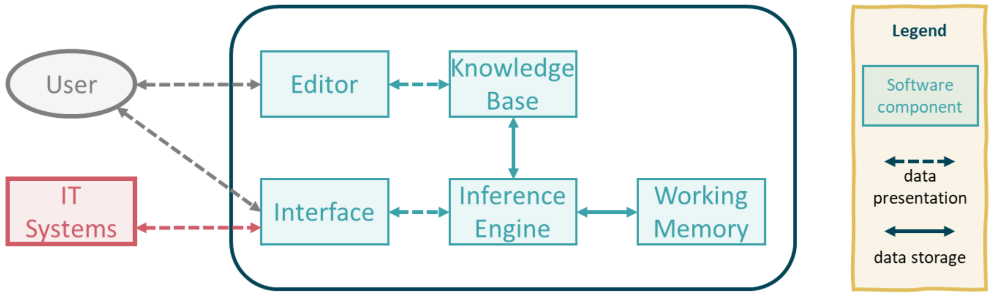


Figure 9.2: Basic architecture of a Knowledge Based System, adopted from Milton (2008)

Knowledge Bases (KBs)

The tool should be composed of several knowledge bases (or special databases) that contain information, rules and structures. Milton (2010) explains how ontologies are the foundations of KBSs because they define what knowledge to be recorded and how it should be represented.

TR 1: The *ACQUAINT-SALTT* KBS is to be based on the SALT-PM ontology such that the requirements generated are structured with respect to each major element.

Furthermore, the framework shows various knowledge bases (KBs) within the Information Layer (IL) which can be accessed by the system and designer at any stage of the design process. These KBs should include both technical and non-technical knowledge such as market trends and users' preferences which will assist the designer to refine the requirements.

TR 2: KBs can be referenced by the designer anytime during the design process.

Based on the Solution Exploration module of the framework (explained in Figure 8.7 and Figure 8.8), the following databases are also required:

TR 3: A library of existing products which can be used in speech and language therapy, defined according to the SALT-PM ontology.

TR 4: A list of features for existing products which can be expressed as ABRs.

TR 5: Because products may be developed for different clients, a database management system (DMS) for clients will ease project handling.

Note that existing or past products are products which possess affordances reflected in the SALT-PM ontology.

User Interface

As mentioned in Chapter 8, through the *D-SALTT* framework, once the design brief is received, the designer interacts with the graphical user interface (GUI) of the computer tool. A GUI which is a type of user interface that contains graphical icons, is also known as the front-end of tool, and is necessary to allow the user to execute the functions provided by the tool, specifically to:

TR 6: Start new or edit existing projects.

TR 7: Specify or change the details of the project, such as name, volumes, client, and target dates.

TR 8: Select personas so that customer needs are easily captured.

TR 9: Generate new needs based on the SALT-PM ontology.

TR 10: Modify the customer needs.

TR 11: See potential artefacts that satisfy the provided requirements in a solution exploration space.

TR 12: See the attributes (ABRs) of these matching artefacts.

TR 13: Refine requirements based on matching artefacts.

TR 14: Visualise how requirements influence the product cost.

TR 15: View the generated requirements.

TR 16: Save the requirements.

TR 17: Consult with the relevant knowledge libraries.

TR 18: Inform the designer about various elements on the GUI, especially if they are related to the SALT-PM.

Inference Engine

The inference engine, or the back end of the support tool, represents the Knowledge Layer (KL) in the *D-SALTT* Framework. It handles the available knowledge such that user needs are mapped into affordance-based requirements and find matching solutions to aid the designer in understanding the users' needs better, refining requirements or identifying market gaps. Another module within the inference engine should be the cost estimator module, which would estimate how a requirement would influence the production cost/selling price of the artefact.

TR 19: Coupled to TR 1, customer needs are to be mapped into a list of ABRs.

TR 20: Existing toys are to be retrieved based on the desired SALTT characteristics.

TR 21: An estimate of the cost involved in implementing the customer needs is presented to the user before finishing the requirement generation process.

Working memory

As part of the KL, the working memory should be able to record the information being inputted by the designer during a session such that when the designer goes back to a previous section of the GUI, information is not lost. The inference engine uses the information in the working memory to compare it or use it to make computations with respect to the knowledge within the KBs. Intermediate results are also stored within the working memory, which is then refreshed once a new project session is started.

TR 22: Requirements being inputted and choices done by the designer are kept until the designer finishes the project session.

TR 23: Stored requirements of past projects session can be loaded into the working memory so that the designer can review them.

Editor

As reflected by the Knowledge Management Layer (KML) within the *D-SALTT* framework, the tool should allow an expert to update the knowledge bases and the models located in the backend through a separate user interface referred to as the editor. Ideally, even parts of the inference engine should be allowed to be updated in cases algorithms become outdated, as described in Chapter 8.

TR 24: Each module within the Information Modelling Layer and KBs within the Knowledge Layer can be updated through a secondary GUI.

9.2 Tool Implementation Boundary

Due to the timeframe and scope of this research, only the requirements that were deemed necessary to support the evaluation of the *D-SALTT* framework architecture were implemented within *ACQUAINT-SALTT*. The level of implementation of each TR is shown in Table 9.1.

Table 9.1 Summary of the level of implementation of requirements in ACQUAINT-SALTT

TR	***ACQUAINT-SALTT* Requirements**	**Level of Implementation**
1	Structured upon SALT-PM elements	✓✓✓
2	Provide knowledge libraries related to product development and market	✓
3	Provide a library of existing products used in SALT	✓✓✓
4	Provide a library of ABRs for each existing SALTT product	✓✓✓
5	Implement a database for clients	✓
	Provide a GUI that allows designers to:	
6	Start new or edit existing projects	✓✓
7	Specify or edit project details	✓✓
8	Automate requirements generation through personas	✓
9	Define customer needs (based on SALT-PM)	✓✓✓
10	Edit customer needs	✓✓✓
11	Explore potential solutions that match requirements	✓✓✓
12	Display ABRs of potential solutions	✓✓✓
13	Refine requirements	✓✓✓
14	Understand how requirements influence product cost	✗
15	See the compiled requirements while being generated	✓✓✓
16	Save the requirements	✓✓✓
17	Access knowledge libraries	✓✓
18	Read tooltips for each SALTT and GUI control elements	✓✓✓
19	Map requirements into ABRs	✓✓✓
20	Search for potential existing solutions	✓✓✓
21	Calculate the cost to implement requirements	✗
22	Store requirements of a project that is work in progress	✓✓✓
23	Load requirements of a past project	✓
24	Secondary UI for Knowledge Management	✗

Legend: ✓✓✓ - Fully supported, ✓✓ - Partially supported, ✓ - Incomplete support, ✗ - Not implemented

No support for requirement cost estimation

TR14 and TR21 are heavily dependent on how the required solution is synthesised, that is, on decisions taken post requirements elicitation. Because cost models for the various SALT-PM sub-elements are not yet available, this requirement was not implemented.

Precompiled list of ABRs for existing products used in SLT in the database

A list of 64 assessment and intervention tools (such as flashcards, toys and apps) that are used during speech and language therapy with children were compiled based on discussions with SLPs, book (Jackie Cooke and Williams, 1985) suggestions and SLT online resources[15,16,17,18]. Each product was described as per the SALT-PM ontology that amounted to 123 variables. A further 11 variables were included to define a unique ID, name, image, manufacturer, dimensions (LxWxH), weight, price, release year and a hyperlink to a web page. These variables enabled product search within the Solution Mapper module.

Marketed affordances

Furthermore, each product was accompanied by a list of pertaining affordances as per TR4. Rather than extracting subjective affordances from artefacts as discussed in Cormier et al. (2014), in this research, the approach of (Heljakka and Ihamäki, 2019a) was adapted. Toy products' marketed play affordances were extracted from their marketed description obtained from a common source, *Amazon.com*. The affordances were manually extracted from the marketed description by relating the affordance to the intended end user(s). Then they were formalised into ABR statements as explained in Section 8.3.2. The marketed descriptions included design specifications such as the number of cards or battery duration. Such figures were included in the affordance statement. This means that some of the extracted ABRs, in reality, are affordance-based

[15] https://www.melissaanddoug.com/shop-by/skill/speech-and-language-skills-1/
[16] https://speakplaylove.com/13-sorting-activities-for-language-development/
[17] https://www.amazon.com/shop/speedyspeech?listId=F536F2Q35H7E
[18] https://noisyclassroom.com/games/board-games-to-encourage-speaking-and-listening-and-communication/

specifications. Appendix C lists 15 toy products and their marketed ABRs as an example.

Provision of knowledge libraries

The basic infrastructure to view the knowledge repositories within the tool has been implemented and an example of a knowledge library is provided in the form of a document that resembles how the information would look within the tool. This will allow the evaluators of *ACQUAINT-SALTT* appreciate the benefits that such a feature in the tool would provide.

Updating knowledge

A secondary UI for updating the backend has not been implemented. However, the system and the databases rely on object-oriented principles, meaning that new updates could easily replace existing blocks of code. Similarly, the data residing within the database, such as the existing products, their affordances and clients can be updated by replacing the whole database.

9.3 Implementation Software

The UI of the tool was first prototyped using Adobe XD, a vector-based UX design tool for software applications. The layout and functions of the buttons were simulated pictorially to establish a storyboard of the implemented solution. An example is provided in Figure 9.3.

Computer Models

Unified Modelling Language (UML) was chosen as the modelling language to represent the computer model of *ACQUAINT-SALTT*. Computer models facilitate software development because they divide the software program into small parts or building blocks, allowing developers to understand the inputs, outputs and how information needs to flow. Because UML is a general-purpose modelling language, one would need different diagrams to represent the prototype system (Schmuller, 2001). Before the actual implementation, a use-case diagram and an activity diagram were constructed as explained next.

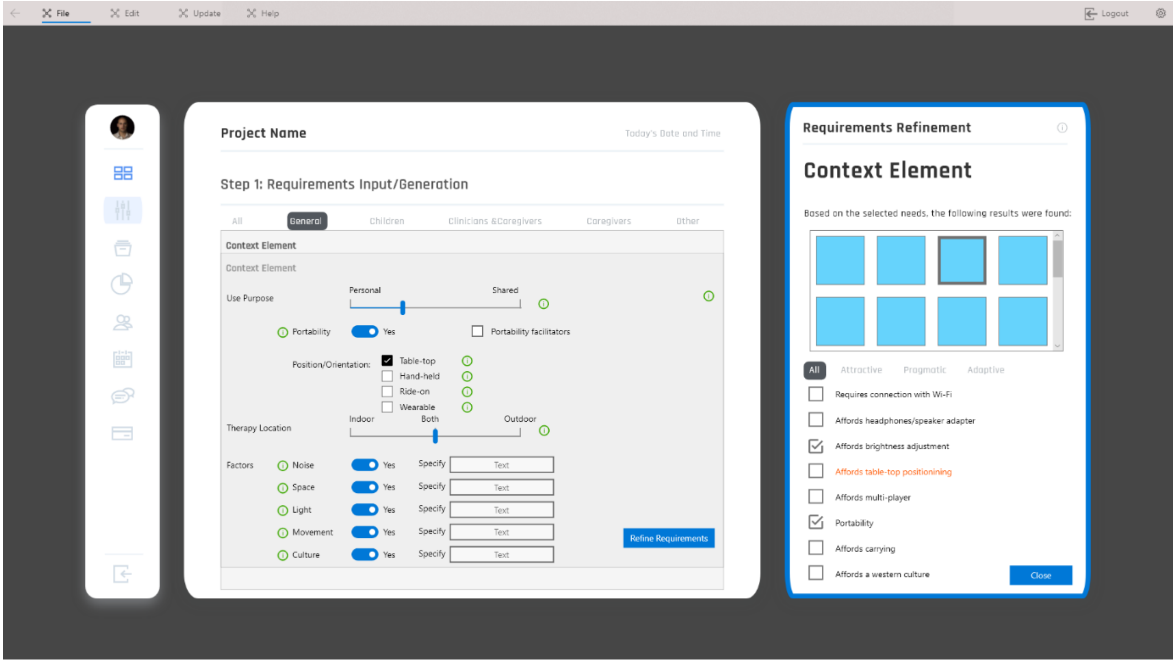


Figure 9.3 Prototype user Interface for the Context element

Use-case diagram

The use-case diagram in *Figure 9.4* focuses on the user of *ACQUAINT-SALTT*, that is, the designer, and on the envisaged reality by modelling how design activities will be conducted when using ACQUAINT-SALTT. In a use-case diagram, the user is referred to as the *actor*. A *use-case* represents a functionality with which the designer will interact. *Include relationships* enable the reuse of a use-case into the 'calling' use-case, whilst *extend relationships* allow the creation of a new use-case by widening the behaviour of the base use-case.

Activity diagram

The activity diagram in Figure 9.5 models the allowable actions in *ACQUAINT-SALTT* according to the implemented functions. It also provides information on what is required at a particular instance to generate the list of ABRs. Thus, activity diagrams help the developer envision the designer's interactions with the prototype tool.

As depicted in Figure 9.5 when the designer reaches the main UI of ACQUAINT-SALTT, he/she is presented with a few possible actions, namely, to access the knowledge libraries, start a new project or open an existing one. Different knowledge libraries can be accessed through the knowledge bases.

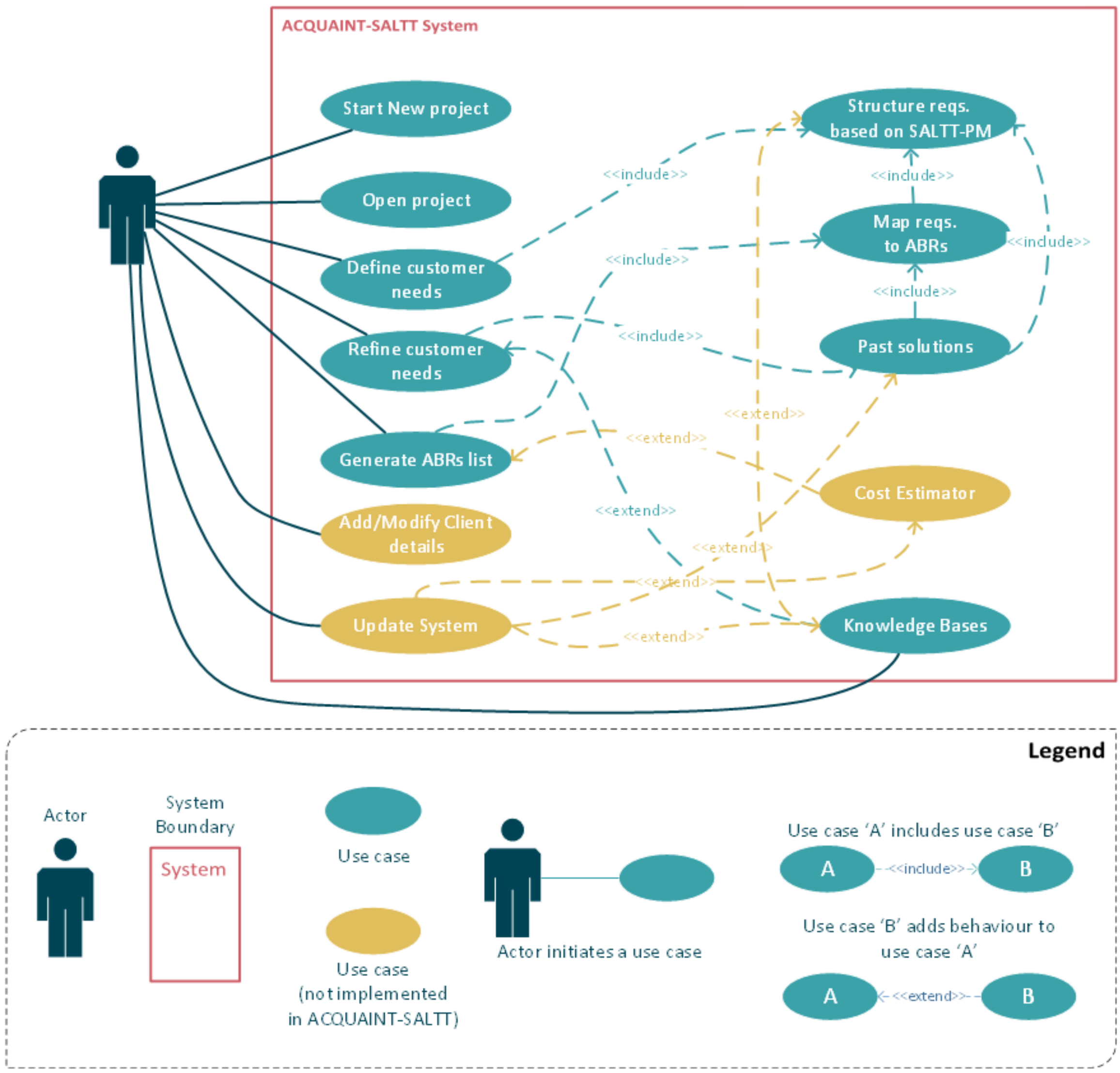


Figure 9.4: ACQUAINT-SALTT Use-case Diagram

Starting a new project requires the designer to enter the project details, select a persona, input or generate the initial requirements for each SALT-PM element, refine the requirements by searching for and exploring potential solutions, and finally save the generated list of ABRs. These activities are shared by the open project activity. Decision points represent the choices that the designer needs to make when using the tool. For instance, since the SALT-PM contains 12 elements, if the designer wants to input the customer needs for each element, the requirements can be refined by exploring the existing solutions each time.

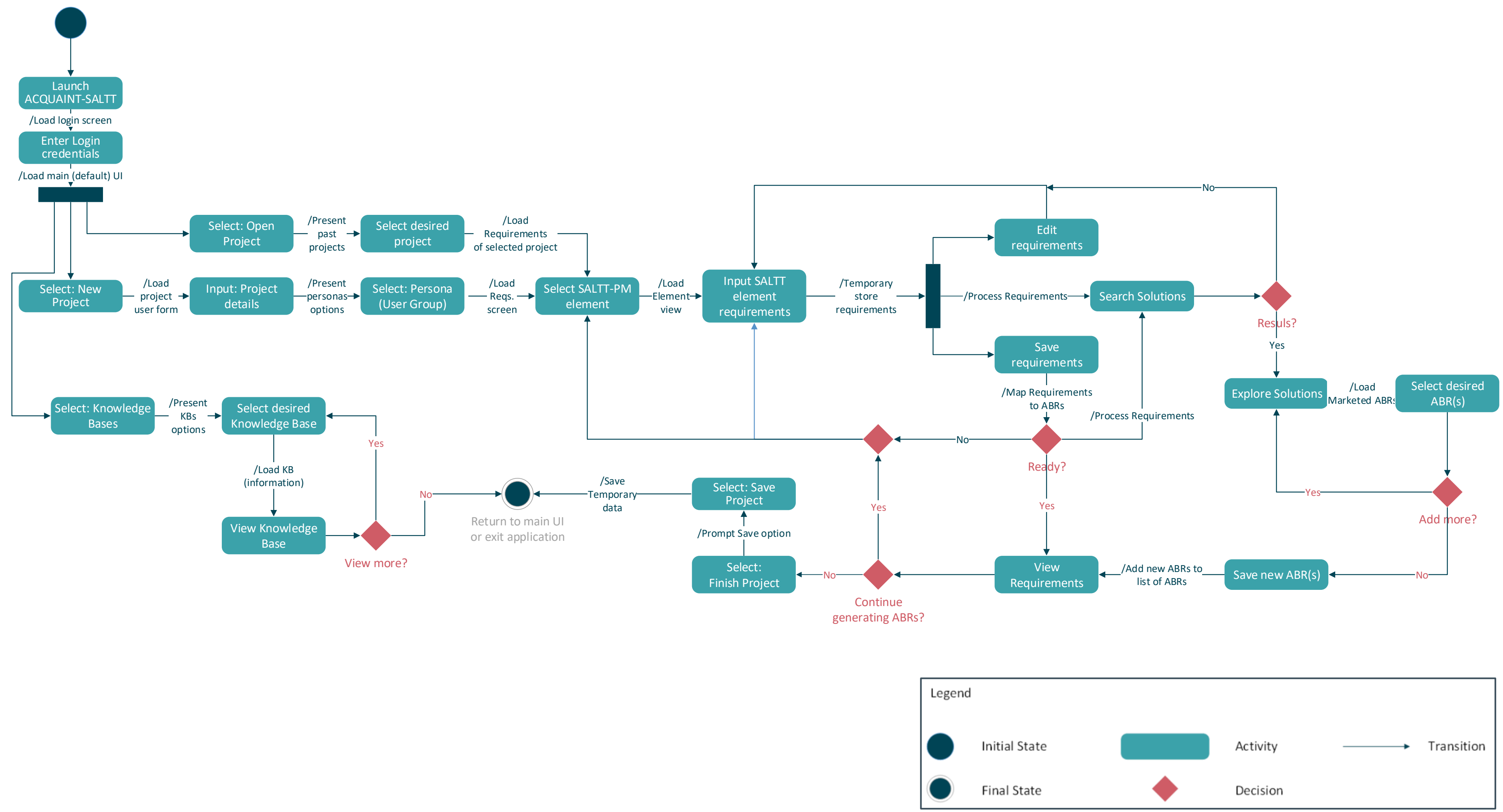


Figure 9.5: ACQUAINT-SALTT Activity Diagram

ACQUAINT-SALTT was then developed as a standalone application using Qt, a cross-platform software development kit that uses Qt Modelling Language (QML), a declarative UI markup language for designing UIs, and C++ and Python programming languages for the backend. The tool connects to an SQLite database from where information about the existing toys is extracted. The reason why it was decided to develop the tool from scratch using the Qt development kit rather than CLIPS, PCPACK or PROTÉGÉ as suggested in Milton (2008), is mainly because nowadays, designers are no longer bound to desktop PC to carry out design activities. Being a cross-platform software development tool allows any application to be deployed to any operating system, including mobile devices. Furthermore, such tools allow for modern graphical control elements (GCE) elements such as range sliders, providing richer user interface user experience.

Knowledge representation

The SALT-PM lightweight ontology serves as the backbone for the knowledge representation approach adopted within the implementation, namely, an object-oriented or frame-based approach, where each artefact is described by the 123 sub-elements discussed in Section 6.2. This allows for procedural rules to be applied as part of the knowledge-based system and hence for new design projects to be created and for existing products within the database to be queried.

The next sections describe how each layer of the *D-SALTT* framework was implemented in the *ACQUAINT-SALTT* prototype tool by presenting a walkthrough of the User Interface layer.

9.3.1 Implementation of the User Interface Layer

Launching ACQUAINT-SALTT

Once the prototype tool is launched, the designer is presented with a welcome screen in the main screen area with possible actions that can be done, as shown in Figure 9.6. The *Main Menu* is located to the top left corner. For this prototype version, only *New Project* and *Knowledge Bases* buttons are functional. The side screen area on the right-hand side is blank by default.

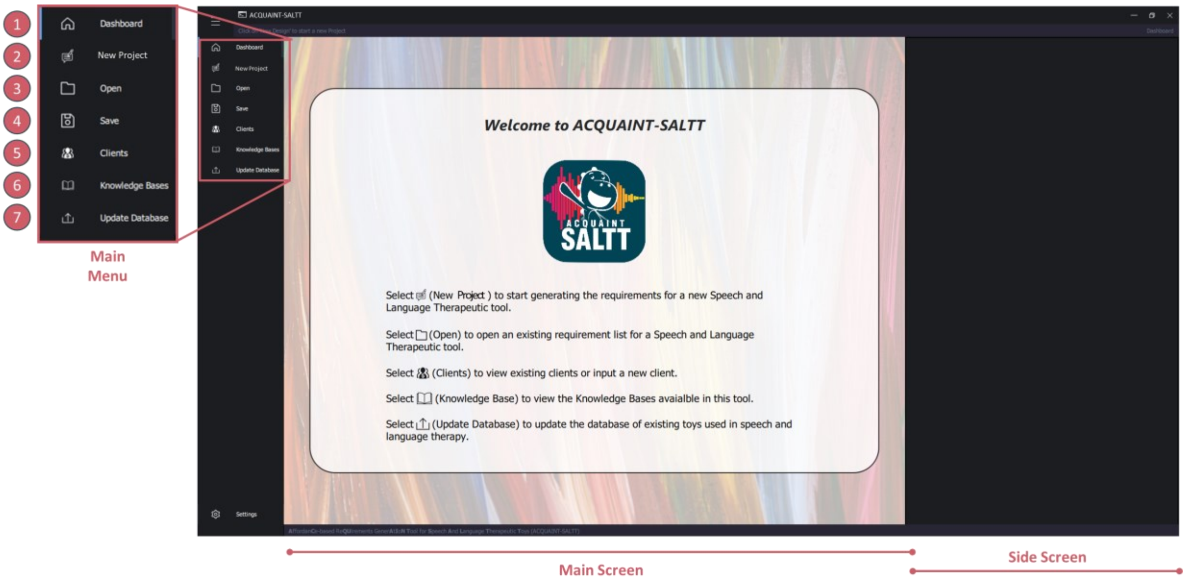


Figure 9.6: Welcome screen of ACQUAINT-SALTT

Accessing knowledge libraries

As per Step 2[a] of the *D-SALTT* framework (Figure 8.2), the designer can access the domain knowledge at any point in time. Figure 9.7 shows how relevant knowledge can be made available to the designers. In this case, the results of Balzan et al. (2019) are shown in the first tab. Other libraries can be included in separate tabs. As explained in Section 9.2, this knowledge is not connected to a knowledge base in the current prototype implementation.

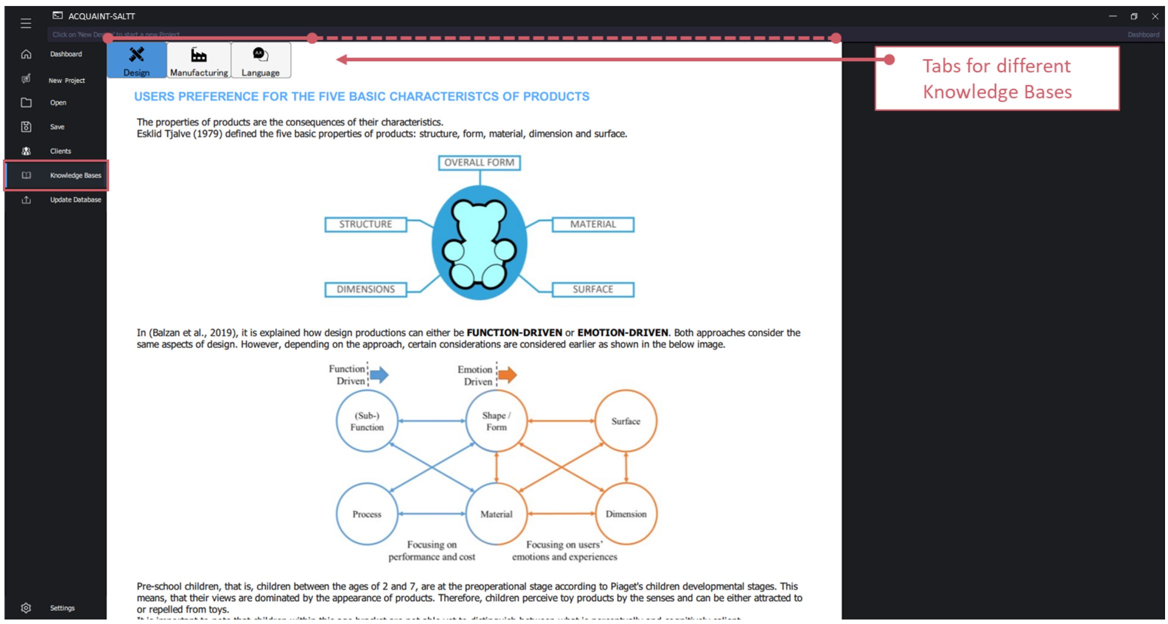


Figure 9.7: Example of a Knowledge Base (Step 2ª)

Starting a new project to generate a list of ABRs for SALTT

If one decides to start a new project (Step 2[b] in *D-SALTT*), that is, to generate the list of ABRs for a SALTT, after selecting the "New Project" button on the main menu, the designer is presented with the new project user form, as shown in Figure 9.8. This user form allows the designer to input basic product details such as the project name, client name, available budget, and the deadline.

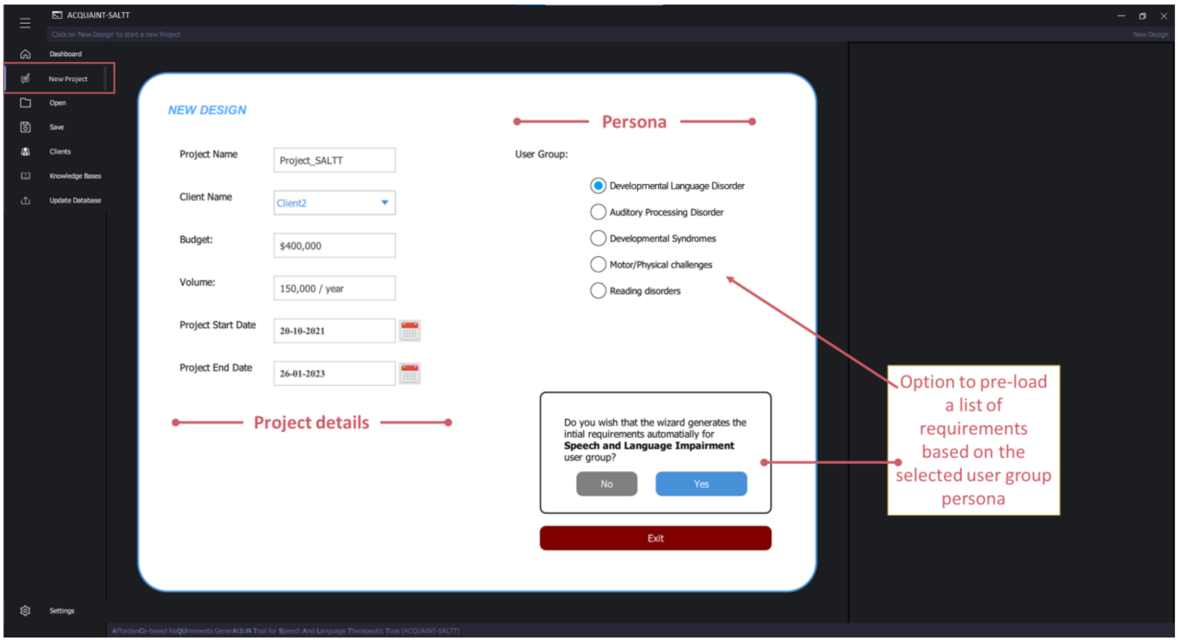


Figure 9.8: Starting a New Project in ACQUAINT-SALTT (Stage I)

Persona Consideration

As in Stage I of the *D-SALTT* framework architecture, the user form also allows the designer to specify a user group for whom the artefact (SALTT) will be intended. For *ACQUAINT-SALTT*, five personas of user groups that may receive SLT were considered, as shown on the right-hand side of the main screen. Apart from the DLD persona, where children have no other health condition that influences their needs, the other personas are related to a primary health condition which contribute to speech and language difficulties, as mentioned in González-Fernández and Hillis (2013) . These are Auditory Processing Disorder, Developmental Syndromes, such as down syndrome or autism, Motor/Physical challenges, such as cerebral palsy, and reading disorders, for example, dyslexia.

Because the actual intervention needs depend on the needs of the children, the main differences between these personas are in the Accessibility element.

If a user group (persona) is selected, the system prompts the designer whether it is desired to preload the requirements for the selected persona. In either case, the designer would still be allowed to alter the desired requirements. Figure 9.9 shows the main GUI of *ACQUAINT-SALTT*, which is presented to the designer to start generating/modifying the requirements. This reflects Stage II of the framework architecture.

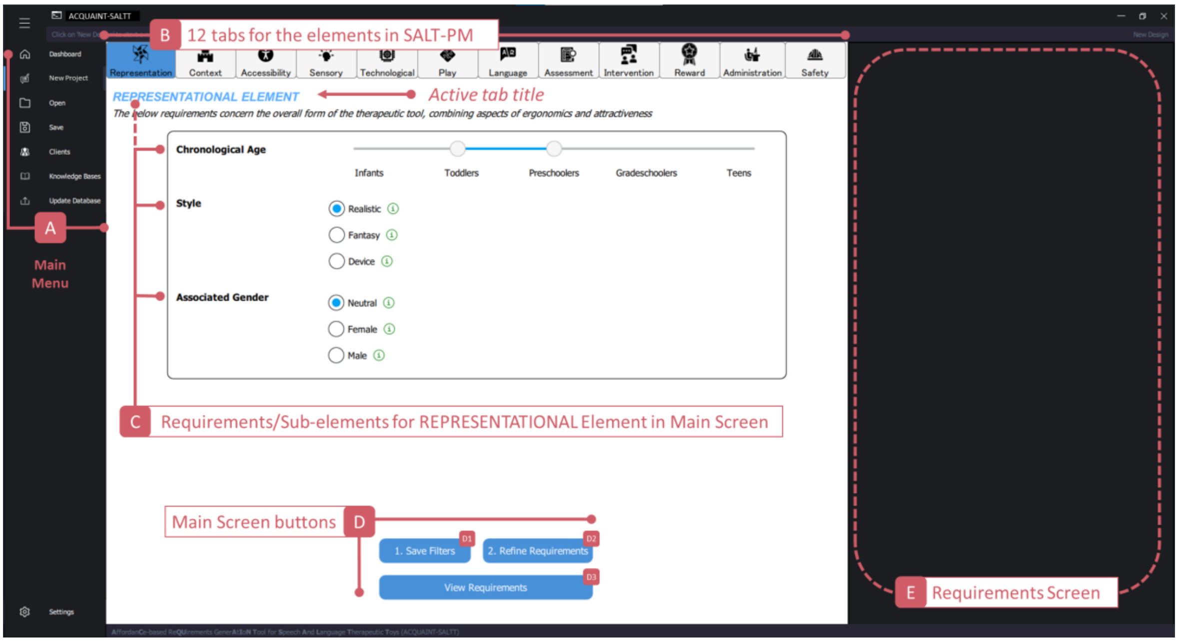


Figure 9.9: Requirements generation (Stage II) for the Representation element

12 tabs based on the SALT-PM ontology

In Figure 9.9, areas on the GUI have been marked by letters. Area ***A*** denotes the main menu whereas area ***B*** shows the 12 tabs representing the elements of the SALT-PM ontology. In this screenshot, area ***C*** shows the Representation element The title of the element indicates the active tab just below area ***B,*** and the design considerations are listed within the rounded corners box - in this case, the sub-elements of the Representation element. Requirements can be specified by interacting with the GCEs, such as radio boxes, checkboxes, sliders, range sliders and switch buttons.

Mapping requirements into affordance-based requirements (ABRs)

Once the desired requirements have been indicated, the designer can interact with three buttons in area ***D***. Unless button "1. Save Filters" (***D1***) is pressed, the selected requirements will be retained in the working memory only. On the contrary, once ***D1*** is pressed, the requirements are translated into ABRs (Step 7[a] and Stage IV) and get saved into a text and HTML file. In the current version of *ACQUAINT-SALTT*, each ABR is semi-hardcoded, meaning that every GCE representing a sub-element is associated with an ABR. The details of the ABR change based on the value that the GCE is set to. For instance, if a checkbox is checked, its ABR becomes active, and similarly, if the slider is positioned at a particular step, the value assigned to that step is assigned to the ABR related to that slider, thus mapping requirements into ABRs. For the selection shown in Figure 9.9, the following ABRs are the generated:

Example of the mapped requirements into ABRs

```
## REPRESENTATION ELEMENT ##
~~ ERGONOMICS REQUIREMENTS ~~
The product affords TODDLERS the ability to use the product.
The product affords up to PRE-SCHOOLERS the ability to use the product.
~~ AESTHETICAL REQUIREMENTS ~~
The product affords CHILDREN the ability to use a product with a REAL object/animal representation.
~~ GENDER REQUIREMENTS~~
The product affords CHILDREN the ability to use a GENDER-NEUTRAL product.
```

Finding potential solutions from the database

Button ***D1*** is pressed whenever the designer is ready to save the selected requirements. The designer can also press button ***D2***, that is, "2. Refine Requirements", to see whether any existing (past) products used in therapy match the selected criteria within that tab. This essentially means that *ACQUAINT-SALTT* does a search within the database of toys for any products that fall within the range of the desired requirements. The rules of the product searches for each tab/element are explained in the next section. Figure 9.10 shows how area ***E*** (side screen or Requirements screen) becomes active, and within it, products that match the desired requirements are listed in area ***F***, the solution exploration space (Stage III).

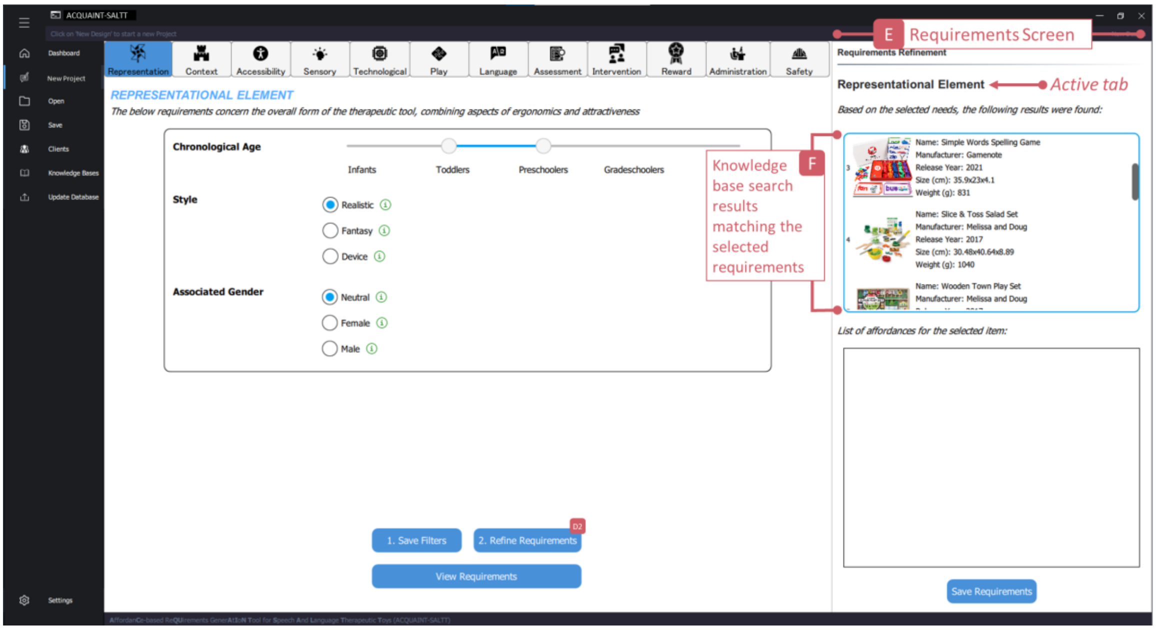


Figure 9.10: Mapping solutions to the solution exploration space

User-Needs Expansion – Stage III

Each potential match in area ***F*** is represented by a search result number, picture, product name, manufacturer, release year, dimensions, and weight. Clicking on a particular result, say on the image of a toy, the marketed ABRs are revealed in area ***G***, as shown in Figure 9.11. The designer can browse the ABRs of each toy, and any ABRs that are desired can be selected by ticking the checkboxes. Thus, expanding the requirements as in Stage III of the *D-SALTT* framework architecture. The selected requirements can be added to the list of ABRs generated by pressing button ***H***, "Save Requirements".

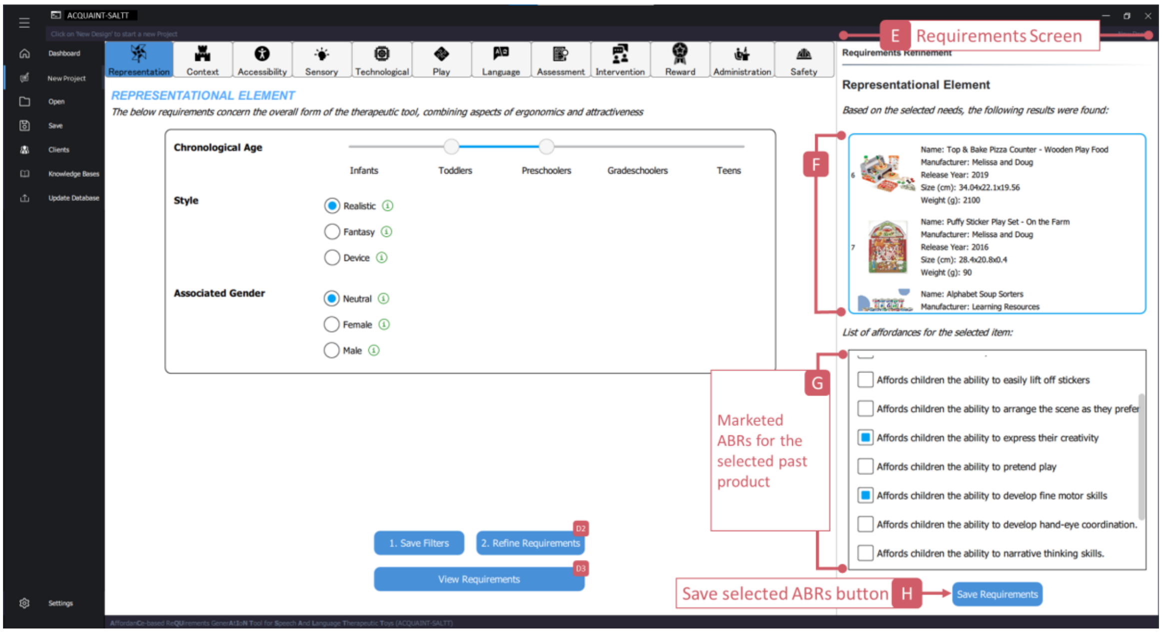


Figure 9.11: User-Needs expansion - stage III

Finding market gaps

In case that no results are displayed in area ***F***, market gaps are said to have been identified. Market gaps can also be found across tab views. Pressing different tabs in area ***B*** allows the designer to navigate to other elements of the SALT-PM ontology. As shown in the screenshots of Figure 9.14 to Figure 9.24, each tab view allows the designer to specify requirements related to that element by interacting with the GCEs. The buttons of area ***D*** function independently of the element being considered, and so are the parameters (requirements) defined in each view. Consequently, each view may lead to different search results in area ***F***. In other words, this means that the desired requirements for one element do not influence a product search within another tab. Therefore, when search results across tabs do not match, market gaps exist as there is no single product that owns the same multiple set of parameters.

Viewing the list of ABRs that have been generated

The list of requirements that have been generated so far can be viewed by clicking on button ***D3*** ("View Requirements") on the main screen, as shown in Figure 9.12.

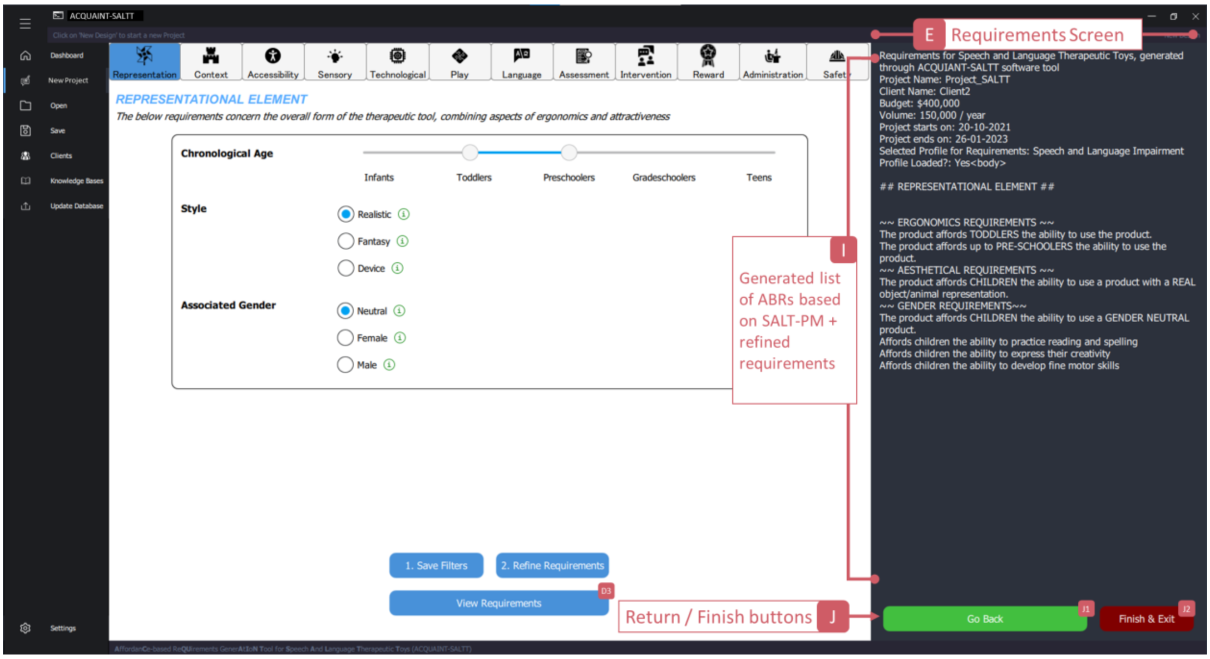


Figure 9.12: Viewing requirements

The side screen (area ***E***) is replaced by the list of ABRs as shown in area ***I***. On a closer look to this area, one can notice that the project details that have been specified in the new project user form (Figure 9.8) are at the top of the ABR list that has been generated. At the bottom, the last two ABRs that been selected in Figure 9.11 (through area ***G***) have been included to the list.

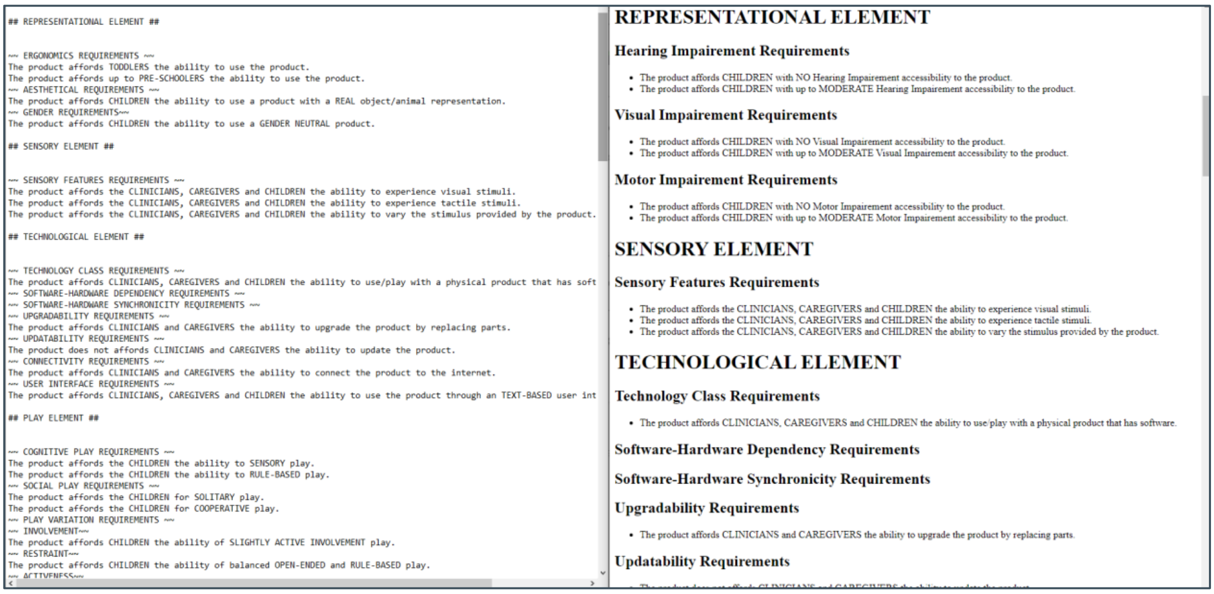
Requirements Compilation - Stage IV

Area **J** has two buttons: ***J1*** and ***J2***. The ***J1*** ("Go Back") button loads the previous view on the side screen, as shown in Figure 9.11. The designer may continue to consider other tabs to specify requirements for other elements. Searching for matching solutions may be repeated in different views, and one can add ABRs from different solutions open-endedly. Pressing the ***J2*** ("Finish & Exit") button will conclude the requirement generation process, and *ACQUAINT-SALTT* generates two files:

(i) a text file containing the generated ABRs

(ii) an HTML file, which is a replica of the text file with improved heading structure

A comparison of the two file formats is provided in Figure 9.13. Improvements to the HTML code can improve the aesthetics and readability of the HTML variant.



(a) (b)

Figure 9.13: List of generated ABRs in (a) text and (b) HTML format

Generating the requirements for the other elements

Figure 9.14 to Figure 9.24 illustrate screenshots of the GUI for the remaining eleven elements in the SALT-PM. The designer does not need to go through all the 12 tabs of *ACQUAINT-SALTT*, nor it is required to follow a particular order when considering elements. Moreover, one can use *ACQUAINT-SALTT* to generate the ABRs of mainstream toys by not considering SALTT related elements.

Representation element

Figure 9.9 to Figure 9.12 show the GUI of the Representation element as the ABRs were being generated. The Chronological age sub-element can be controlled through a range slider where one is able to specify the range of ages by whom the artefact will be used. The Style and Gender sub-elements feature radio boxes where the designer is only allowed to specify one option.

Context element

The GUI for the Context element is depicted in Figure 9.14. The ABRs for the Purpose of Use and Mode of Use sub-elements can be specified using the provided checkboxes. The ABRs of the other sub-elements can be included by activating the switches. Note that for the environmental factors, once the switch is clicked, the designer is presented with a text field to input further information about the AUCA-ABR.

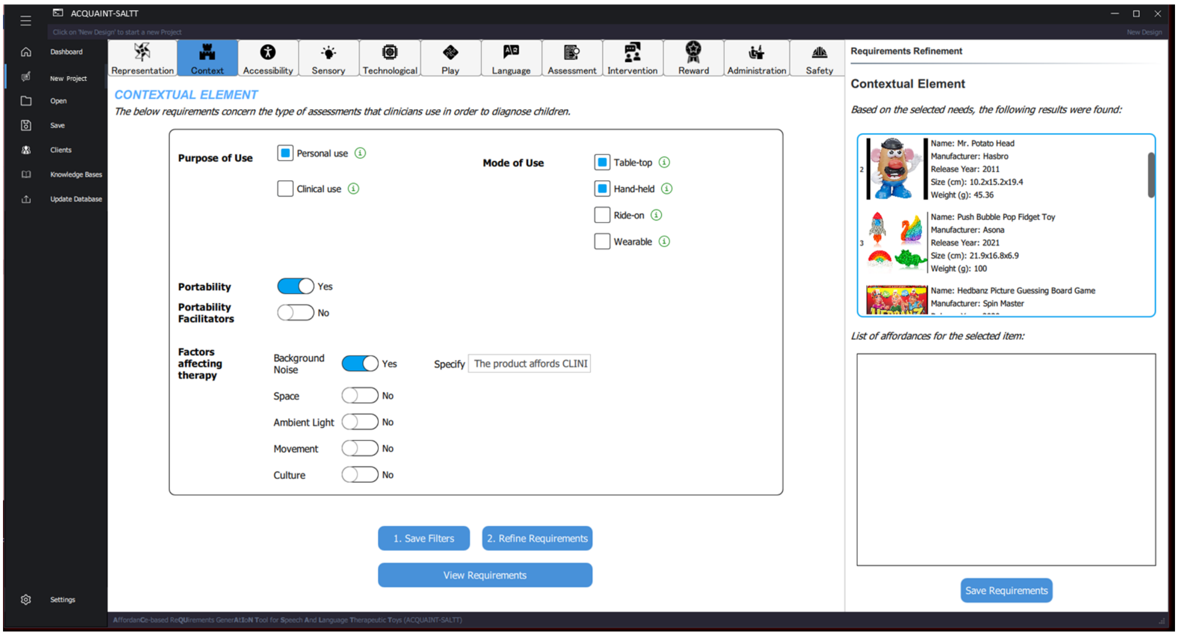


Figure 9.14: Context element GUI

Accessibility element

Figure 9.15 shows the user interface for the Accessibility element. Range sliders have been deployed to be able to specify the range of impairments for which the SALTT will be suitable.

Sensory element

Figure 9.16 shows the Sensor element GUI. Checkboxes have been used to generate the ABRs for this element.

Technology element

The GUI of the Technology element is shown in Figure 9.17, and it is controlled mainly by sliders. The Dependency and Synchronicity sub-elements only become active if the Technology Class slider is on the Phygital class. Similarly, Upgradability, Updatability, Connectivity and User Interface become active when the Technology Class slider is either on the Digital or Phygital classes.

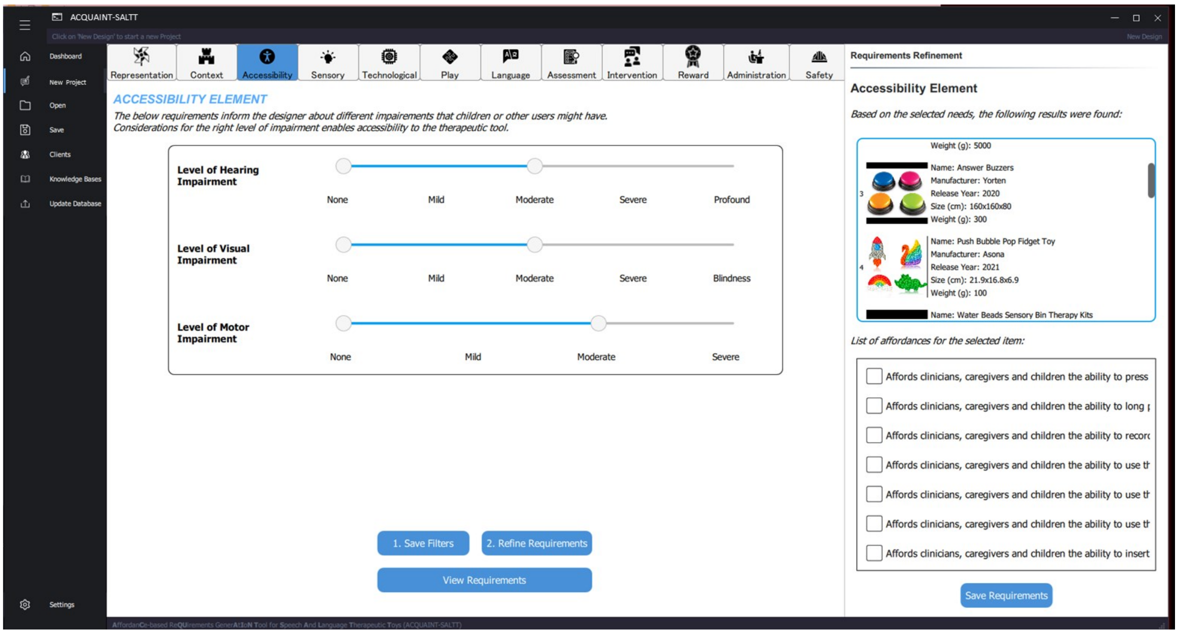


Figure 9.15: Accessibility element GUI

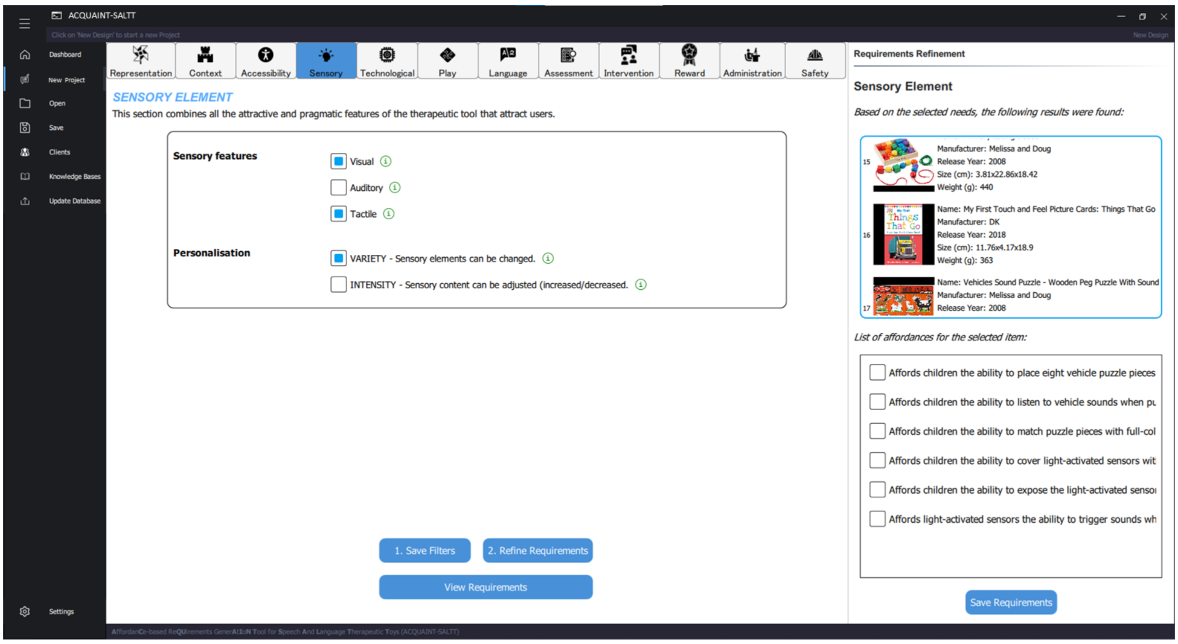


Figure 9.16: Sensory element view

Play element The ABRs for the sub-elements of the Play element can be generated through checkboxes and sliders, as shown in Figure 9.18.

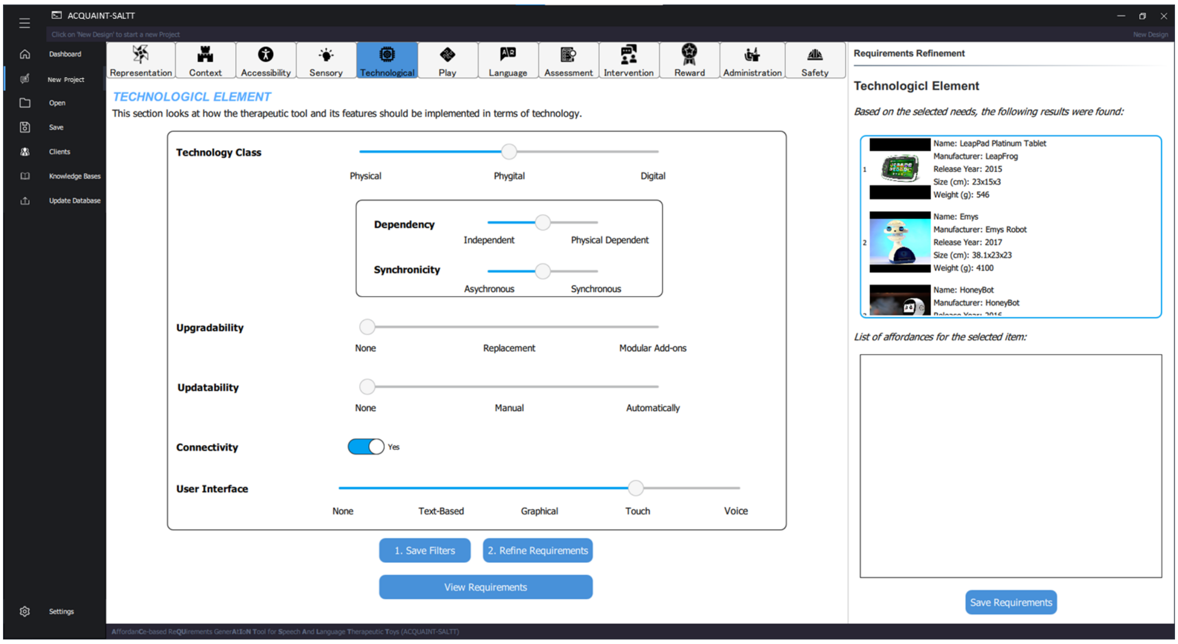


Figure 9.17: Technology element GUI

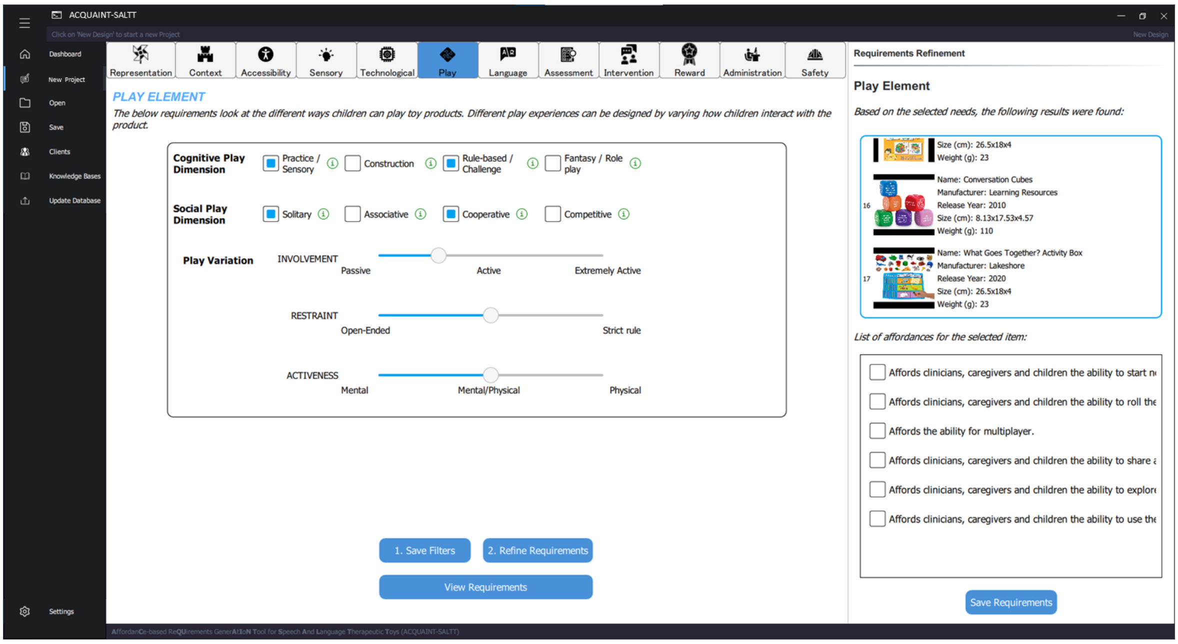


Figure 9.18: Play element GUI

Language element The GUI of the Language element consists of several GCEs, as shown in Figure 9.19. The slider for the Sentence Complexity sub-element remains disabled if no Expression technology is selected. Not visible in Figure 9.19, the GUI of the Language element also includes fields (GCEs) to specify the language(s) for the SALTT. This feature is like the Assessment Language sub-element shown in Figure 9.20 for the Assessment element.

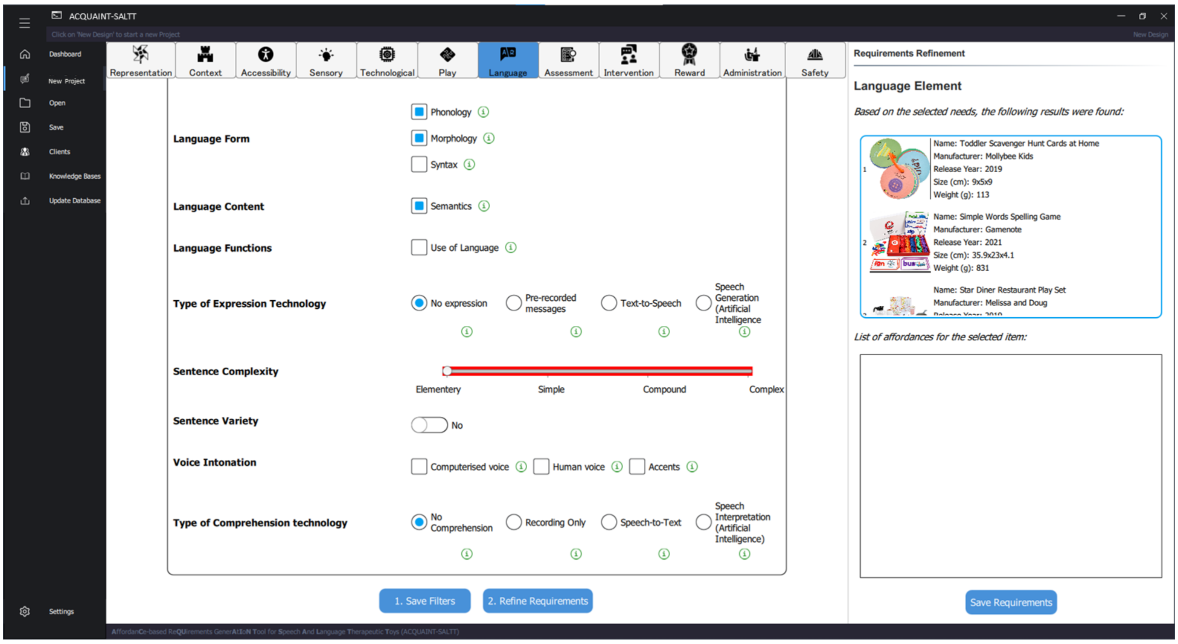


Figure 9.19: Language element GUI

Assessment element

Through this view, the designer can specify the assessments that need to be included within the SALTT, as portrayed in Figure 9.20. Verbal assessments can be in different languages, and therefore, the GUI allows the designer to specify which assessment languages are required.

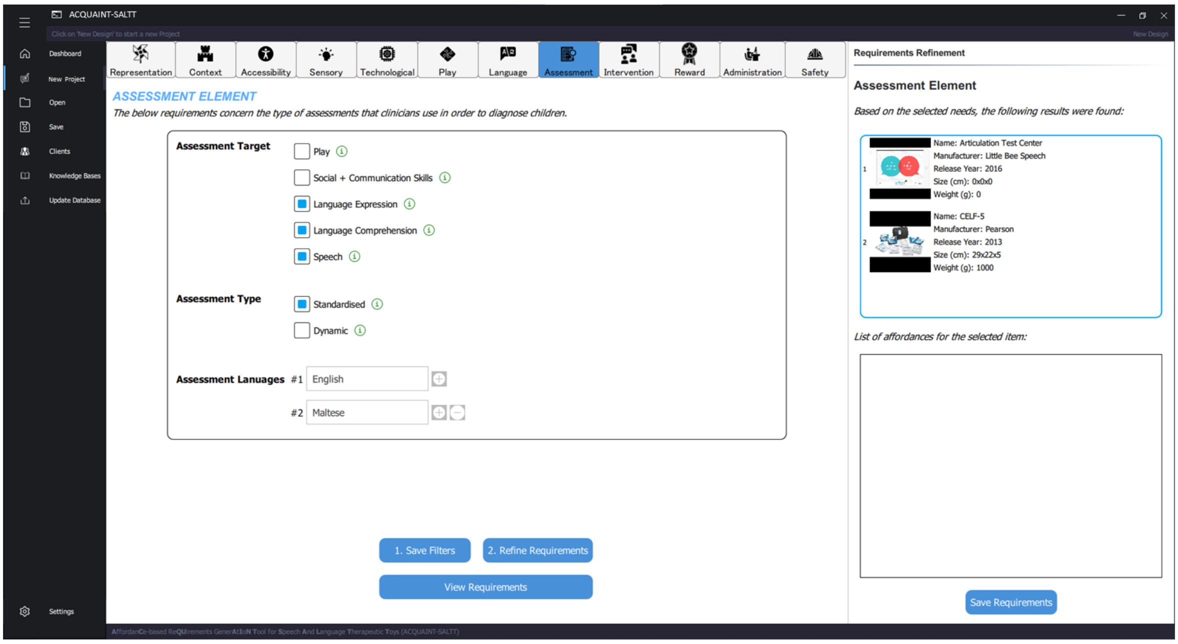
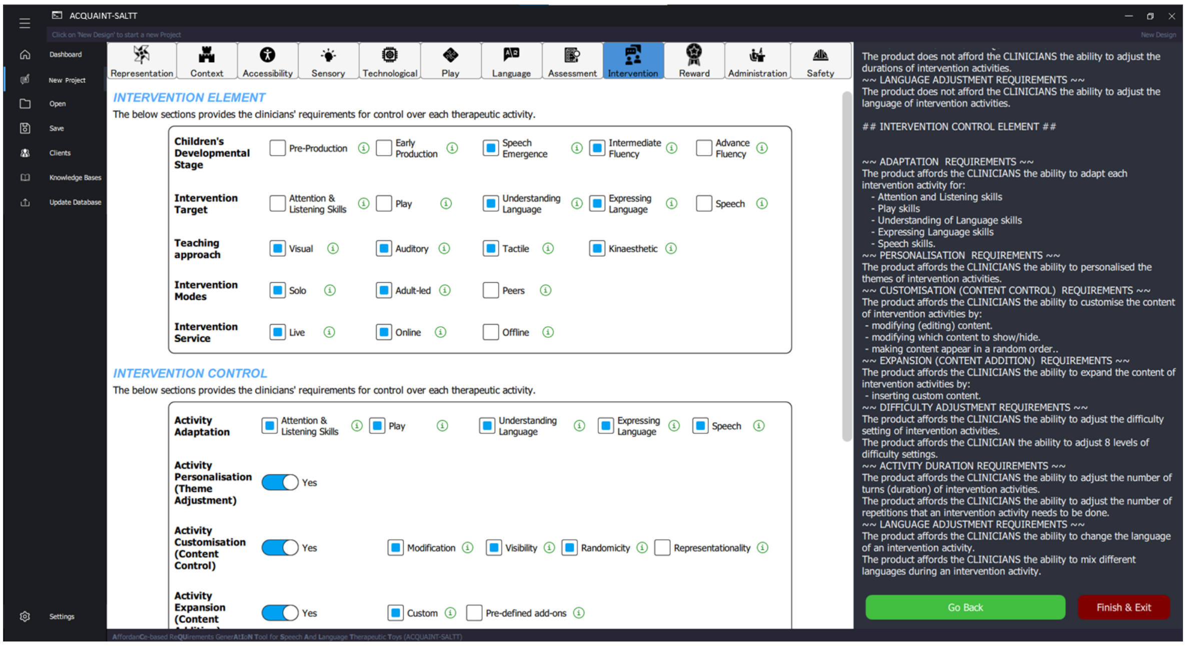


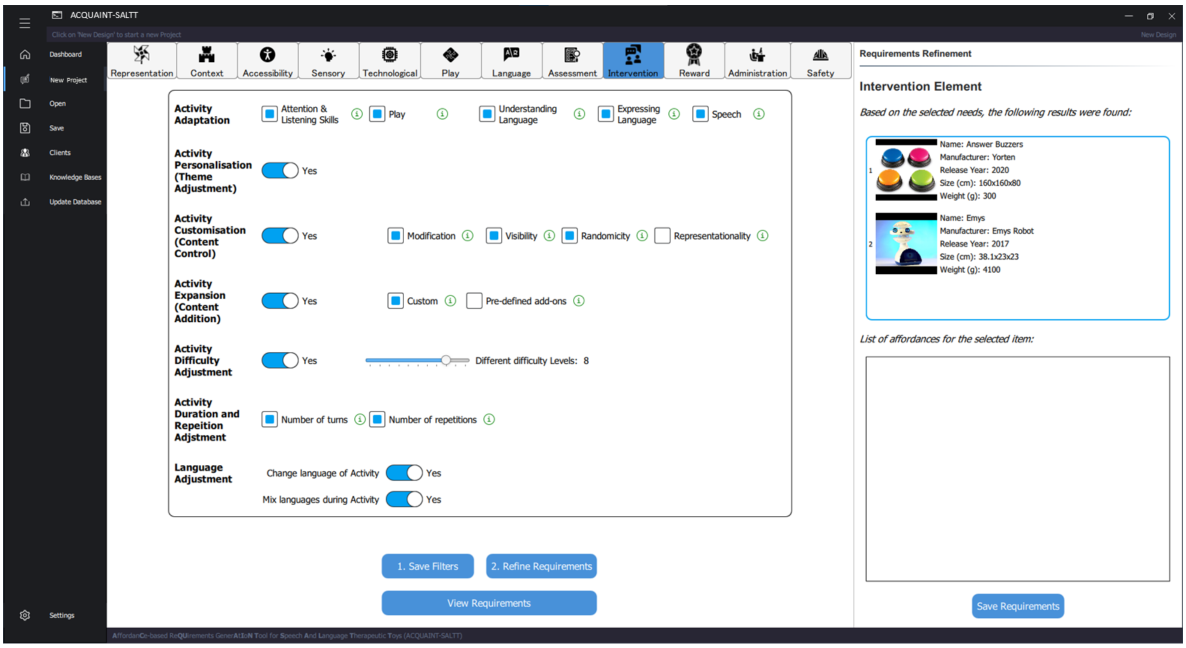
Figure 9.20: Assessment element GUI

Intervention element

The Intervention element GUI consists of two sections, shown in Figure 9.21 (a) and (b). The former section is the actual Intervention element, and the latter is called the *Intervention Control* section. These were separated because existing toys with such an element of controllability are not available, and therefore, the second section is not used to search for matching products. The Intervention element is composed of checkboxes.



(a)



(b)

Figure 9.21: (a) Intervention element, and (b) Intervention Control GUI

Intervention Control

The GUI of the *Intervention Control* section generates the requirements that will provide the much-needed intervention flexibility for the SLPs. As discussed in Chapter 6, each sub-element of this section addresses the different facets of intervention for SLPs to provide a tailored intervention programme to their clients.

Reward element

The GUI for the Reward element is shown in Figure 9.22, mainly consisting of checkboxes.

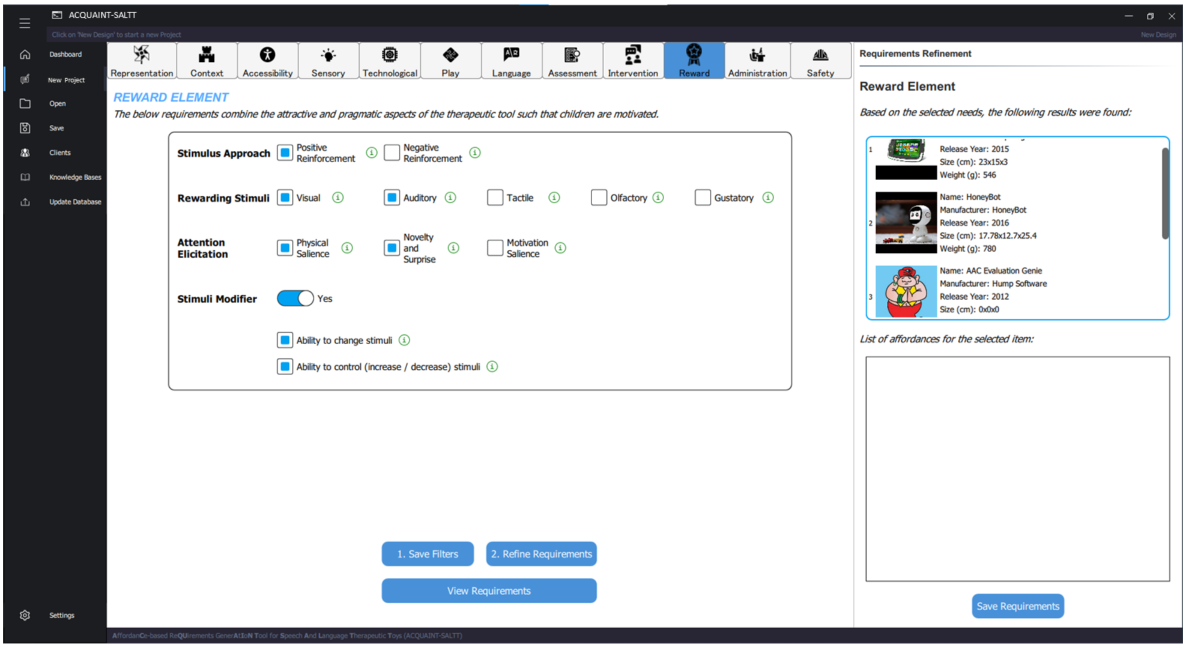


Figure 9.22: Reward element GUI

Administration element

The GUI of the Administration element shown in Figure 9.23 allows the designer to generate the requirements for features within SALTT that would support the SLPs role. Various switches within the GUI enable the designer to tick the corresponding checkboxes.

Safety element

The GUI of the Safety element, shown in Figure 9.24, is composed of a range slider with which the designer can specify the age range of the intended users, and two sliders to specify which safety standards to consider when implementing the features of the SALTT.

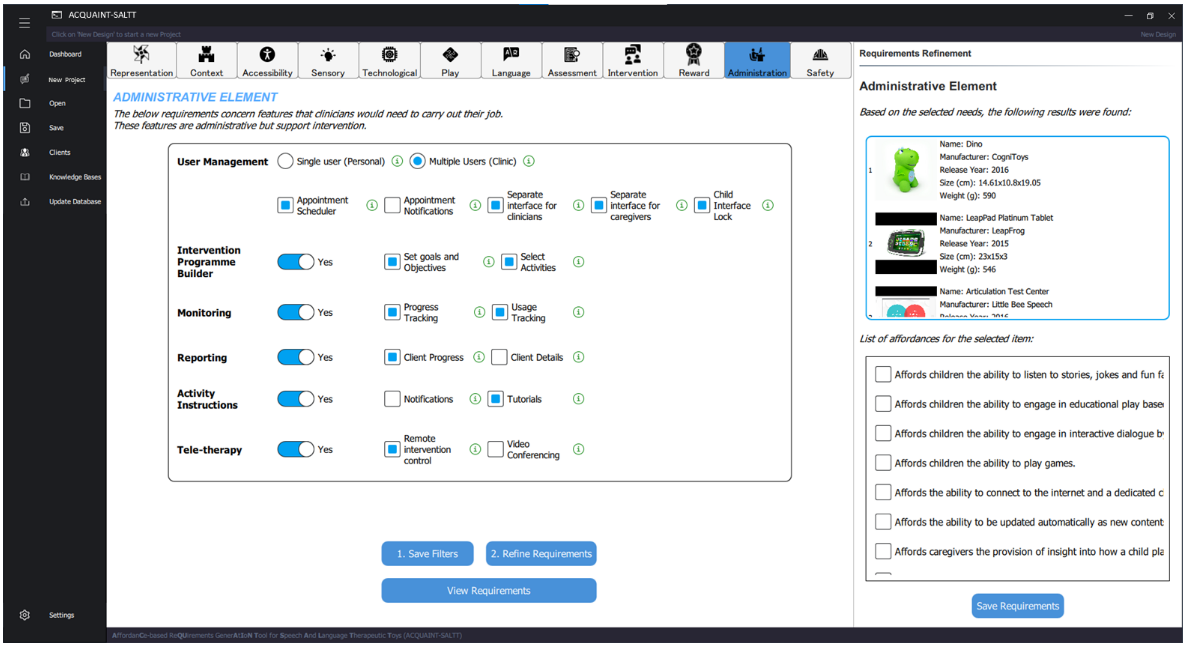


Figure 9.23: Administration element GUI

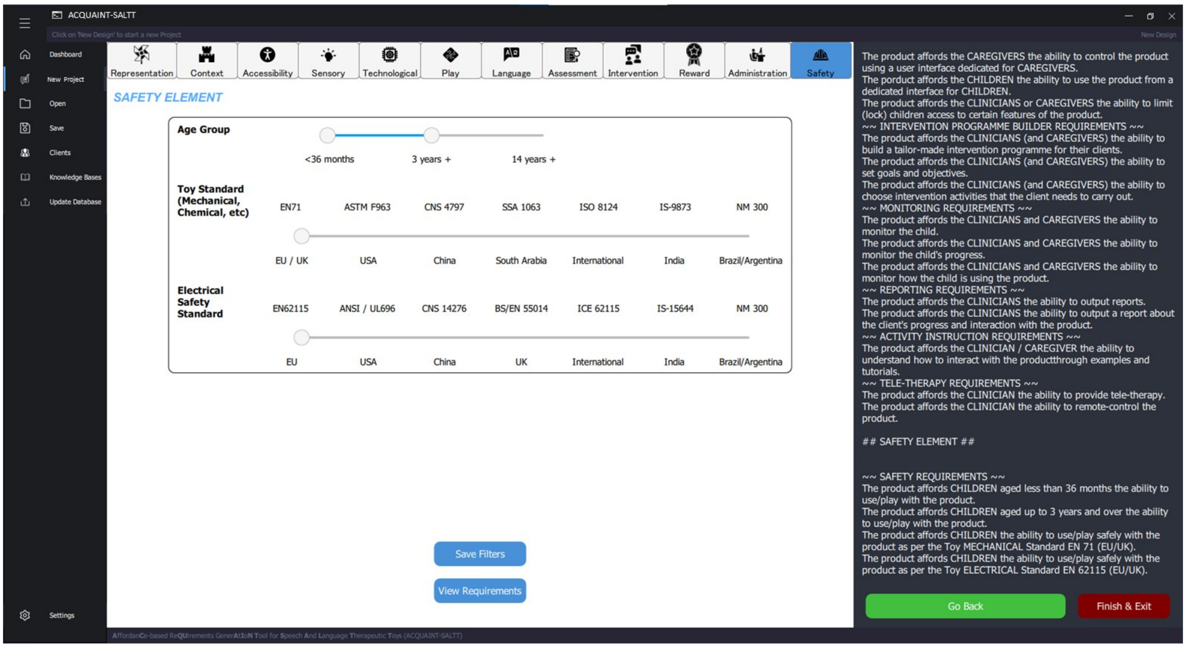


Figure 9.24: Safety element GUI

Tooltips

Tool requirement (TR) 18 specified the inclusion of tooltips that support the user (designer) of *ACQUAINT-SALTT* to understand each term shown on the GUI. As shown in Figure 9.25, tooltips are displayed when the mouse is hovered on the text and information icons (ⓘ).

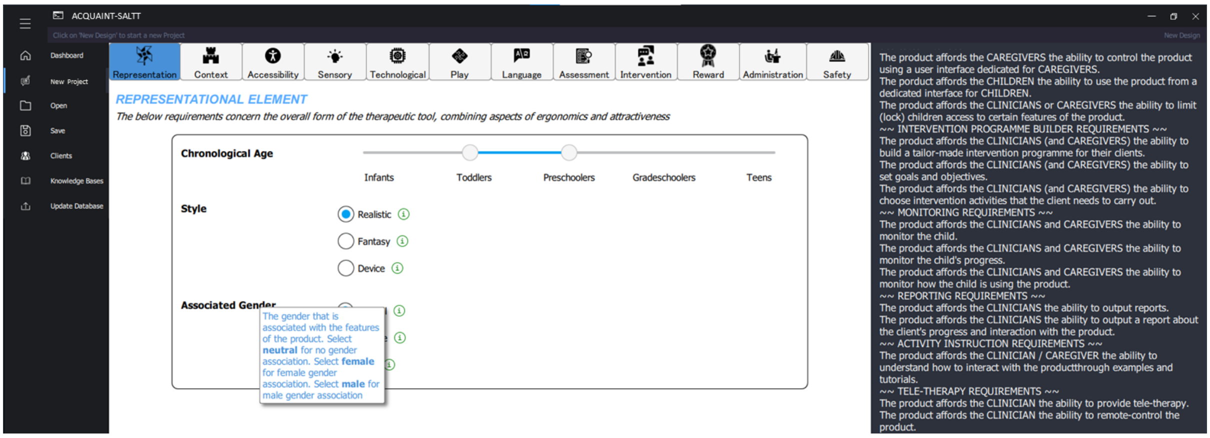


Figure 9.25: Example of a tooltip within the GUI of ACQUAINT-SALTT

9.3.2 Mapping existing solutions to requirements

An ontology-based information retrieval approach has been used within *ACQUAINT-SALTT* (Munir and Sheraz Anjum, 2018). As explained when discussing market gaps, the search for existing solutions in each tab view occurs independently, giving rise to a larger set of results from which new ABRs (or ABSs) can be mapped to the solution being investigated. Rules in the form of If…Then…Else statements on the sub-elements of the SALT-PM ontology have been used to find appropriate matching results.

In order to limit the number of omissions in the search results, when a sub-element is not ticked/activated, that sub-element is not included in the searching rule. In this way, unselected sub-elements are considered as optional rather than undesired. Such sub-elements have been marked by the symbol '*'.

Representation element rule

Solution exploration within the Representation element depends on the chronological age bracket of children for whom the SALTT is being designed for, the overall form required for the SALTT and the associated gender that it will have.

Rule 1

IF		Chronological Age Min >= *Age Min*
	AND	Chronological Age Min <= *Age Max*
	AND	Chronological Age Max <= *Age Max*
	AND	Chronological Age Max >= *Age Min*
	AND	Form == *Style*
	AND	Associated Gender == *Gender*
THEN		Retrieve matching solutions for the Representation element

where,

$Style \in \{realistic, fantasy, device\}$, and
$Gender \in \{neutral, feminine, masculine\}$.

Context element rule

Solution exploration within the Context element depends on the use purpose, mode of use, portability, and environmental factors (EnvFactor) concerning the SALTT being designed.

Rule 2

IF		Use Purpose == *Purpose*
	AND	Mode of Use == *Mode*
	AND	Portability*
	AND	EnvFactorNoise* AND EnvFactorSpace* AND EnvFactorLight* AND EnvFactorMovement* AND EnvFactorCulture*
THEN		Retrieve matching solutions for the Context element

where,

$Purpose \in \{Personal, Clinical\}$, and
$Mode \in \{tableTop, handHeld, rideOn, wearable\}$.

Accessibility element rule

Solution exploration within the Accessibility element depends on the hearing, visual and motor impairments of children.

Rule 3

IF		Hearing Impairment Min >= *Hearing Level Min*
	AND	Hearing Impairment Min <= *Hearing Level Max*
	AND	Hearing Impairment Max >= *Hearing Level Min*
	AND	Hearing Impairment Max <= *Hearing Level Max*
	AND	Vision Impairment Min >= *Vision Level Min*
	AND	Vision Impairment Min <= *Vision Level Max*
	AND	Vision Impairment Max >= *Vision Level Min*
	AND	Vision Impairment Max <= *Vision Level Max*
	AND	Motor Impairment Min >= *Motor Level Min*
	AND	Motor Impairment Min <= *Motor Level Max*
	AND	Motor Impairment Max >= *Motor Level Min*
	AND	Motor Impairment Max <= *Motor Level Max*
THEN		Retrieve matching solutions for the Accessibility element

where,

$Hearing\ Level\ \in \{None, Mild, Moderate, Severe, Profound\}$,
$Vision\ Level\ \in \{None, Mild, Moderate, Severe,\ Blindness\}$, and
$Motor\ Level\ \in \{None, Mild, Moderate, Severe, \}$.

Sensory element rule

Solution exploration within the Sensory element depend on the sensory features and level of sensory control offered by the SALTT.

Rule 4

IF		sensoryVisual* AND sensoryAuditory* AND sensoryTactile*
	AND	sensoryVariety* AND sensoryIntensity*
THEN		Retrieve matching solutions for the Sensory element

Technology element rule

Solution exploration within the Technology element mainly depends on the technology class. If the latter is purely physical, then it means that the designer is looking for a low-tech SALTT. On the other hand, if the class is set to Phygital or Digital other conditions apply as explained by Rule 5.

Rule 5

IF		Technology Class != *Physical*
	AND	Upgradability == Upgrade
	AND	Updatability == Update
	AND	Connectivity*
	AND	User Interface == UI
	IF	Technology Class == *Phygital*
	AND	Physical Dependency == DepPhysical
	AND	Digital Dependency == DepDigital
	AND	Synchronicity == Sync
	THEN	Retrieve solutions for the Technology (Phygital) element
THEN		Retrieve solutions for the Technology (Digital) element
ELSE		Retrieve solutions for the Technology (Physical) element

where,

$DepPhysical \in \{0,0.25,0.50,0.75,1\}$, 0 being completely independent and 1 completely dependent.
$DepDigital \in \{0,0.25,0.50,0.75,1\}$, 0 being completely independent and 1 completely dependent,
$Sync \in \{0,0.25,0.50,0.75,1\}$, 0 being completely asynchronous and 1 completely synchronous,
$Upgrade \in \{none, \mathrm{replacement}, addOn\}$,
$Update \in \{none, \mathrm{manual}, automatic\}$,
$UI \in \{none, \mathrm{textBased}, graphical, touch, voice\}$.

Play element rule

Solution exploration within the Play element depends on the type of cognitive and social play that will be offered by the SALTT and their variation.

Rule 6

IF		Practice Play* AND Construction Play* AND Rule-Based Play*
	AND	Role Play* AND Solitary Play* AND Associative Play* Cooperative
	AND	Play* AND Competitive Play*
	AND	Involvement == *InvLevel*
	AND	Restraint == *ResLevel*
	AND	*Activeness == ActLevel*
THEN		Retrieve matching solutions for the Play element

where,
$InvLevel \in \{0.00, 0.25, 0.50, 0.75, 1.00\}$, 0 being completely passive and 1 extremely active,

$ResLevel \in \{0.00, 0.25, 0.50, 0.75, 1.00\}$, 0 being completely open-ended and 1 completely rule-based,
$ActLevel \in \{mental, mental/physical, physical\}$.

Language element rule

Solution exploration within the Language element depends on the required languages, their form, content and functions, the type of expression technology, sentence complexity and variety, and the type of comprehension technology. Note that voice intonation was not made an influencing factor since it is a SALTT-specific attribute.

Rule 7

IF		Language == *Languages*
	AND	Phonology* AND Morphology* AND Syntax* AND Semantic*
	AND	Language Use*
	AND	**IF** Expression Technology != No Expression ∉ ExpTechnology
	AND	Sentence Complexity == Complexity AND Sentence Variety*
	AND	Comprehension Technology == CompTechnology
THEN		Retrieve matching solutions for the Language element

where,

$Languages \in \{Languges\ defined\ by\ designer\}$,
$ExpTechnology \in \{preRecorded, \text{t}extToSpeech, speechGeneration\}$,
$Complexity \in \{elementertary, simple, compound, complex\ \}$,
$CompTechnology \in \{noComprehension, recording, speechToText, speechInterpretation\}$.

Assessment element rule

Solution exploration within the Assessment element depends on the assessment target, type and languages.

Rule 8

IF		Assessment Language == assess*Languages*
	AND	Play* AND SocComm* AND LangExpression* AND LangComp*
	AND	Speech* AND StdAssessment* AND DynAssessment*
THEN		Retrieve matching solutions for the Assessment element

where,

$assessLanguages \in \{\text{Assessment}\ languges\ defined\ by\ designer\}$, *Intervention element rule*

Solution exploration within the Intervention element depends on children's developmental age, intervention target, teaching approach, intervention mode, intervention service and language. No rules have been applied to the Intervention control element since it is SALTT-specific.

Rule 9

IF		InterDevelopPreProd* AND InterDevelopEarlyProd*
	AND	InterDevelopSpeechEmerge* AND InterDevelopIntSpeech*
	AND	InterDevelopAdvSpeech* AND InterTargetAttention
	AND	InterTargetPlay* AND InterTargetUnderstanding*
	AND	InterTargetExpressing* AND InterTargetSpeech*
	AND	InterApproachVisual* AND InterApproachAuditory*
	AND	InterApproachTactile* AND InterApproachKine*
	AND	InterModeSolo* AND InterModeAdult*
	AND	InterModePeers* AND InterServiceLive*
	AND	InterServiceOnline* AND InterServiceOffline*
	AND	Intervention Language == *interLanguages*
THEN		Retrieve matching solutions for the Intervention element

where,

$interLanguages \in \{\text{Intervention } languges\ defined\ by\ designer\}$,

Reward element rule

Solution exploration within the Reward element depends on the nature of reinforcement mechanism, the type of rewarding stimulus, and the type of attention elicitation. Because the reward adjustment feature is very specific, this was not included in the rule.

Rule 10

IF		Positive Reinforcement* AND Negative Reinforcement*
	AND	Visual Reward* AND Auditory Reward* AND Tactile Reward*
	AND	Olfactory Reward* AND Gustatory* AND
	AND	Physical Salience* AND Novelty* AND Motivation Salience*
THEN		Retrieve matching solutions for the Reward element

Administration element rule

Solution exploration within the Administration element depends on the type of user management, intervention programme building, monitoring, reporting, instructions and tele-therapy features.

Rule 11

IF		User Management == Users
	AND	Intervention Programme Builder*
	AND	Monitoring* AND Reporting* AND Instructions*
	AND	Tele-therapy*
THEN		Retrieve matching solutions for the Administration element

where,
$Users \in \{singleUser, multipleUsers\}$.

9.4 Part B Conclusions

Implemented features from the D-SALTT framework

This chapter discussed the prototype computer-based implementation of the *D-SALTT* framework into a KBS called *ACQUAINT-SALTT*, which allows designers to generate a comprehensive list of ABRs for SALTTs, given that each element of the SALT-PM is considered. Although only a few features were not (entirely) implemented, as demonstrated by the detailed walkthrough of *ACQUAINT-SALTT*, design support can be provided through computer-based tools during the task clarification stage such that designers would gain domain-specific knowledge. This implementation also suggests that the *D-SALTT* framework can be used to develop ABR generation tools in other domains if another taxonomy of design considerations replaces the SALT-PM ontology.

Rule-based search for potential solutions

Given that the solution mapper is based on a set of independent rules, it allows designers to refine the original requirements and find suitable solutions by varying the sub-elements of SALT-PM. Therefore, *ACQUAINT-SALTT* provides the means by which requirements can be understood easier.

End of Part B

This chapter ends the Part B of this dissertation which has defined the knowledge models for the phenomena described in Part A. Part C begins with a formal evaluation of *ACQUAINT-SALTT* with typical stakeholders. This evaluation will be used as a basis to validate the hypothesis postulated in this research.

PART C
Evaluation, Discussion and Conclusion

10. EVALUATION OF THE *D-SALTT* FRAMEWORK ARCHITECTURE

The moment man first picked up a stone or a branch to use as a tool, he altered irrevocably the balance between him and his environment.

James Burke, Connections, 1978

This chapter describes the evaluation of the D-SALTT framework supported through the ACQUAINT-SALTT prototype tool. Section 10.1 explains how the evaluation study was carried out, including the evaluation criteria and difficulties encountered. Evaluation results on the framework and its implementation are listed in Section 10.2. Key conclusions drawn from the formal evaluation of the proposed design support are presented in Section 10.3.

10.1 Evaluation Approach

Because ACQUAINT-SALLT is a prototype implementation of the *D-SALTT* framework, the evaluation of the tool is the indirect appraisal of the framework and its modules. Prototype or actual tools make it easy for the participants to comprehend the abstractness of the frameworks (Blessing and Chakrabarti, 2009), especially since the *D-SALTT* framework is a high-level representation of how affordance-based requirements can be generated.

10.1.1 Evaluation objectives

The aim of this evaluation is two-fold as shown in Figure 10.1.

Evaluation Objective #1 (EO1)

The first evaluation objective (EO1) is to understand whether from the *D-SALTT* framework designers would benefit in generating and understanding requirements during the Task Clarification stage by means of ABRs for SALTTs.

Evaluation Objective #2 (EO2)

The second objective (EO2) was to evaluate the actual prototype tool, *ACQUAINT-SALTT*, in terms of a computer-based tool that guides the designer in understanding the different considerations that need to be taken when developing SALTTs while assessing its strengths and limitations.

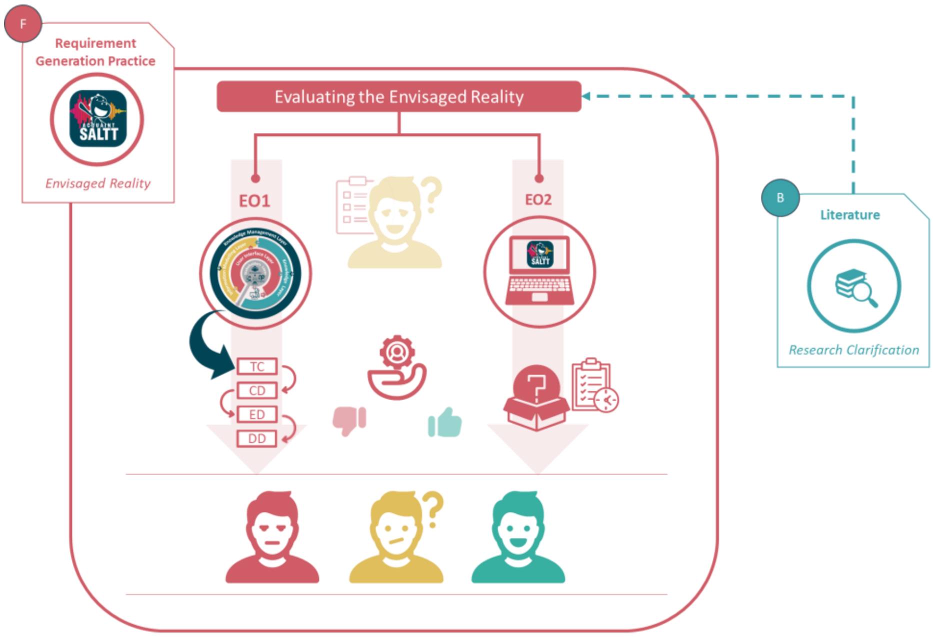


Figure 10.1: Evaluation study objectives

10.1.2 Evaluation Criteria

As described in Section 1.5, the final objective of this research was to evaluate the implemented outcomes of this dissertation. Based on the research problem formulated in Chapter 5, five evaluation criteria were postulated to investigate whether designers will be willing to use such a framework in their practice. These will assess the extent to which:

Evaluation Criterion #1

EC1: the framework fits in the designer's workflow during the task clarification stage;

Evaluation Criterion #2

EC2: requirements, expressed as ABRs, provide a better understanding of the design problem;

Evaluation Criterion #3

EC3: designers are made aware of the different end-users requirements for SALTT;

Evaluation Criterion #4

EC4: designers would find the characteristics of the tool useful and necessary in *ACQUAINT-SALTT*;

Evaluation Criterion #5

EC5: the intended support planned in the framework architecture would augment the benefits of the support provided (in the prototype tool) if fully implemented.

10.1.3 Evaluation Structure

Each evaluation session consisted of three stages as portrayed in Figure 10.2

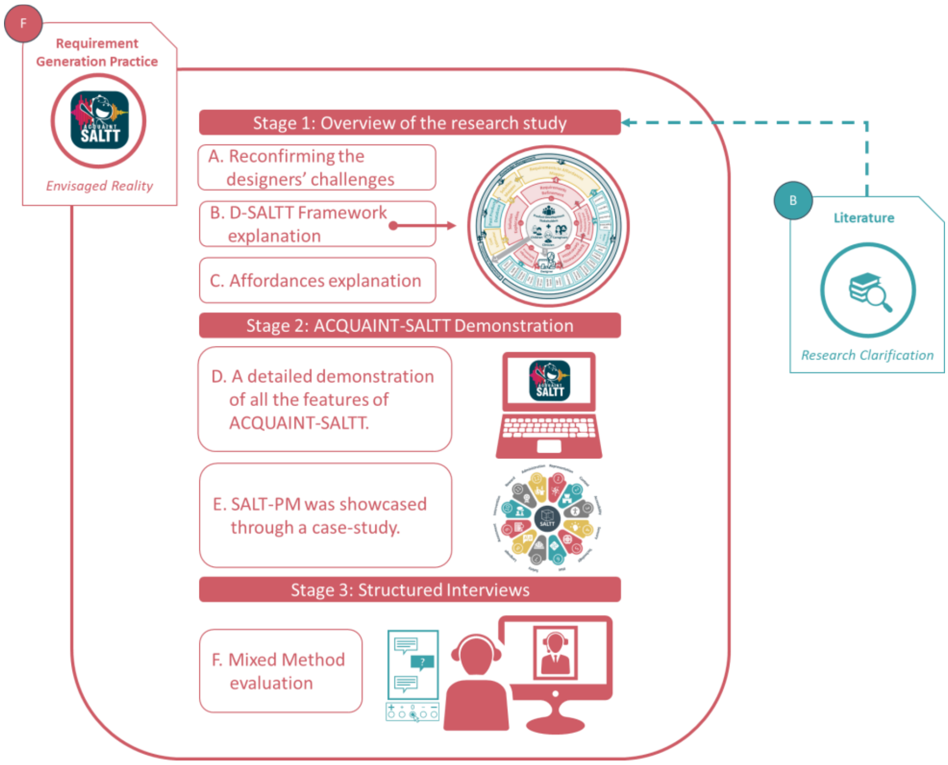


Figure 10.2: Structure of Evaluation study

Stage 1 The first stage, which took around fifteen minutes, provided the participants with a background of this Ph.D. research. An explanation about affordances and ABRs followed to ensure that each participant was familiar with how requirements were defined in *ACQUAINT-SALTT*.

Stage 2 In the second phase, the ACQUAINT-SALTT prototype tool was demonstrated. The demonstration lasted an hour on average, and it involved a detailed run-through of every feature, including a fabricated case study for the design of a typical SALTT. The case study outcome was a detailed document containing a list of use-phase focused, affordance-based requirements for a SALTT.

Stage 3 A structured interview was carried out in the final phase to assess the D-SALLT framework and the actual support tool, *ACQUAINT-SALTT*. The evaluation results were analysed through a mixed method approach.

10.1.4 Evaluation Difficulties

Assessment approach

Due to limitations caused by the COVID-19 pandemic, the framework and the prototype tool could not be evaluated in person through a hands-on approach. Although *ACQUAINT-SALTT* is a stand-alone executable software, copies of this prototype tool were not distributed to the participants as this could have led to further technical challenges. Instead, the demonstration of stage 2 was provided online by sharing the screen on Google Meet, a video communication application.

Sample size and recruitment of participants

A limitation of this study is that only 14 participants were recruited. However, as can be seen from the results in Section 10.2, a clear indicative saturation point was reached for all questions, making results consistent with minimal variability regardless of the number of years of experience. As indicated by Morse (2000), when the nature of the study is obvious and has a narrow scope, as is the case with this study, the sample size can be smaller. Furthermore, the findings revealed in van Dijk (1995) show that six evaluators are generally enough to obtain all possible comments during an initial evaluation.

It is important to highlight the encountered challenge in recruiting participants because no toy designers were available locally. Given that the total length of the evaluation was two hours, an inducement of €70 was offered to each participant. Although many efforts were made to recruit overseas evaluators, it was challenging to reach toy designers specifically. A possible reason for this is attributed to the niche area of therapeutic toys. Participants were recruited through the LinkedIn online platform and by commissioning AIJU[19], a Spanish technological centre specialising in toys, to act as gatekeeper and find relevant designers for this evaluation study.

19 AIJU Technological Institute for Children's Products and Leisure (https://www.aiju.es/en)

Limited functionality

As indicated in Chapter 9, the tool requirements and the *D-SALTT* framework were not fully implemented in the *ACQUAINT-SALTT* prototype tool. Nonetheless, the purpose of missing features was explained and evaluated as per the final evaluation criteria.

Limited knowledge

Another limitation was the amount of knowledge placed in the knowledge libraries within the implemented prototype. Because it was mainly based on SALT-PM, *ACQUAINT-SALTT* cannot provide ABRs on other lifecycle phases of SALTTs.

Type of evaluation

These limitations in executing an effective evaluation of *ACQUAINT-SALTT* fall in line with the problems highlighted in (Blessing and Chakrabarti, 2009; Duffy and O'Donnell, 1998). For this reason, the overall purpose of the evaluation was to understand the usefulness of the tool in terms of its strengths and limitations in providing the required support during task clarification.

10.1.5 Evaluation Procedure

Ethics approval

This research was approved by the ethics committee of the Faculty of Engineering at the University of Malta (application number 9591-280821).

Recruitment

Prior to participation, participants were sent an information letter and a consent form to sign where they agreed to allow the researcher to record the online evaluation sessions.

Table 10.1 lists the participants' information, who were recruited from seven different countries in Europe and the US. Their years of experience (YOE) varied between 5 and 30 years (Mean = 14.1 years, Std. Dev. = 8.5 years). In terms of their highest level of education, one was a full professor, eleven had a Master's degree, and two had a Bachelor's degree.

*Table 10.1: Participants' details (*YOE: Years of Experience)*

Participant	Gender	YOE*	Role	Org. Size	Country
ES1	F	10	Product Designer / Project Manager	L	Germany
ES2	M	4	Toy Product Designer and Inventor	L	UK
ES3	M	15	Creative Director and Professor	S	Italy
ES4	F	8	Freelance Industrial Designer	(FL)	Italy
ES5	M	20	Product Research and Development Manager	L	Cyprus
ES6	M	30	Full Professor and Cofounder of a Toy Company	L	Spain
ES7	M	5	Product (Toy) Designer	L	Cyprus
ES8	F	22	Educator and Toy Designer	L	US
ES9	F	11	Product Design Manager	L	Spain
ES10	F	11	Toy Designer	L	Spain
ES11	F	10	Marketing and Toy Product Designer	S	Spain
ES12	M	6	Toy Designer / Founder of a Toy Company	S	Canada
ES13	F	30	Research Development and Innovation Manager	L	Spain
ES14	M	15	Product Director	L	Spain

Structured interviews with 5-scale Likert scale

The evaluation questions were divided into three parts and were targeted to answer the evaluation criteria. The first set of questions was aimed at evaluating the overall *D-SALTT* framework on its own. Questions about the adopted format for ABRs statements were asked in the second part. In the third part, the questions were formulated to evaluate the actual prototype implementation. On average, the interviews took around 45 minutes.

Pilot study

A pilot study was carried out with one Master's engineering student prior to the actual evaluations. This led to the simplification of the content in stage 1 (explanation) and a better explanation of how *D-SALTT* maps to *ACQUAINT-SALTT*. A few questions were reworded, and images were included in the questionnaire.

Data collection

Given that statistical analysis does not always present in-depth insight into the participant's feedback and experience, qualitative analysis can fill such gaps when describing the reasons for the supplied feedback. Furthermore, through thematic analysis, patterns in data can be identified, resulting in the understanding of phenomena. For this reason, the mixed method approach described in Chwo et al. (2018) was adopted where participants' feedback was organised in themes. All interviews were recorded and later transcribed for qualitative analysis. Participants' feedback was read multiple times and coded in an iterative process, to reduce subjective bias, refine the identified themes and address the evaluation criteria for the framework.

10.2 Evaluation Results

Participants' feedback was collated under six themes as shown in Figure 10.3, and discussed in the following sub-sections.

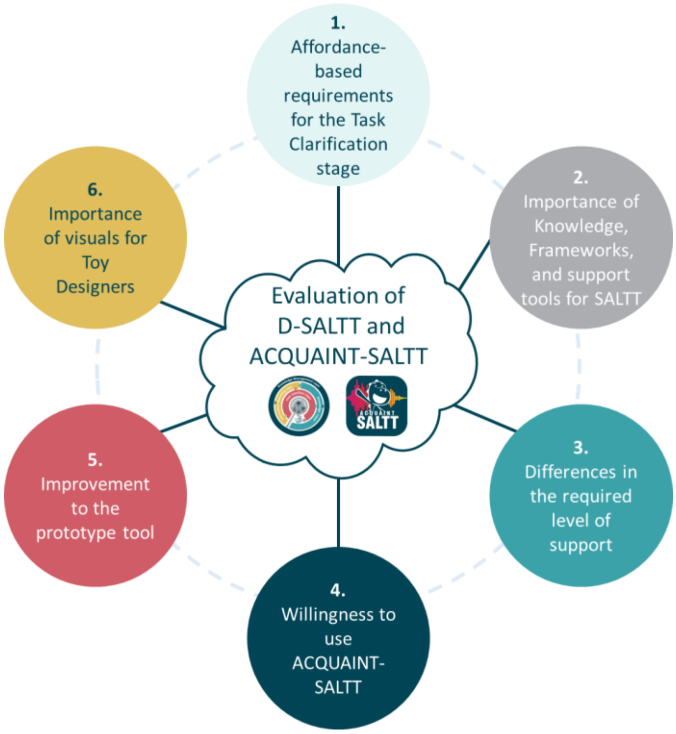


Figure 10.3: Identified themes during the evaluation of D-SALTT and ACQUAINT-SALTT

10.2.1 Theme 1: ABRs for the Task Clarification stage

Finding 1

Designers understand the benefits of affordance-based requirements (ABRs)

64.29% of the participants had never heard about design affordances. Nonetheless, participants had a positive attitude towards affordance-based requirements as reflected in the results of Figure 10.4. All participants strongly agreed or agreed that (a) ABRs can be understood easily, (b) can facilitate user identification, (c) can help designers understand the benefits that the product will give to the end user, and (e) are solution independent.

How do you rate the following statements about affordance-based requirements?

a) Affordance-based requirements can be understood easily
b) Affordance-based requirements facilitate user identification
c) Affordance-based requirements help designers understand the benefits that the product will give to the end-user
d) Affordance-based requirements help designers understand how the end user will interact with the product.
e) Affordance-based requirements are solution independent
f) Affordance-based requirements promote further creativity

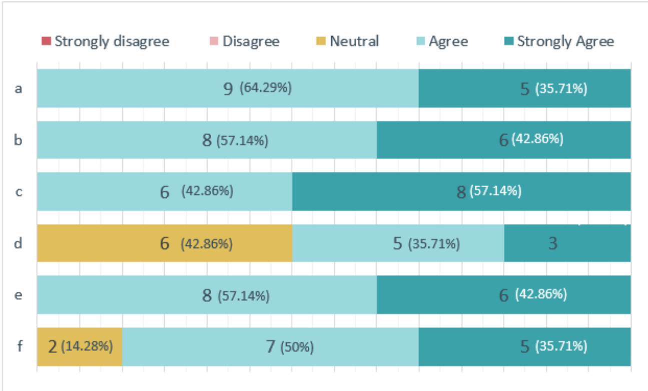


Figure 10.4: Participants preferences to the characteristics of ABRs

Finding 2

ABRs do not constrain the designer but promote creativity

Most (87.14%) of the designers strongly agreed or agreed that (f) ABRs would promote further creativity because ABRs are solution-independent, whilst two participants (14.29%) gave a neutral reply because they believed that creativity is an innate characteristic.

Finding 3

Designers need further support to fully understand how end users will interact with the SALTT

Although 57.14% of the participants strongly agreed or agreed that (d) affordance-based requirements will help them understand how end-users will interact with the product, the rest (42.86%) provided a neutral reply. ES7 stated that it is impossible to predict exactly how the end user will interact with the product but "*only an idea in [their] mind of how the user is going to use it*".

Finding 4

SALTT ABRs are clear to understand

Participants were also asked to rate their level of satisfaction with the way ABRs are generated within ACQUAINT-SALTT. As shown in Figure 10.5, all participants said that they were satisfied.

Overall, how satisfied are you with the ability to generate a list of affordance-based requirements

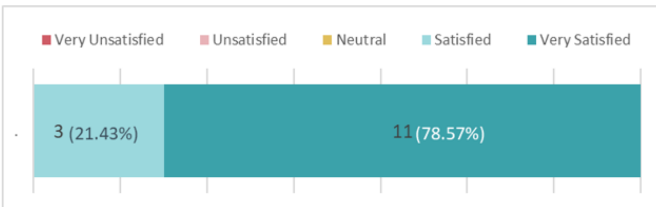


Figure 10.5: Participants' satisfaction on the way ABRs are generated in ACQUAINT-SALTT

Finding 5

Products' marketable descriptions can be used to add /

During the demonstration, participants were very interested in how marketable descriptions of existing products were used to extract their affordances and in *inspire further requirements*

return use them to refine the requirements for product being designed. In fact, this was suggested to be one of the main strengths of *ACQUAINT-SALTT*, with 85.71% being "Very satisfied" and 14.29% being "Satisfied" to be able to add ABRs from existing toy products. This result is shown in Figure 10.6.

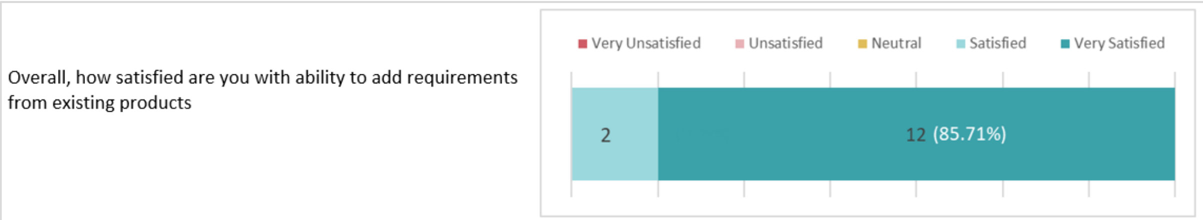


Figure 10.6: Participants' satisfaction on using marketable descriptions of existing toys to generate ABRs

Finding 6

ABRs extracted from marketable descriptions of existing products contribute to discover of new ABRs

According to ES3, the way the *D-SALTT* framework architecture (and *ACQUAINT-SALTT*) handles requirements it gives designers:

> *"the ability to discover new things about toys that you know. For example, you can discover new affordances about an existing toy. Sometimes you might think that you know everything about the product but if you study it very well, you discover other things".*

Given that affordance-based requirements for existing products were manually extracted from the marketable description, two designers suggested automating the compilation of the database of toys and their respective affordances.

10.2.2 Theme 2: Importance of Knowledge, Frameworks, and support tools for SALTT

Finding 7

When the design problem is supported through adequate means, the requirements can be easily understood.

As explained in Chapter 2, the design of toy products is heavily unsupported and as a result, designers struggle during the early stages of product development. When the participants were asked (a) to what extent they agree that the presented framework can support the designer in understanding the given requirements, all participants responded positively, as shown in Figure 10.7.

To what extent do you agree that the presented framework architecture is able to:

a) Support the designer at understanding the given requirements?
b) Support you with the generation of new requirements?
c) Motivate you to explore unforeseen requirements?
d) Motivate you to improve the product being designed?
e) Motivate you to explore more creative solutions?

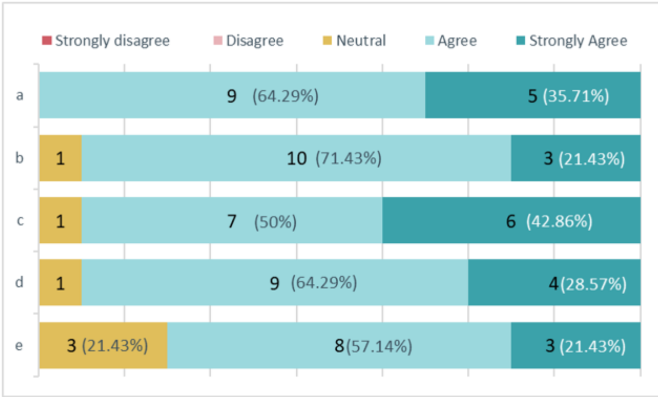


Figure 10.7: Participants' level of agreement on the support provided by D-SALTT

Finding 8

Support at the task clarification stage can enhance creativity rather than restrict it

As portrayed in Figure 10.7, 13 out of 14 participants (92.86%) agreed or strongly agreed that the framework architecture would (b) support them with the generation of new requirements, (c) motivate them to explore unforeseen requirements and (d) improve the product being designed. A participant (7.14%) gave a neutral reply to each statement. Lastly, when the participants were asked whether the framework architecture would (e) motivate them to explore more creative solutions given that it considers existing products in the market, only three participants gave a neutral reply (21.43%) while the rest were in favour.

Finding 9

Using ACQUAINT-SALTT prototype tool for the generation of SALTT-related requirements eases the task clarification stage

Furthermore, as shown in Figure 10.8, when the questions were focused on the prototype tool to assess the level of implementation of the framework architecture, all participants strongly agreed or agreed that (a) *ACQUAINT-SALTT* supports the requirements generation task and (d) is useful for the generation of requirements of SALTT. 92.86% of the participants were positive that (b) *ACQUAINT-SALTT* helps designers to understand requirements and that (c) it addresses an exhaustive list of user requirements for SALTT. In each case, a participant gave a neutral reply. Most participants agreed (50%) or strongly agreed (35.71%) that (g) *ACQUAINT-SALTT* is helpful for starting to generate design concepts for SALTT due to the solution exploration space.

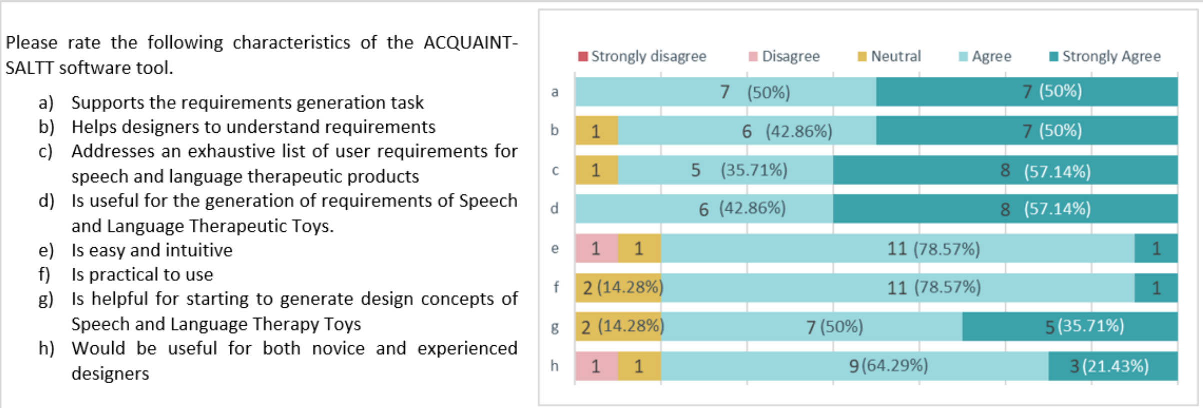


Figure 10.8: Participants' level of agreement on the characteristics of ACQUAINT-SALTT

Finding 10

ACQUAINT-SALTT is easy to use and fits in the design process.

Similarly, 85.72% of the participants agreed that (f) the prototype tool is practical to use for requirements generation. Two participants (ES7 and ES12) gave a neutral reply. When the participants were asked (e) whether the tool is easy and intuitive, and (h) if it would be useful for both novice and experienced designers, 85.72% of the participants were in favour, 7.14% provided a neutral reply, and another 7.14% disagreed. Common feedback on both questions revealed that the implemented tool provides support to any designer given that it contains a repository of knowledge. However, ES01 believed that an experienced designer would benefit more or "*might use the tool in a better way*" given that he/she knows the market better.

Given the detailed demonstration that was provided on ACQUAITN-SALTT, participants were asked whether they require anything else to use the tool to design SALTT products. Only one participant (ES12) said that further hands-on practice is required. The other participants collectively said that said that the "*demonstration was complete*", "*very comprehensive*", "*everything [was] clear*" and "*based on this structure [of the tool] and the knowledge gained*", they would be ready to use the tool.

Finding 11

Design support is required for both novice and more experienced designers

ES1 commented that the tool has everything she needs for the task clarification stage to help start developing concepts. However, as noted earlier, ES2 commented that when a novice designer is presented with such a vast number of considerations and requirements, the designer is overwhelmed. ES12 partly agreed with ES2 but also remarked that there are designers, like ES1, that prefer a high level of detail. ES13 stated that this tool alone is not enough to support novice designers, but they need further support. This proves that design support is required at all levels, especially to support designers entering new fields or industries.

Finding 12

Creativity depends on the experience of the designer but ACQUAINT-SALTT supports it.

As mentioned in Askland et al. (2010) among various factors, creativity stems from the designers' pre-existing knowledge and any supporting knowledge at their disposal which will allow them to use their experience in a particular design problem. DS10 said:

> *"from my experience, for a creative solution, I am not comfortable to use tools. To generate requirements, I would use the tool but to generate creative solutions I do not need tools. [Having tools] will help, but I will need to close the tool and then start generating ideas. Seeing the [existing] toys [within the tool], in one way, it may inspire me and maybe I will design something similar, but if I do not get inspired, I will definitely come up with something original. However, seeing toys that exist is very useful to have reference."*

This contradicts what has been said in Chapter 2 (Section 2.4.5), where design freedom diminishes with gains in design knowledge. Design freedom does not necessarily mean creativity but can be related to how the designer works, such as the methods used during the design process or the way requirements are generated. Supporting these activities should not influence creativity.

Finding 13

ACQUAINT SALTT may bridge the task clarification and concept design stages if integrated with collaborative

Given that most toy designers are inspired by market gaps, "*aha moments*", tacit knowledge, and creative skills, design support tools early in the design process are uncommon among the participants. When asked whether they would like to *idea generation applications such as mood boards*

see *ACQUAINT-SALTT* integrated with another computer-based tool, as noted in Chapter 2, most designers (64.29%) said they could not see how this was possible since they do not use any specific tools. For instance, ES12 and ES13 said that "*it would be difficult to integrate it*" with 3D modelling software, primarily because, according to ES3, "*the task clarification is a step done much earlier than CAD or some other task*". ES6 explained that "*tools that are based on databases are really difficult to match with [other] existing tools*".

ES1 said that integrating *ACQUAINT-SALTT* with another existing software could be helpful but not essential. ES12 argued that ACQUAINT-SALTT could be connected "*with the database of all the toys that have been developed in [their] company*". ES14 said he would integrate it with a "*safety requirements program [developed by a particular company] that helps you do the toy's packaging information*".

ES10 and ES11 mentioned online collaborative platforms that help them generate concepts, namely, the visual discovery online engine Pinterest and online mood/whiteboards such as Miro. ES11 said, "*imagine you can put every product search that [ACQUAINT-SALTT] has generated in a Miro panel*", and ES10 explained that "*with this platform (Miro) you can make mind maps super easy, and you can share it with others. Maybe you can share it with a clinician to evolve and exchange ideas about the design with the whole team*". In doing so, "*this tool (ACQUAINT-SALTT) could be used during meetings [with clients]*".

10.2.3 Theme 3: Differences in the required level of support

Finding 14

D-SALLT follows the activities of the task clarification stage

Participants were asked to state to what extent they agree that the *D-SALTT* framework architecture would support their role during the Task Clarification stage. 78.57% of the participants strongly agreed or agreed, while the others (n=3) gave neutral feedback. Those in favour explained that the way the framework architecture was explained, step by step, "*is very clear and reflects how the designer should work*" (ES5), "*interesting, with a very clear pipeline of tasks*" (ES3), comprehensive (ES13), "*very suggestive and contains all the elements to consider in the early phase [of the] design process*" (ES6), among other comments. ES3 appreciated that the end users are in the centre of the framework architecture, stating that "*I like that in the process, designers and clinicians somehow meet*". He also commented that "*the way you showed [the framework] to me in steps, it was clear. However, seeing it as a single picture it looks like a maze*".

Similarly, ES1, even though she agreed that the framework architecture supports her role, she felt that "*there is a lot of information in one framework*" and that it should be divided into two frameworks. ES8 said that it needs to be visually improved. ES12 stated that "*many designers do not have in-depth knowledge to understand the framework*", and when considering the mainstream market, ES11 explained that she would generally keep it simple by just identifying the gap through market research. This feedback means that a tool would be more beneficial for the industry than a framework.

Finding 15

A structured approach towards requirements generation helps the designer in getting a clear picture of the different requirements

The requirements for SALTTs were organised and based on the 12 elements of the SALT-PM. Participants were asked about the importance of having requirements structured for (i) a generic product and (ii) a SALTT artefact, as shown in Figure 10.9. For the (a) generic product, 92.86% of the participants agreed to have a structured approach, whereas one participant had a neutral opinion on the matter. ES4 said that "*it is very difficult to think about everything at the same time*", and according to ES5, ES6, ES7, and ES10, the more information the designer has in the beginning, the better the end product will be. Like ES11, ES3 said that some designers "*would still focus on a few requirements*" rather than having a long list of requirements.

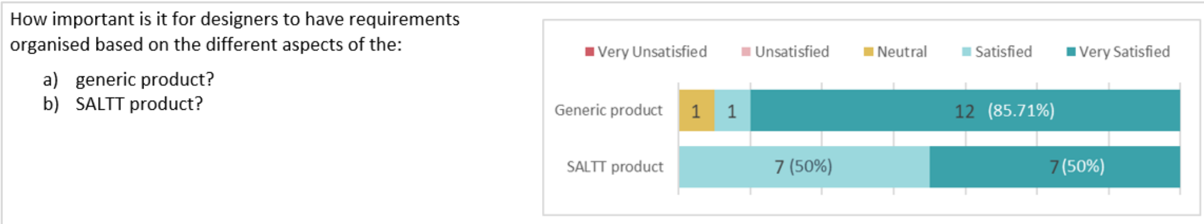


Figure 10.9: Participant's preference on a structure approach in generating requirements

In the case of a (b) SALTT artefact, all participants favoured a structured approach. ES1 remarked that "*it helps to organise the work in a methodological way…[and with a structured list] I could take certain categories of requirements or I can delegate some elements to different team members*". ES10 argued that "*it will be very helpful to have them organised … [because when] mov[ing] from this stage of the design to the creative stage and start making concepts, usually you lose all the organisation*". Because SALTTs are very specific, ES7 stated that he "*find[s] this structured approach very useful in knowing their requirements*".

Finding 16

The designer should be allowed to freely choose which group of requirements to generate

Whilst ES2 provided a similar comment for structured requirements, he also said:

> *"I would gradually fill the requirements as the design progresses because in the beginning, you may not know that you require a particular requirement. It depends on the importance of the elements. For me it is easier to start with the most important requirements so that I can prioritise between them and build the requirements as the design progresses."*

This feedback was echoed by other designers. ES13 mentioned that he "*first start with the play element*". ES3 and ES11 pointed out that they would only work on a few elements in the beginning. ES2 explained that "*the design process is not linear, it's like a wave. So certain information would be useful at different stages*".

10.2.4 Theme 4: Willingness to use *ACQUAINT-SALTT*

Finding 17a

ACQUAINT-SALTT, being research-based, is highly useful and will save time during the task clarification stage.

Throughout the interviews, the participants were asked different questions to determine their willingness to use *ACQUAINT-SALTT*. As shown in Figure 10.10, all participants were likely to (a) use *ACQUAINT-SALTT* to understand the different requirements for SALTT products or (b) recommend the tool to a friend. ES13 commented that for such a niche application, *ACQUAINT-SALTT* would be very useful because it is based on the knowledge generated in this Ph.D. study and related literature about children within this field.

How likely would you be to:

a) use ACQUAINT-SALTT to understand the different requirements for SALTTs?
b) recommend ACQUAINT-SALTT to a friend?

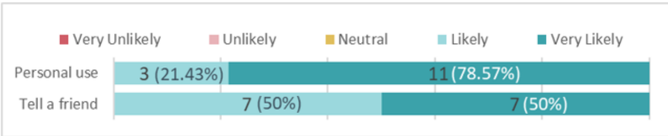


Figure 10.10: Willingness to use ACQUAINT-SALTT or suggest it to a friend

Finding 17b

ACQUAINT-SALTT will allow designers to put more effort in creating better products

ES10 stated that the tool "*provides me a way to focus on the real usability of the product*". Similarly, ES7 said that "*to consider all the different aspects of a speech and language therapeutic toy will take me a lot of time, but the requirements are detailed, and ultimately I will end up with a better result*".

Finding 18

ACQUAINT-SALTT provides knowledge to support designer who have never designed SALTTs

ES11 stated that "*considering that I have never designed a SALTT, it would be a really big help to use it*". Likewise, ES8 remarked that the tool "*is very specific. Usually, it is very difficult to access experts (clinicians) or to double-check requirements with experts for a second opinion when getting requirements from caregivers*". This feedback confirms the phenomenon articulated in Chapter 2, i.e. that designers are not close enough to the end user and that certain requirements from specific users are more challenging to determine, especially ones that require multidisciplinary knowledge.

Finding 19

ACQUAINT-SALTT is also suitable to generate the

Participants were asked to mention cases where *ACQUAINT-SALTT* would be helpful in the requirements elicitation of mainstream toys. The scope of this *requirements for mainstream toys*

question was to understand whether, from the provided demonstration, the participants could foresee cases where the tool would be useful. The general feedback was that designers would only use a selective number of elements and reject the elements that concern the clinicians as users of the toy. ES7 said that although the specifications for mainstream toys will change, the knowledge can still be used. Various sub-themes emerged as participants mentioned ways of how the tool could be used in their work. ES1 and ES14 argued that the Safety and Language elements are also applicable to mainstream toys.

Finding 20

ACQUAINT-SALTT serves as a checklist

Others highlighted the fact that the tool serves as a checklist (ES2), "*to refine the requirements given by Marketing and Sales*" (ES5), "*to [discover] other requirements that we didn't plan from the beginning*" (ES9) or "*when the design brief is missing or not specific, one might use this tool to build the brief by focusing on one element at a time*" (ES4).

Finding 21

ACQUAINT-SALTT urges designers to think how users will interact with the SALTT

ES1 and ES3 mentioned that having requirements in terms of affordances is beneficial, especially in cases where there are small children or a special group of children that require the designer to think and do research.

Finding 22

ACQUAINT-SALTT can be used as a benchmarking tool

The fact that the tool shows the designer existing toy products that match the desired requirements, the tool can be used for benchmarking or to research the competition (ES10), and to identify market gaps or explore how one can improve or innovate on existing products (ES4).

Finding 23

ACQUAINT-SALTT should be more generic to consider other therapeutic areas

The last sub-theme was adaptability. According to ES13, the tool can be used "*to start a new line of products*", or as ES8 commented, for "*specific educational or feature toys having light and sound [technologies]*". ES6 mentioned how the tool would be more useful if other therapy areas were considered and urged that future development should focus on widening the applicability of the tool to other niche areas.

10.2.5 Theme 5: Improvement to the prototype tool

Finding 24a

In the current state, ACQUAINT-SALTT (actual solution) has useful features.

ACQUAINT-SALLT is based on *D-SALTT* framework architecture. However, due to various challenges and limited knowledge in implementing every module, some features such as the cost estimator and knowledge update modules were left out. As shown in Figure 10.11, designers were asked to rate their overall level of satisfaction for the implemented features.

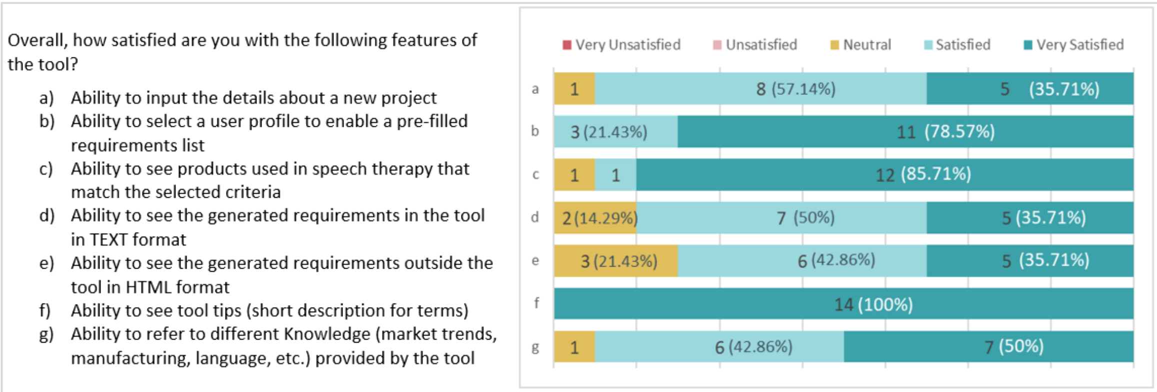


Figure 10.11: Participants' satisfaction on the features of ACQUAINT-SALTT

The (a) ability to start a new project and input relevant details was positively welcomed by all participants except for one designer who does not need to specify who the client will be when starting a new project. All participants (100%) were content with the (b) ability to select a persona and the tool would generate a pre-filled list of requirements. The (c) ability to see products used in speech therapy that match the selected criteria was received well, with only one participant (ES3) giving a "Neutral" reply and stating that the user interface for this feature needs "*more polishing*" in terms of usability.

Similarly, the (d) ability to see requirements being generated in the tool while the designers are exploring different elements was rated positively, with two participants assigning a "Neutral" rating since aesthetics improvements are necessary. A 100% "Very satisfied" rating was given to the (f) tool's ability to display tooltips for every term shown in the user interface. Finally, the (g) ability to access the repository of knowledge within the tool was welcomed positively. One neutral rating came from ES11, who remarked that "*nowadays, everything works with links. Ideally, one would be able to click the product and then see more information and their commercial video*".

Finding 24b

Planned features for the <u>intended solution</u> will enhance ACQUAINT-SALTT

Participants were asked to rate their satisfaction if all the modules mentioned in the D-SALLT framework architecture were to be implemented or further improved. 64.29% of the participants would be "Very Satisfied" while 28.57% would be "Satisfied" to see the remaining features included in *ACQUAINT-SALTT*.

Finding 25

ACQUAINT-SALTT should consider design specifications to reflect better the task clarification stage

The possibility of adding the ability to specify design specifications was proposed to the participants. Twelve participants (85.71%) were in favour, stating that it would be beneficial and that technical specifications could act "*as a filter than would limit the number of results*" (ES3). ES8 proposed that "*even suggestions could be helpful because designers do not always know what they can have or is possible*". ES1 proposed a feature to be able to distinguish between "*must haves and wishes requirements as this would be very helpful in prioritising between requirements*". ES2, who was against adding a design specifications feature, argued that most technical specifications are identified "*at the concept stage or later*", whereas ES6 said that he "*prefer[s] to see the expansion of the tool in other therapy areas rather than having technical specifications*".

Finding 26

The D-SALTT's cost estimator module cannot be one model to fit all enterprises

Three participants (ES7, ES9, and ES13) discussed the Cost Estimator module of the *D-SALTT* framework architecture and whether it would be useful to estimate cost changes when requirements are updated, even after the Task Clarification stage. Although this would be a good add-on, one of the challenges in implementing this feature is that cost models will vary between one manufacturer and another. Cost models depend on whether one can do a component in-house or procure it locally or from a different continent. The support tool would need to consider other stakeholders' requirements, such as manufacturing, because that influences the cost and the design.

Finding 27

D-SALTT (and ACQUAINT-SALTT) can be useful after the task clarification stage, especially if it has requirements management features

Only one participant (ES8) does not think that the *D-SALTT* framework architecture is relevant after the Task Clarification stage. He argued that he would not refer to a framework again after he had seen it the first time. ES3 argued that "*requirements change during the design process, and [one] would want to know how these changes influence other factors such as cost*". Similarly, ES4 said that because many things can change during the product development, it would be good to compare which requirements were satisfied.

Finding 28

Designers need access to knowledge throughout the design process

Moreover, ES1 noted that one "*can go back to [access] all the knowledge within the [tool]*". In fact, 78.57% and 21.43% of the participants said that they would be "Very satisfied" and "Satisfied", respectively, if *ACQUAINT-SALTT*'s Knowledge Repository is improved further in the future.

10.2.6 Theme 6: Importance of visuals for Toy Designers

Finding 29

Design support tools need to be visually engaging with User Interfaces (UI) that provide meaningful User Experience (UX)

The fact that toy designers are very visual in their work became evident while interviewing the participants. Most of the suggested improvements were related to the design of the user interface. ES13 commented that more graphics need to be added to the user interface of *ACQUAINT-SALTT* to make it more attractive, "*more user-friendly*" (ES2) and "*look fresher*" (ES10). ES8 mentioned that currently, *ACQUAINT-SALTT* contains "*too much text. Designers like simplicity. So, icons would help the designer go through some things more quickly*".

Finding 30

Taxonomy of the SALT-PM needs to be subdivided into lower level elements

Although all participants were informed that they could choose to consider any number of SALTT elements they wished, ES12 questioned why the tabs representing SALT-PM were arranged in that order. A similar comment was made by ES2, suggesting that there should be fewer tabs.

Finding 31

ABRs should be elaborated by pictures and videos to understand how existing toys are used

About the generated ABRs, ES3, ES8 and ES11 commented that they want to see more pictures, links to video commercials and products' webpages and "*a final panel with all the products, like in a mood board*". Although the HTML version of the compiled ABRs list (Figure 9.13) looks slightly better than the text file version, it still needs further improvement and ideally be integrated within the tool rather than as an external file. ES8 mentioned that pictures are not always enough to understand all the affordances offered by a toy, and thus, "*videos of how the toy should or can be used*" are necessary.

10.3 Chapter Conclusions

D-SALTT aids the task clarification stage and beyond

Given that the actual design process starts from, and subsequently based upon, a requirements list, the requirements need to be sound and understood by the designer. The *D-SALTT* framework architecture is built upon the activities the designer is meant to carry out during the task clarification stage. This evaluation revealed how designers positively received the framework and the prototype tool, *ACQUAINT-SALTT*, as a supporting means for their role during the early design phase without hindering the creative process. Being based on the SALT-PM and other knowledge bases, the usefulness of D-SALTT and the tool extends to the later design stages as they act as points of reference to which designers can revisit, modify, and consult. Additionality, coupled with the feature to search for similar products, designers are supplied with a basis for the concept design phase.

ACQUAITN-SALTT as a requirement generation tool

Through the evaluation study, 14 participants experienced how the affordance-based requirements for SALTTs can be generated using *ACQUAINT-SALTT*. The usefulness of this prototype tool was noted by the various supporting evidence in which participants showed a positive attitude towards the tool, achieving all the study's objectives. Although SALTTs were a relatively 'new' category of toys, through ABRs, they understand how end users are meant to benefit from such an artefact. Equally important, the designers appreciated that *ACQUAINT-SALTT* is a design support tool based on research. Therefore, requirements can be generated and accepted much quicker, allowing them to put more effort into the actual design of the artefact. Designers were surprised by the number of ABRs generated during the demonstration. In today's digital world, the design brief should not be a text document but a multimodal report.

Practical features that facilitate and support the early design process

The usability features embedded in *ACQUAINT-SALTT* and the simplicity of the user interface allowed designers to comprehend how it can be used through a single demonstration. Although improvement suggestions were put forward on the visuals of the tool, designers felt comfortable using the tool themselves and expressed instances where this tool can be valuable.

Structured way to look at the needs of SALTT

Because *ACQUAINT-SALTT* is based on the SALT-PM, end-users SALTT needs were divided into 12 elements. This enabled designers to understand the different aspects of a SALTT and how they differ from mainstream toys, thus providing a clearer picture of the resources required to tackle each element. Furthermore, given that *ACQUAINT-SALTT* does not restrict how many elements are considered, designers said it could be used to elicit mainstream toys' requirements.

The benefits of D-SALTT extend the advantages of ACQUAINT-SALTT

Features that are yet to be implemented in the tool but highlighted in the *D-SALTT* framework architecture were welcomed positively, meaning that the value of *ACQUAINT-SALTT* can be increased in the future. Designers mentioned that the ability to revisit the generated requirements for a certain project would allow them to manage requirements. Additionally, further improvements to ACQUAINT-SALTT can be made to support design collaboration.

11. DISCUSSION

Accept both compliments and criticism.
It takes both sun and rain for a flower to grow.

Marek Kośniowski, 2018

This chapter discusses the results obtained from the evaluation study carried out in Chapter 10. Section 11.1 provides a summary of the research work carried out before the final evaluation study. The strengths and limitations of the framework architecture, the SALT-PM and the implemented framework architecture prototype solution are discussed in Section 11.2. This is followed by a discussion on the extent of validity of the achieved results in Section 11.3. Improvements and future research work directions are emphasised in Section 11.4 Conclusions are presented in Section 11.5.

11.1 Introduction

In this doctoral study, the following research work was carried out to address the five research questions postulated in Chapter 5 and the objectives mentioned in Chapter 1:

Part A: *Chapter 2*

- The designers' challenges were investigated, and it was empirically verified that support at the task clarification stage was required to design SALTT products.

Chapter 3

- The high-level requirements for SALTTs were established through various studies with clinicians and caregivers.
- It was determined that the affordances of toy artefacts influence children's attention spans, emotions, and level of engagement.

Part B: *Chapter 6 - 7*

- The end-users requirements for SALTT products were mapped into the SALT-PM.
- The SALT-PM was validated empirically with clinicians and through a case study where a prototype SALTT was developed and tested with end users.

The results of the studies carried out in Chapters 2, 3, and 7 were discussed in the respective chapters.

Chapter 8

- A user-centred design framework architecture, *D-SALTT*, that supports the elicitation of affordance-based requirements (ABRs) was developed in respect of the leading research question (1) of the dissertation.

Chapter 9

- The *D-SALTT* framework architecture was implemented into the *ACQUAINT-SALTT* prototype tool using the SALT-PM ontology as the basis of the tool.

The following discussion assesses the strengths and weaknesses of the *D-SALTT* framework architecture, SALT-PM and *ACQUAINT-SALTT* prototype tool as per the outcomes of Chapter 10.

11.2 Solution Assessment

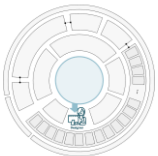
11.2.1 Strengths

D-SALTT strengths

A prescriptive framework architecture that depends on descriptive knowledge

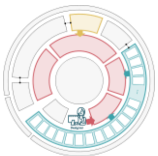
The *D-SALTT* framework architecture was initially intended to support the requirements elicitation of SALTT products only because of the research boundary (RB2) set for the research. However, being implemented as an ontology, SALT-PM is treated as a library that the framework architecture uses to infer domain-specific end-user requirements. This means that the framework architecture is prescriptive and can be used to generate requirements within any domain, provided that an appropriate knowledge library is allocated. The framework architecture shares diverse aspects with existing methodologies because its systematic procedure is intended to support the requirements generation process whilst acquiring domain knowledge. At the same time, the combination of the modules within the framework architecture provides a novel approach to eliciting ABRs. A combined prescriptive and descriptive approach caters for bottlenecks present in one another.

Relevance to the requirements generation process



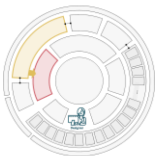
Findings 7 and 14 of Chapter 10 provide empirical evidence that the designers did not find the *D-SALTT* framework architecture intrusive. It supports the requirements elicitation activity without restricting creativity during synthesis (finding 8). The framework architecture values the input of stakeholders who are the source of the requirements and urges designers to carry out field studies before extracting the needs through the computer-based tool.

Support the requirements elicitation process



As Fan and Jiang (2012) argued, pre-built scenarios or personas allow for a set of requirements to be generated quickly. On the other hand, as Pahl et al. (2007) suggest, checklists or knowledge libraries support requirements refinement. As highlighted in findings 5 and 6, the solution exploration space shares the TRIZ concept to further augment the elicited requirements list by looking at past products. This is also proposed in (Neelamkavil and Kernahan, 2003; Pahl et al., 2007). Moreover, the framework architecture embraces the fact that product development and domain knowledge are critical at the beginning of a project.

Significance of the ABR statements at the task clarification stage



The novel aspect of the *D-SALTT* framework architecture lies in the requirements to affordances mapper module, which translates needs into formalised ABRs. Findings 1, 2 and 4 reveal that formalised ABR statements are suitable for expressing customer needs, even though most designers have never heard about the term affordances. This framework architecture can be used as an antecedent to the ABD methodology (Maier and Fadel, 2009b) described in Chapter 2 and the work of Cormier and Lewis (2015). Given that ABR statements are formalised, all requirements have the same format. Moreover, they are expressed in the natural language and detail how the requirement relates the solution to the user (finding

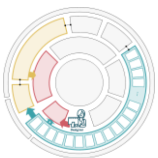
21). ABRs maintain the solution as abstract as possible since they are related to instrumental affordances. Thus, they do not interfere with the designer's creativity. This implies that ABRs can communicate customer needs with any domain because they are dependent on the implemented knowledge libraries.

Significance to the design practice

The designers' willingness to use *ACQUAINT-SALTT* is proof that the *D-SALTT* framework architecture is beneficial to the task clarification stage. Equipped with relevant knowledge about different domains, it allows designers to save time in understanding and capturing the users' needs, allowing them to put effort into other design activities (finding 17). It must be mentioned that the interviews were carried out with designers having a varied range of experience. Whilst novice designers would require better support than more experienced designers, finding 11 disclosed that all designers welcome such tools. This result is significant to the hypothesis given that, as discussed in Chapter 2, toy designers do not use any tools at the beginning of a project. This also indicates that the framework architecture provides the foundation for fulfilling the envisaged reality, as shown in Figure 11.1.

Figure 11.1: Design practice change

Requirements and knowledge documentation



Another strength of the framework architecture is that requirements are collected and gathered through a single source. Vijaykumar and Chakrabarti (2008) mention numerous instances where time is wasted due to dispersed information. By providing a systematic framework that handles the generation of requirements and provides a repository of knowledge libraries, designers are equipped with explicit knowledge required to cater for the uncertainties attached to every new customer problem. Just for this purpose, the designers expressed that the framework architecture may still be relevant to subsequent design stages (finding 27).

SALT-PM strengths

Makes aware the SALTT considerations

The SALT-PM outlines the requirements for SALTT products which is useful for when design briefs are short and lack detail, and the resources and accessibility to crucial experts are limited. It communicates how SLT can be facilitated and delivered through a medium that enables higher cooperation and engagement. Finding 18 discloses how the implemented prototype tool helps designers who have never designed SALTT products to understand the customer needs. Insight about the contexts and the user characterises which may limit the potential of a SALTT are explicitly highlighted at the requirements elicitation stage, along with other considerations such as representation and safety. Instead of decomposing the problem into sub-functions, the SALT-PM ontology provides awareness of the need-related and instrumental affordances described in Chapter 2.

Structures requirements generation

The advantage of an ontology is that it structures information, allowing designers to focus on different aspects of the problem. Finding 15 elucidates that not all designers work in the same way and that an ontology adapts to their style. Some prefer to see the whole picture of the artefact to be designed, whereas others prefer to focus on ones deemed more critical first. It gives designers and project managers alike the ability to plan the required resources and delegate responsibilities. Designers suggested that the SALT-PM acts as a checklist (finding 20), ensuring that all requirements were considered. This provides reassurance that important SALTT characteristics are not overlooked.

ACQUAINT-SALTT strengths

Eases the task clarification stage

ACQUAINT-SALTT provided insight on how the User Interface Layer within the *D-SALTT* framework architecture would ease the requirements elicitation task (finding 9) without interfering with other tasks, or the way designers work (finding 10). The tool does not restrict users from considering SALT-PM elements in a particular sequence, but switch between elements without losing any information. As per finding 16, designers were satisfied to see that they can have control over the requirements that can be generated.

Allows designers to see the requirements being generated

Similarly, the selected requirements were automatically transformed into ABRs and presented on the Requirements (side) screen. This was beneficial in keeping track of the ABRs already considered.

Provides benchmarking and market gap finding possibilities

The other utility of the side screen is the solution exploration space which many designers claimed to be one of the tool's strengths. Apart from eliciting requirements through the marketed ABRs, one can benchmark ideas (finding 22) or get inspired for the concept design stage. The exploration space for each element of SALT-PM is independent of each other, allowing for wider scoping and the identification of market gaps. Designers observed that the solution exploration space could support creativity and innovation (finding 12).

Ulterior uses

In its current form, *ACQUAINT-SALTT* can also elicit requirements for mainstream toys rather than just for SALTTs (finding 19). This is because half of the SALT-PM is based on the children's needs. The Play element extends the therapeutic requirements by offering a usage mode that can be independent of the intervention activities. Conversely, intervention can be based on the sub-elements of play.

Personas linked to the ontology

A set of SALTT attributes were associated with each persona such that when the designer selects a persona, the respective SALTT requirements are generated automatically. However, after loading the preconfigured settings, the designer is still allowed to perform adjustments.

Documentation of requirements

Another benefit of using *ACQUAINT-SALTT* is that requirements are saved into a text file or an HTML file, which can be printed outside the tool's environment. Project details are immediately saved when the designer starts a new project, whilst ABRs belonging to a SALT-PM element are saved when the designer decides so. The ABRs of existing products can also be added to the requirements lists, but the current implementation is limited, as explained in Section 11.4.3.

Supports the designer in understanding each end-user requirements

The strong presence of tooltips within *ACQUAINT-SALTT* was assigned the highest satisfaction rating. Given that designers had no experience with SALTT artefacts, tooltips and the twelve tabs corresponding to the ontology structure prevented designers from being overwhelmed or feeling intimidated by the unfamiliar terms related to SLT.

11.2.2 Weaknesses

D-SALTT weaknesses

High-level representation

The framework architecture intends to show how the end goal, that is, requirements elicitation, will be achieved. Implementation details, such as which technique or algorithms to use, should be part of the solution such that the software developer of the support system is not limited to using a single method of execution but is allowed to explore different approaches. On the other hand, evaluators that work only in the industry claimed that it looked complicated before a step-by-step rundown of the framework architecture was provided.

Weakness in representing requirements in later design stages

Due to *D-SALTT*'s circular representation, the designer's interaction with the users appears to occur just at the beginning of the design process. This is because this doctoral research focuses on the elicitation process only rather than the entire product development process. Moreover, the framework architecture only tackles the refinement of the initial requirements. However, as the principle solution takes shape in the embodiment design stage, requirements may need to be refined in further detail to remain relevant. For this reason, the framework architecture should capture what happens to the requirements following the requirements elicitation stage.

Does not consider other requirements engineering activities

The *D-SALTT* framework architecture lacks the consideration of other requirements engineering activities associated with the task clarification stage, mainly requirements analysis and requirements translation into design specifications. As disclosed in Chapters 2, 4, 8 and 10 practitioners and particular literature argue that these activities should be conducted during the concept design stage or later stages as unknown variables become more precise and requirements conflicts are better understood.

Estimated cost module

The addition of a cost estimation module may inhibit the requirements elicitation process. As a result, the customer requirements might not be thoroughly investigated if cost estimates surpass the established budget. This feature might be more beneficial in the concept design stage since the cost is associated with the implementation. However, organisations working with myriad types of technologies can provide this information, especially if the realisation of certain features involves only software development. Providing cost estimates for each requirement might also affect the designer's freedom to explore alternative solutions as discussed in Chapter 2 for Decision-Based Design. Nonetheless, as detailed in Chapter 10, the cost depends on many factors, and thus, estimates would only apply to a specific organisation. To reduce the cost influence on the requirement generation process, each element's potential should be provided as it will allow the designer to better value the elements and sub-elements provided in the SALT-PM.

SALT-PM weaknesses

Considers the end-user needs only

The main weakness of the SALT-PM ontology is that it considers the SALTT artefact on its own and does not map the relationships between its elements and the end users, their characteristics, affordances, environment, and PD stakeholders. A *heavyweight ontology* (Wong et al., 2012) provides more benefits to the requirements elicitation stage as it allows designers to consider a broader range of requirements, especially if other ontologies, e.g., the product finish ontology of Darlington and Culley (2008) are linked to the SALT-PM ontology.

Challenges in representing existing toys products with the SALT-PM ontology

The SALT-PM ontology consists of 123 sub-elements, of which the majority are concerned explicitly with speech and language therapeutic needs. For this reason, existing toys that are currently used in therapy can only be mapped to the basic elements relating to SLT. For instance, a toy can be said to have intervention attributes but not assessment, reward, or administration features.

ACQUAINT-SALTT weaknesses

Based upon the SALT-PM ontology only

The main user interface of *ACQUAINT-SALTT* is based on the SALT-PM ontology. This means that this prototype tool cannot be used to generate requirements other than SALTT (and mainstream toy products). Furthermore, the knowledge bases within the Knowledge Reference module were not populated; subsequently it does not provide much support.

Requirements documentation needs to be improved

Designers complained about the visuals, mainly on how requirements are outputted once the requirements elicitation process finishes and on the screen. Due to implementation limitations, pressing the button "Save Requirements" multiple times for the same element will not cause requirements of the same category to be overwritten but instead added consecutively to the bottom of the document. Ideally, repeated requirements are overwritten so that only one instance of a requirement is present. As it is, the designer needs to remember that the button does not need to be pressed more than once unless changes are affected. In such cases, the requirements document needs to be manually cleaned to erase repeated requirements. This problem can be fixed by either saving the requirements once at the end of the elicitation process or else implementing a requirements checker that automatically deletes repeated ABRs.

Another problem that results from the sequential input of ABRs into the document is the addition of new requirements from the existing products. In the current version of the tool, ABRs generated from the exploration space are added beneath the set of requirements for the SALT-PM element being considered. Ideally, an option should be given to select whether newly generated ABRs from the existing products are added beneath the element being considered or at the end of the document.

Construct ABRs

ACQUAINT-SALTT should generate the ABR statements based on an ontology rather than on manually pre-compiled statements. This would increase programming efforts as new rules would need to be specified for every type of instrumental affordance. Thus, making the tool suitable for generating requirements in other domains and possibly at concept design stage.

Improving the solution exploration space

In *ACQUAINT-SALTT*, existing solutions that match the required sub-elements are not ranked based on a criterion, such as the best fit, but presented in the solution exploration space in the sequence stored in the database. Whilst this is not necessarily a weakness of the tool, having numerous products to choose from in the solution exploration space can be overwhelming to the designer. The potential level assigned to each element can be used as a weighting factor to rank existing products.

Weaknesses due to limited support provided

In Chapter 9, details of the level of implementation of *ACQUAINT-SALTT* were provided. This meant that the prototype solution did not provide all the features mentioned in the *D-SALTT* framework architecture. As a result, the incomplete support results in weaknesses. These include:

- a missing secondary user interface for the knowledge management;
- a missing cost estimation module;
- a feature to open, read and display previous project files;
- detailed knowledge libraries;
- improved personas representations and requirements generation; and,
- a client database system that contributes to client-related ABRs.

11.3 Validation of Research Results

Applicability of the research results

The evaluation of the framework and prototype tool focused on addressing the objectives set out by the research questions discussed in Chapter 5. The findings presented in Chapter 10 clearly show that toy designers would embrace the proposed approach to design SALTTs. Nonetheless, due to the boundaries set, this research result is only valid for eliciting end-users requirements for SALTT artefacts used by preschool children. Ideally, requirements engineering support should not only be limited to the elicitation process but covers the other activities, including requirements analysis, negotiations and management. Moreover, to provide holistic support, the needs of every stakeholder involved in the artefact's lifecycle should be considered.

The participants that evaluated *ACQUAINT-SALTT* work in different organisations but in the same industry sector – toy products. To extend the validity of the findings, the evaluation study should have more evaluators from different backgrounds in product development. To prove that the *D-SALTT* framework architecture is suitable and effective within other domains, a different information model that replaces the SALT-PM ontology is needed. Also, the questions need to be rephrased to expose any contradicting statements and eliminate any response bias. Moreover, instead of providing an in-depth demonstration, designers can be allowed to use the tool and go through the requirements elicitation process by themselves.

Validation of the D-SALTT framework architecture

Despite the evaluation limitations, the participants' experience and industrial or academic background were valuable in assessing *ACQUAINT-SALTT*. The findings provide a degree of significant evidence for accepting the research hypothesis stated in Section 1.2. This claim can be made because:

- All designers were willing to use *ACQUAINT-SALTT* and recommend it to other designers.
- Most designers (92.86%) noted that they could start using the current version of the tool to elicit SALTT requirements;
- All designers were satisfied by the clarity of formalised ABR statements and with the ease of generating requirements;
- The knowledge within the SALT-PM is research-based and validated;
- Designers expressed their satisfaction with being provided expertise that generally they do not have access to, is limited or unreliable.

- Their desire to see the tool improved, catering for a broader range of therapeutic toys and being accessible to communities for the greater good of society.

11.4 Further improvements

This section proposes improvements that can be made to extend the benefits and reduce the limitations of the contributions. Further work in this regard is motivated by the positive feedback received from the designers and the aspiration to see SALTT products in use within and outside SLT clinics.

11.4.1 Improvements to D-SALTT framework architecture

Automatic retrieval of relevant products for the exploration space, and the extraction of marketable ABRs

The Knowledge Acquisition module within the Knowledge Management Layer of the framework architecture (see Figure 8.2) must account for the automatic extraction of marketable ABRs from existing products appropriate for SLT. This could be implemented through data-mining techniques to scan e-commerce or patent databases for relevant products using the SALT-PM ontology as guidance. Having more products within the Past Products database makes market gap analysis more robust whilst aiding the designer in discovering unforeseen affordances or new design knowledge. The marketing description associated with these products could be analysed for the presence of affordances and automatically converted into formalised ABR statements. As in Hou et al. (2019), online customer reviews can be used to augment the list of ABRs related to the product.

Provide examples of ABRs

Affordances permit designers to understand user-artefact interaction. Examples or descriptions of an affordance could be provided by extracting information from existing products or other sources. Whilst this would help the designers comprehend how the user intends to use the artefact, it will aid during the concept design stage. The intention is not to limit the designers' creativity but to inform them that improvements or new interactions can be designed. Knowledge about user characteristics, capabilities, and limitations can be presented next to the required affordances.

Provide means to analysis requirements

Coupled with future work on the SALT-PM ontology, designers can be guided in weighing the importance of customer needs. From a planning and solution synthesis perspective, this would allow them to prioritise requirements, if factors associated with market trends, company goals and SLT considerations are factored in. Options to list requirements as demand or wants could also support requirements analysis.

Design Specifications

The current framework architecture does not account for translating requirements into design specifications for the reasons explained in Chapter 2 (Section 2.4). However, to complement the subsequent design stages, the framework architecture should provide means by which ABRs with associated quantitative values or a known specification could be specified (finding 25). The SALT-PM ontology needs to be refined for this improvement to be included. For instance, by identifying the child's motor impairment, the requirement can be accompanied by the range of permissible values for weight and dimensions of the SALTT, among others.

Other requirements engineering tools

The requirements are important to the whole product development process. Thus, to increase the framework's relevance, other aspects of requirements engineering should be added. These include the ability to identify and resolve conflicting requirements, means of facilitating the traceability of requirements and the level of degree they have been implemented, and means to document requirements changes.

11.4.2 Improvements to SALT-PM

Potential of each element

In Chapter 7, SLPs were asked to rate the elements of the SALT-PM. However, the result could not be used as an indication of the potential of each element. This is because the potential level is linked to the level of implementation. Further investigation is required to understand how each element contributes to the artefact's intrinsic potential level.

High-level ontology

The hidden benefit of ontologies is that they can be expanded to include more details about the product or connected to other ontologies by mapping relationships. The SALT-PM ontology should be refined into a heavyweight ontology by specifying how each sub-element relates to the users, to other (sub) elements within the model, the environment, and product development ontologies, as suggested in Darlington and Culley (2008). Ontologies related to the manufacturing, packaging and distribution, and disposal of SALTT artefacts will provide a holistic perspective of the product development stakeholders' needs. A SALTT can be implemented as a product-service system (PSS) by offering tele-healthcare services. PSS ontologies would then need to be connected to the SALT-PM ontology to support designers elicit lower-level requirements. By having a complex network of ontologies, operational ABRs can be elicited and formalised according to the relationships mapped between ontologies.

11.4.3 Improvements to ACQUAINT-SALTT

Enhancing the prototype solution to reflect the D-SALTT framework architecture

In the evaluation study, designers were made aware of the features not implemented in *ACQUAINT-SALTT*, including the cost-estimator module, comprehensive knowledge libraries and the Knowledge Management Layer. Their future implementation would be welcomed, as reflected by the designers' positive feedback (finding 24). One of the strong points of the framework architecture is the Knowledge Bases module within the Knowledge Layer. However, in *ACQUAINT-SALTT*, this module was not implemented in sufficient detail to cover all the aspects of the framework architecture. Future work in this aspect would contribute to the implementation of other ontologies. This would extend the tool's usefulness because designers may need to consult information throughout the entire design process (finding 28).

Improving the visuals of the user interface

Some negative remarks about *ACQUAINT-SALTT* were made about the user interface's visuals and user experience. It was suggested to make the UI more appealing to designers (finding 29) by adding more pictures/icons to reduce the text content. The amount of information presented to the designer at once can be reduced by categorising the twelve elements of the SALT-PM into a higher hierarchy or by hiding the Requirements (side) screen when not being used.

Enhancing the representation of ABRs

Further work is required in the documentation of the ABRs list. It was suggested that the document is made more visually appealing, containing illustrated examples of the ABRs, especially ones extracted from existing solutions. Finding 31 showed that the designers are interested in multimodal examples for the documentation of ABRs, including videos and hyperlinks to explore further the existing solution.

Adding other domains

Four designers remarked that the solution could be structured to cater for other types of toy products. This would involve a prompt screen prior to inputting the project details, where the designer is asked to select the (toy) product for which requirements will be elicited. Upon selecting the domain, the tool would load an interface based on the respective ontology.

Add a collaborative environment

Three designers see *ACQUAINT-SALTT* as a potential collaborative tool. Suggestions were made to upgrade the tool by providing a space where the elicited requirements can be discussed or developed into concepts with other team members remotely. This can provide grounds for brainstorming sessions or support the initial phases of the concept design stage with tools such as mood boards or online whiteboards. In this way, *ACQUAINT-SALTT* would be more useful when the actual designing activities start, predominantly if the knowledge libraries are further populated. By adding these features, the management of requirements can be supported as these then become important in monitoring requirements evolvement. One alternative implementation is to use the document generated from the tool within a separate tool.

Add scenarios

Developing scenarios rather than just personas would significantly improve the requirements generation process as per the benefits discussed in Chapter 4.

11.5 Chapter Conclusions

This chapter discussed the key outcomes of this doctoral research, which led to fulfilling the objectives and addressing the hypothesis set in the beginning. The findings of the evaluation provided evidence that the *D-SALTT* framework architecture has significance in:

- Supporting designers in generating affordance-based requirements
- Providing designers with computer-based tools early in the design process
- Highlighting the significance of the design-artefact-user relationship.

Moreover, appropriate knowledge such as the SALT-PM ontology ensures that the requirements are elicited more comprehensively. This aids designers in starting the concept design stage with a clear definition of the customer problem.

Despite these positive aspects, a few limitations exist in the *D-SALTT* framework architecture. Improvements in this regard have been suggested as future work.

In particular, the *D-SALTT* framework architecture should support other activities within requirements engineering such that requirements are managed throughout the product's lifecycle. For instance, feedback from SALTT products developed in this research can be fed back to improve the SALT-PM ontology.

The next chapter underlines the conclusions from this research and the contributions to knowledge.

12. CONCLUSIONS

Leading in a complex world means recognizing the simple things you can do to make things better.

Condoleezza Rice, 2016

In this final chapter, the conclusions of each part of the dissertation are highlighted in Sections 12.1 to 12.3, followed by a summary of the contributions to knowledge made through this work, as disclosed in Section 12.4. Based on the results achieved, future research work directions are identified in Section 12.5.

12.1 Research Problem Conclusions

Knowledge availability during the initial phase of a new product design project is critical for a product's success. In Chapter 1, it was argued how both novice and experienced designers would find a new industry challenging until they become familiar with the domain. It was emphasised how important it is for designers to take a user-centred design approach when dealing with socio-technical problems such as the research context of this dissertation, that is, speech and language therapy (SLT). Designers stand better chances of creating the right product with a clear understanding of the end-users context. One way to thrive in this regard is to understand how the end user would like to use the artefact rather than just what the artefact will be good for.

As explained in Chapter 2, the philosophy behind the affordance-based design is that the artefact's purpose is appraised with respect to the end users (and their environment) by merging the functional and human implications in design. From the study conducted with designers it is concluded that due to various difficulties and limitations, the end-users needs are not entirely understood, and thus they find it challenging to start generating concepts. Furthermore, failing to elicit the actual needs of the end users will influence the amount and types of interactions users will have on the final product. In Chapter 3, apart from establishing the main requirements for SALTT artefacts, from the study conducted with preschoolers it is concluded that the affordances of toy products influence children's attention span and engagement. It was implied that if the right affordances are considered in SALTT, children's attention span during SLT can increase.

Outcomes from the literature review

From the findings made in the literature review it is concluded that:

- Prescriptive and descriptive requirements elicitation approaches are both beneficial to the designer. Prescriptive approaches provide the framework of how the end-users needs will be extracted, whilst descriptive methods determine what requirements will be extracted.
- Further to generic support, domain knowledge supplies designers with the specific needs of the end users. Research for the elicitation of requirements for SALTT artefacts from clinicians, caregivers and children's points of view is minimal as end users are considered separately.
- Most of the literature looks at generating requirements that determine what the product is suitable for and does not consider how it will be used. An affordance perspective captures requirements about everything that will be done with the artefact, including intended and non-intended, functional, and non-functional behaviour.

- Requirements are specified in terms of one user group. However, in SALTT products, a hierarchy of end users that necessitates different modes of use is present.

Hence, it was concluded that existing requirements generation tools are not suitable within the context of this research. This led to the formulation of the research problem.

12.2 Solution Development Conclusions

A descriptive knowledge model for SALTTs

To provide designers with detailed domain knowledge about the requirements of SALTTs, the speech and language therapy potential model (SALT-PM) was developed in Chapter 6. It is concluded that the SALT-PM captures the requirements of clinicians, caregivers and children for an artefact that facilitates therapy in different use situations, within and outside the clinical setting. In Chapter 7, the soundness of the SALT-PM was validated by speech-language pathologists (SLPs), and through the outcomes of the studies conducted with *Olly Speaks*, a SALTT prototype. Studies on *Olly Speaks* provided evidence that the SALT-PM ontology allows the designer to consider the requirements of the key players involved in SLT such that the developed SALTT affords the respective users. Apart from providing a means by which therapy was facilitated, it was also shown that *Olly Speaks* enticed children to therapy, resulting in longer attention spans and engagement, thus addressing the SLP's main challenge.

The potential of SALTT artefacts

Through the SALT-PM, it is concluded that it is possible to describe an artefact's usefulness or potential for SLT. Although a measure for the potential of SALTT was not determined in this dissertation because of the complex relationship between certain elements, it can be generally stated that the more SALT-PM's sub-elements are considered, the higher the intrinsic potential of the artefact for therapy. On the other hand, the extrinsic potential of a SALTT depends on its usefulness to the end users.

The distinguishing features of the prescriptive D-SALTT framework

In Chapter 8, based on the designers' needs (Chapter 2) and the gap in the literature (Chapter 4), the *D-SALTT* framework (Figure 8.2) was proposed for the development of a computer-mediated support tool. The framework can be distinguished from the state-of-the-art literature on various factors. It is concluded that the main difference is the output of a list of formalised affordance-based requirements (ABRs) statements, specifying how the artefact to be designed relates to the user(s), their characteristics, goals and environment. It is concluded that an explicit formalism of ABRs is essential to communicate the needs of stakeholders whilst keeping the problem abstract.

Moreover, the framework is founded on the knowledge coming directly from the stakeholders and the knowledge stored in libraries (bases). The latter allows personas or scenarios to generate pre-defined needs, elicit further requirements using knowledge as checklists, and structure the requirements document. The framework also allows designers to identify new requirements through existing solutions. As a final step, a cost-estimation module was also proposed to assess the commercial feasibility of requirements such that the designers get an idea of the resources required.

Conclusions from Chapter 8

Overall, it is concluded that the *process* of generating requirements through the *D-SALTT* framework is novel, as none of the reviewed literature matches the stages by which user needs are captured, refined and transformed into ABRs.

Conclusions from Chapter 9

Considering the research and implementation challenges, the prototype tool *ACQUAINT-SALTT* demonstrated how the *D-SALTT* framework could be coupled with the SALT-PM ontology and utilised to familiarise designers with the needs of

SALTTs' end users and to elicit ABRs for SALTT artefacts, even if they do not have access to end users.

12.3 Solution Evaluation Conclusions

Evidence for the research hypothesis

The evaluation of ACQUAINT-SALLT led to a degree of evidence that the developed framework and ontology provide designers adequate support to understand the requirements of SALTT. This is evident from the strengths that emerged during the evaluation of the developed solution, including:

D-SALTT framework strengths

+ the framework supports the requirements elicitation process and does not interfere with the other activities in the task clarification stage;

+ the use of ABRs allows designers to think beyond the product's function;

SALT-PM strengths

+ the SALT-PM lightweight ontology provides insights into a domain where reliable knowledge is hard to access;

+ the SALT-PM structures the requirements elicitation process and ensures that all relevant end-users needs are considered;

ACQUAINT-SALTT strengths

+ *ACQUAINT-SALTT* eases the task clarification stage as it guides the elicitation process for SALTT or mainstream toy products through a practical user interface;

Despite these strengths, the main weaknesses highlighted are:

D-SALTT weaknesses

- because the D-SALTT framework is intended for requirements elicitation, it does not aid the designer in translating requirements into specifications;

SALT-PM weaknesses

- the SALT-PM is not a heavyweight ontology because the relations between the sub-elements are not defined.

- the SALT-PM considers the end-users needs only;

ACQUAINT-SALTT main weakness

- is based on the SALT-PM ontology only.

Future improvements

Even though the framework and the prototype tool were well received by the participants, it is concluded that further improvements can enhance:

1. the *D-SALTT* framework to support other activities of requirements engineering, including the inclusion of engineering specifications;
2. the Knowledge Management Layer of the *D-SALTT* framework such that manual and automatic updates are separated;
3. the user experience of *ACQUAINT-SALTT*;
4. the knowledge bases of *ACQUAINT-SALTT* to provide better support.

Other improvements that merit further research are highlighted in Section 12.5.

12.4 Ph.D. Contributions

Based on the outcomes of this research, it is concluded that this dissertation has made the following original contributions to knowledge.

First contribution

The main contribution of this doctoral research is:

> *the D-SALTT framework architecture, a user-centred design framework for the generating affordance-based requirements. Coupled with the SALT-PM, designers can elicit use-phase requirements for SALTT artefacts.*

From an early design stage, the framework urges designers to be closer to stakeholders and use reliable existing knowledge and similar products to elicit, understand and improve the stakeholders' needs. Affordances-based requirements encourage designers to factor in the users' abilities and the context in which the artefact will be used. In *ACQUAINT-SALTT*, the framework was adopted and used with the SALT-PM ontology to deconstruct the needs of SLT players whilst providing a structure to understand those needs.

The significance of the first contribution from an academic perspective

From the two descriptive studies reported in Chapters 2 and 10, it is concluded that designers experience a high degree of uncertainties and challenges at the task clarification stage. These can be reduced through design support tools that provide an empathic understanding of the users and their needs. The affordance-based approach infers relational requirements which detail how the users will interact with the artefact within an environment throughout the artefact's life cycle. Thus, when realising ABRs, the designer cannot disassociate the function or feature from the users' context.

The significance to knowledge of the first contribution from an industry perspective

With the current prototype of *ACQUAINT-SALTT*, the industry has support in eliciting requirements for SALTT artefacts. Apart from this, the results also demonstrate that the *D-SALTT* framework can be helpful in other applications, provided that the proper knowledge is used. The aim of such tools is not to stop stakeholders from acting as informants in the design process but to enable designers thoroughly understand the context of the problem, support their observations, and ensure that they have collected at least the basic requirements. Tools based on research would solve situations when designers do not have access to crucial domain experts.

Support tools for the task clarification stage address problems associated with an ill-defined design brief, including unnecessary design iterations due to missing requirements. Thus, the provision of tools such as *ACQUAINT-SALTT* would allow designers to focus on the actual design and explore more creative concepts and perform earlier prototype testing more often.

Second contribution

Driven by the research context of this dissertation, the second original contribution to knowledge is:

> *the Speech and Language Therapy Potential Model (SALT-PM), which identifies the needs of clinicians, caregivers and children for an artefact that facilitates speech and language therapy. The SALT-PM emphasises twelve different aspects that designers need to consider when designing SALTTs.*

Each element of the SALT-PM is a collection of related considerations, referred to as sub-elements, extracted from different research areas, including children's development, toy design and play for all, speech-language therapy, and persuasiveness of rewards. When combined, these elements represent a unique model that provides detailed insight into the needs of SALTTs' end users. Unlike Mertala et al.'s (2016) FMP model (see Chapter 3), which concerns the classification of toy products, the SALT-PM was conceived to assist the requirements generation process. This means that designers can use it as a checklist to ensure that appropriate considerations have been made and to validate the final design.

The significance to knowledge of the second contribution from an academic perspective

This contribution's significance towards academia is that it coalesced multidisciplinary knowledge to address the creation of socio-technical artefacts for SLT. From a design perspective, the SALT-PM exposes aesthetic, functional and non-functional, behavioural, emotional, and cognitive requirements identified through a user-centred design approach. As detailed in Section 12.5, new research avenues on how design can address different types of affordances can be explored. On the other hand, the SALT-PM draws implications that artefact design has on the SLT practice. Chapter 7 showed that the SALT-PM provides SLPs insight into how SALTTs' characteristics and features can constrain their applicability to the SLT practice. Furthermore, it recognises the need to verify the SALTTs' effectiveness, reliability, and efficiency in treating developmental language disorders.

The significance to knowledge of the second contribution from an industry perspective

From an industry perspective, the SALT-PM is testimony to the mutual benefits that product development firms and healthcare practitioners can get when they collaborate to identify the real needs of novel product applications. In industry, the standalone SALT-PM promotes the development of SALTT products as it can be used as a checklist for the end-users needs. From an SLP point of view, it can guide novice practitioners to select appropriate (therapeutic) products and rank toys based on their potential.

12.5 Future Research

In this section, future research avenues which merit further research are disclosed.

A heavyweight ontology linked with other product lifecycle requirements ontologies

As discussed in Chapter 11, the SALTT artefact can be described by a more detailed ontology linking requirements belonging to the whole product lifecycle. Such a complex system of ontologies can inform the designer how requirements conflicts arise and thus support requirements negotiation activities. The research question to be addressed is:

> *How can the SALT-PM ontology be developed further and combined with other ontologies to augment the support it can provide to the designer?*

Establish a weighting value for the SALT-PM elements

Further research is required to establish the potential of each element in the SALT-PM model and how it relates to the end users. One route in tackling this research avenue is to treat the Technology element like the Safety element, that is, as a mandatory element when specific sub-elements are desired. To accomplish this, the intrinsic potential of each sub-element should be determined as well. The extrinsic potential can also be determined by classifying developmental language disorders. The question for this research avenue is:

> *How to establish the SALTT artefact potential (SAP)?*

Investigate requirements involving developmental affordances

E.g. The product affords children the ability to

Mertala et al. (2016) divide play affordances into pragmatic, attractive and adaptive affordances. In Balzan et al. (2018), it is also shown that children select to play with certain toys due to affective affordances. During the development of the prototype tool *ACQUAINT-SALTT*, affordances of existing toys were extracted *develop counting skills.*

from the marketed description and categorised based on the aforementioned types of affordances (see Appendix C). Affordances that led to the development of skills could not be classified as pragmatic, attractive, adaptive or affective but were listed under a new category, *developmental affordances*. Such type of an affordance is also not present in the affordances basis of Cormier et al. (2014). Future research on this type of affordance could establish knowledge of children's educational products and the extent to which educational products succeed in contributing to the development of children. The research question to be addressed is:

> *How can affordances be used to evaluate the developmental value of educational products?*

The benefit of using ABR statements is that this kind of affordance can still be easily communicated to the designer. However, the three tiers of affordances (Bærentsen and Trettvik, 2002) discussed in Chapter 2 can provide further insight into how the designer can implement such requirements. Developmental affordances are need-related affordances, and according to Bærentsen and Trettvik (2002) these can be explained through instrumental and operational affordances. For instance, motoric-developmental affordances can be traced to physical manipulations. Harston's (2003) classification of affordances can be used to specify Cognitive, Physical (Adaptive), Sensory (Attractive or Experiential) and Functional (Pragmatic) affordances. On the other hand, different theories need to be used to explain cognitive-developmental affordances, such as the ability to improve one's memory skills. A tentative research question for this research avenue is:

> *How can requirements involving developmental affordances be effectively communicated to the designers?*

Investigate requirements involving affective affordances

In Chapter 3, the term affective affordances was also proposed for explaining ulterior motives that drive children towards certain toy products. Because it was not the focus of this research work, affective affordances were not explored further. People attach personal feelings to artefacts, so a potential research question in this regard could be:

> *Can designers create opportunities for users to embed affective affordances?*

Explore other therapeutic domains

This research achieved positive evaluation results because it imparted knowledge to designers that is not easily accessible or time-consuming to generate. Moreover, the structure format of the SALT-PM ontology facilitated the understanding of the requirements for SALTTs. To cater to other types of therapeutic toys, the first six elements and the Reward element of the SALT-PM can be re-used, provided that play is an integral step of the therapy. Therefore, the research question to be addressed is:

> *How can the Speech and Language Therapy Potential Model be adapted to cater for other toy- or play-mediated therapy?*

These research avenues propose further opportunities for contributions to knowledge within the field of design and prospects for developing design support tools designers need to complement their expertise and skills.

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APPENDIX A: CHILDREN'S DEVELOPMENT

Appendix Table A.1 Levels of attention, adopted from Cooke and Williams (1985)

Stage & Developmental Age	Description
Level 1 (0 to 1 year)	The period when the child's level of attention is deficient. The child's attention swaps between objects, people, or events continuously.
Level 2 (1 to 2 years)	During this period, the infant has single-channelled attention where one can concentrate on a specific self-chosen task. As a result, the child might not cooperate with other tasks and would ignore external stimuli.
Level 3 (2 to 3 years)	At this level, the child still cannot channel multiple stimuli from various sources but can shift his attention, visual and auditory, with the help of an adult.
Level 4 (3 to 4 years)	The child can now shift his or her visual and auditory attention at his own will.
Level 5 (4 to 5 years)	The child can now execute a task while listening to verbal instructions. This means that his attention is two-channelled.
Level 6 (5 to 6 years)	Now the child can fully control and sustain attention whilst manipulating objects and receiving other inputs from the visual and auditory channels.

Appendix Table A.2 Development of Play, adopted from Besio et al. (2017)

Type of Play & Developmental Age	Description
Practice Play (2 months – 3 years)	Play is characterised by simple body movements at this early age. Infants experiment with objects to stimulate their senses, understand cause and effect, and improve their gross and fine motor skills.
Symbolic/Fantasy Play (18 months +)	At this age, children should start to recognise and use symbols. This allows them to assign new meanings to objects. They first start to simulate things that adults do, such as taking care of a doll and then move to more complicated symbolic play, including object substitution or pretending to use objects. As they develop the concept of acting, children start role-playing more complicated actions and even narrate a story.
Construction Play (3 years +)	Practice play is taken to a whole new level when the child starts to gather, arrange, and combine or fit similar objects such as blocks to form a new object based on the symbolic representation of ideas.
Rule Play (3 years +)	In this play mode, children play together by following preestablished and accepted rules.
Solitary Play (3-4 moths +)	Until their social skills develop, children engage themselves in playing on their own, even in the presence of other children. Children may occupy themselves with practice, fantasy or constructive play but do not consider what other children are doing.
Associative Play (7 months +)	The child is still too young to play with others towards a shared goal. Although the child is focused on a different activity at this

	age, social skills such as sharing, lending, and taking turns will start to be learned.
Cooperative Play (18 months +)	At this age, children would join peers and play with toys, materials, or games where they work together towards a common goal.
Competitive Play (3 years +)	At the stage, children learn to play games against their peers. Children slowly familiarise themselves with the concept of winning and losing.

Appendix Table A.3: The development of comprehension, adopted from Cooke and Williams (1985)

Comprehension aspect of language & Developmental Age	**Description**
First verbal labels (6-10 months)	At this age, the child starts to understand simple words but cannot understand the same concept when words are part of complex sentences.
Noun-noun combinations (2 – 2 ¼ years)	Between these ages, the child starts to relate to nouns but is not yet capable of understanding verbs, prepositions, adjectives, adverbs, etc.
Verbs (2½ years +)	Because verbs are more abstract than nouns, children take longer to understand such language concepts. They first learn verbs of actions that they can perform, such as run, throw and stand up.
Attribute and Spatial Relationships (2½ – 4 years)	During this age bracket, children's language expands remarkably. They slowly start to associate things that go together, like using adjectives such as a big elephant and a tiny mouse.
Prepositions (2½ – 4 years)	Spatial terms such as 'on', 'in' and 'under' start making sense and by the end of this age bracket children learn more complex prepositions such as 'between' and 'in front'.
Pronouns (2½ – 3 years)	The first pronouns that children learn are 'I', 'you' and 'we', and by the age of 3, they learn to use them and their possessive form in expressive language. 'He' and 'she' and 'they' are learned afterwards.
Tenses (2½ – 4 years)	As children become more exposed to language, they understand using the past tense and then progress into the future tense.

Appendix Table A.4: The development of language structure, adopted from Fierro-Cobas and Chan (2001)

Monolinguals	**Bilinguals (Sequential)**
Stage 1: The cooing stage (0-6 months)	Interactional period
Stage 2: The babbling stage (6-8 months)	Inference period
Stage 3: The holophrastic stage (9-18 months)	Silent period
Stage 4: The two-word stage (18-24 months)	Code switching period
Stage 5: The telegraph stage (24-30 months)	
Stage 6: The later multiword stage (30+ months)	

Appendix Table A.5: Speech sound development ages, adopted from the Goldman Fristoe Test of Articulation-2

Age	Initial Sound	Medial Sound	Final Sound
2 years	/b/ /d/ /h/ /m/ /n/ /p/	/b/ /m/ /n/	/m/ /p/
3 years	/f/ /g/ /k/ /t/ /w/	/f/ /g/ /k/ ng /p/ /t/	/b/ /d/ /g / /k/ /n/ /t/
4 years	/kw/	/d/	/f/
5 years	ch j /l/ /s/ sh y /bl/	ch j /l/ /s/ sh /z/	/l/ ng ch j /s/ sh /r/ /v/ /z/
6 years	/r/ /v/ /br/ /dr/ /fl/ /fr/ /gl/ /gr/ /kl/ /kr/ /pl/ /st/ /tr/		
7 years	/z/ /sl/ /sp/ /sw/ th	th	th

APPENDIX B: AFFORDANCE-BASED REQUIREMENTS FOR SALTTS

Appendix Table B.1: Formalisation of the ABRs for the Representation element

Representation element				
Chronological Age (Ergonomics)				
The product affords	infants	the ability to use/play	(with) the product.	
The product affords	toddlers	the ability to use/play	(with) the product.	
The product affords	pre-schoolers	the ability to use/play	(with) the product.	
The product affords	grade-schoolers	the ability to use/play	(with) the product.	
The product affords	teens	the ability to use/play	(with) the product.	
The product affords	up to infants	the ability to use/play	(with) the product.	
The product affords	up to toddlers	the ability to use/play	(with) the product.	
The product affords	up to pre-schoolers	the ability to use/play	(with) the product.	
The product affords	up to grade-schoolers	the ability to use/play	(with) the product.	
The product affords	up to teens	the ability to use/play	(with) the product.	
Style (Overall form)				
The product affords	children	the ability to play	with the product	having a real object/animal representation.
The product affords	children	the ability to play	with the product	having a fantasy representation.
The product affords	children	the ability to play	with the product	having a device-like representation.
Associated Gender				
The product affords	children	the ability to play	with a gender-neutral product.	
The product affords	children	the ability to play	with a feminine product.	
The product affords	children	the ability to play	with a masculine product.	

Appendix Table B.2: Formalisation of the ABRs for the Context element

Context element				
Purpose Of Use Requirements				
The product affords	clinicians and caregivers	the ability to use	the product	with a single CHILD.
The product affords a	child	the ability to use	the product	for personal use.
The product affords	clinician and caregivers	the ability to use	the product	with multiple children
The product affords	children	the ability to share	the product.	With other children.
Mode Of Use Requirements				
The product affords the	clinicians, caregivers, and children	the ability to position	the product	on a tabletop or any other flat surface.
The product affords the	clinicians, caregivers, and children	the ability to hand hold	the product.	
The product affords	children	the ability to ride	the product.	
The product affords	children	the ability to wear	the product.	
Portability Requirements				
The product affords	clinicians, caregivers, and children	portability	of the product.	
The product affords	clinicians, caregivers, and children	the ability to hold	the product	from graspable interfaces to facilitate portability.
Environmental Requirements				
The product affords	clinicians, caregivers, and children	improved hearing capabilities	of the product	in noisy environments.
The product affords	clinicians, caregivers, and children	the ability to use	the product	in a confined or large spaces.
The product affords	clinicians, caregivers, and children	improved visibility	of the product and its content.	When used in highly/barely lit environments.
The product affords	clinicians, caregivers, and children	improved handling	of the product	when used during movement.
The product affords	clinicians, caregivers, and children	the ability to use	the product	in a particular culture.

Appendix Table B.3: Formalisation of the ABRs for Accessibility element

Accessibility element				
Hearing Impairment Requirements				
The product affords	children	with no hearing impairment	accessibility	to the product.
The product affords	children	with mild hearing impairment	accessibility	to the product
The product affords	children	with moderate hearing impairment	accessibility	to the product.
The product affords	children	with severe hearing impairment	accessibility	to the product.
The product affords	children	with profound hearing impairment	accessibility	to the product.
The product affords	children	with up to no hearing impairment	accessibility	to the product.
The product affords	children	with up to mild hearing impairment	accessibility	to the product.
The product affords	children	with up to moderate hearing impairment	accessibility	to the product.
The product affords	children	with up to severe hearing impairment	accessibility	to the product.
The product affords	children	with up to profound hearing impairment	accessibility	to the product.
Visual Impairment Requirements				
The product affords	children	with no visual impairment	accessibility	to the product.
The product affords	children	with mild visual impairment	accessibility	to the product.
The product affords	children	with moderate visual impairment	accessibility	to the product.
The product affords	children	with severe visual impairment	accessibility	to the product.
The product affords	children	with blindness visual impairment	accessibility	to the product.
The product affords	children	with up to no visual impairment	accessibility	to the product.
The product affords	children	with up to mild visual impairment	accessibility	to the product.
The product affords	children	with up to moderate visual impairment	accessibility	to the product.
The product affords	children	with up to severe visual impairment	accessibility	to the product.
The product affords	children	with up to blindness visual impairment	accessibility	to the product.
Motor Impairment Requirements				
The product affords	children	with no motor impairment	accessibility	to the product.
The product affords	children	with mild motor impairment	accessibility	to the product.
The product affords	children	with moderate motor impairment	accessibility	to the product.
The product affords	children	with severe motor impairment	accessibility	to the product.
The product affords	children	with up to no motor impairment	accessibility	to the product.
The product affords	children	with up to mild motor impairment	accessibility	to the product.
The product affords	children	with up to moderate motor impairment	accessibility	to the product.
The product affords	children	with up to severe motor impairment	accessibility	to the product.

Appendix Table B.4: Formalisation of the ABRs for the Sensory element

Sensory element				
Sensory Features Affordance-based Requirements				
The product affords the	clinicians, caregivers, and children	the ability to experience	visual stimuli.	
The product affords the	clinicians, caregivers, and children	the ability to experience	auditory stimuli.	
The product affords the	clinicians, caregivers, and children	the ability to experience	tactile stimuli.	
The product affords the	clinicians and caregivers	the ability to vary	the stimulus	provided by the product.
The product affords the	clinicians and caregivers	the ability to control	the intensity of the stimulus	provided by the product.

Appendix Table B.5: Formalisation of the ABRs for the Technology element

Technology element				
Technology Class Requirements				
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that has no software.
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that has software.
The product affords	clinicians, caregivers, and children	the ability to use/play	with a software product.	
Software-Hardware Dependency Requirements				
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that is not (0%) dependent on the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that is a little (20%) dependent on the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that is somewhat (40%) dependent on the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that is partially (60%) dependent on the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that is mostly (80%) dependent on the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	that is entirely (100%) dependent on the software (and vice-versa).
Software-Hardware Synchronicity Requirements				
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	where changes in the hardware are not (0%) synchronous with the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	where changes in the hardware are a little (20%) synchronous with the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	where changes in the hardware are somewhat (40%) synchronous with the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	where changes in the hardware are partially (60%) synchronous with the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	where changes in the hardware are mostly (80%) synchronous with the software (and vice-versa).
The product affords	clinicians, caregivers, and children	the ability to use/play	with a physical product	where changes in the hardware are entirely (100%) synchronous with the software (and vice-versa).
Upgradability Requirements				
The product does not afford	clinicians and caregivers	the ability to upgrade	the product.	
The product affords	clinicians and caregivers	the ability to upgrade	the product	by replacing parts.
The product affords	clinicians and caregivers	the ability to upgrade	the product	through modular add-ons.
Updatability Requirements				
The product affords the	clinicians and caregivers	the ability to update	the product.	Manually.
The product affords the	clinicians and caregivers	the ability to update	the product.	Automatically.
Connectivity Requirements				
The product affords	clinicians and caregivers	the ability to connect	the product	to the internet.
User Interface Requirements				
The product affords	clinicians, caregivers, and children	the ability to use	the product	without a user interface.
The product affords	clinicians, caregivers, and children	the ability to use	the product	through a text-based user interface.
The product affords	clinicians, caregivers, and children	the ability to use	the product	through a graphical user interface.
The product affords	clinicians, caregivers, and children	the ability to use	the product	through a touch user interface.
The product affords	clinicians, caregivers, and children	the ability to use	the product	through a voice user interface.

Appendix Table B.6: Formalisation of the ABRs for the Play element

Play element				
Cognitive Play Requirements				
The product affords the	children	the ability to engage	in sensory play.	
The product affords the	children	the ability to engage	in construction play.	
The product affords the	children	the ability to engage	in fantasy play.	
The product affords the	children	the ability to engage	in rule-based play.	
The product affords the	children	the ability to engage	in solitary play.	
Social Play Requirements				
The product affords the	children	the ability to engage	in associative play.	
The product affords the	children	the ability to engage	in cooperative play.	
The product affords the	children	the ability to engage	in competitive play.	
Play Variation Requirements – Involvement				
The product affords	children	the ability to engage	in passive involvement play.	
The product affords	children	the ability to engage	in slightly active involvement play.	
The product affords	children	the ability to engage	in moderately active involvement play.	
The product affords	children	the ability to engage	in highly active involvement play.	
The product affords	children	the ability to engage	in extremely active involvement play.	
Play Variation Requirements – Restraint				
The product affords	children	the ability to engage	in open-ended play only.	
The product affords	children	the ability to engage	in open-ended play.	with some degree of freedom.
The product affords	children	the ability to engage	in balanced open-ended and rule-based play.	
The product affords	children	the ability to engage	in rule-based play	with some degree of freedom.
The product affords	children	the ability to engage	in rule-based play only.	
Play Variation Requirements – Activeness				
The product affords	children	the ability to engage	in mental play only.	
The product affords	children	the ability to engage	in mental and physical.	
The product affords	children	the ability to engage	in physical play	only.

Appendix Table B.7: Formalisation of the ABRs for the Safety element

Safety element						
Age-Safety Requirements						
The product affords	children	aged less than 36 months	the ability to use/play		with the product.	
The product affords	children	aged 3 years and over	the ability to use/play		with the product.	
The product affords	teens	aged 14 years and over	the ability to use/play		with the product.	
The product affords	children	aged up to 36 months	the ability to use/play		with the product.	
The product affords	children	aged up to 3 years and over	the ability to use/play		with the product.	
The product affords	teens	aged up to 14 years and over	the ability to use/play		with the product.	
Safety Standard Requirements						
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard EN 71 (EU/UK).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard ASTM F963 (USA).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard CNS 4797 (China).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard SSA 1063 (South Arabia).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard ISO 8124 (International).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard IS-9873 (India).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy MECHANICAL Standard NM-300 (Brazil/Argentina).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard EN 62115 (EU/UK).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard ANSI/Ul 696 (USA).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard CNS 14276 (China).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard BS EN 55014 (UK).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard ISO 62115 (International).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard IS-15644 (India).
The product affords	children		the ability to use/play	safely	with the product	as per the Toy ELECTRICAL Standard NM-300 (Brazil/Argentina).

Appendix Table B.8: Formalisation of the ABRs for the Language element

Language element				
Language(s) Requirements				
The product affords the	clinicians, caregivers, and children	the ability to communicate	in the (Language) language.	
Language Control Requirements				
The product affords the	clinicians and caregivers	the ability to define	the frequency of different languages	in the product.
The product affords the	clinicians and caregivers	the ability to set	the main language of the product.	
Language Form Requirements				
The product affords the	clinicians, caregivers, and children	the ability to practice	the selected language/s	with proper phonology.
The product affords the	clinicians, caregivers, and children	the ability to practice	the selected language/s	with proper morphology.
The product affords the	clinicians, caregivers, and children	the ability to practice	the selected language/s	with proper semantics.
Language Content Requirements				
The product affords the	clinicians, caregivers, and children	the ability to listen/practice	the selected language/s for different uses.	
Expression Requirements				
The product affords the	clinicians, caregivers, and children	the ability to listen to	words/phrases	that are pre-recorded by actors (DS)
The product affords the	clinicians, caregivers, and children	the ability to listen to	words/phrases	that are outputted through Text-to-Speech technology (DS)
The product affords the	clinicians, caregivers, and children	the ability to listen to	words/phrases	that are outputted through Speech Generation (AI) technology (DS).
Sentence Complexity Requirements				
The product affords	clinicians, caregivers, and children	the ability to listen	to elementary sentences.	
The product affords	clinicians, caregivers, and children	the ability to listen	to simple sentences.	
The product affords	clinicians, caregivers, and children	the ability to listen	to compound sentences.	
The product affords	clinicians, caregivers, and children	the ability to listen	to complex sentences.	
Sentence Variety Requirements				
The product affords	clinicians, caregivers, and children	the ability to listen	to a variety of sentences.	
Voice Intonation Requirements				
The product affords	clinicians, caregivers, and children	the ability to listen	to a computerised voice.	
The product affords	clinicians, caregivers, and children	the ability to listen	to a language accent	for the specified native language.
Comprehension Requirements				
The product affords the	clinicians, caregivers, and children	the ability to speak	to the product	through Recording only.
The product affords the	clinicians, caregivers, and children	the ability to speak	to the product	through Speech-to-Text technology.
The product affords the	clinicians, caregivers, and children	the ability to speak	to the product	through Speech Interpretation (AI) technology.
The product affords the	clinicians, caregivers, and children	the ability to record	words/phrases.	

Appendix Table B.9: Formalisation of the ABRs for the Intervention element

Intervention element					
Developmental stage requirements					
The product affords the	clinicians (and caregivers)		the ability to use	the product	with children at the pre-production stage.
			OR		
The product affords	children	at pre-production stage	the ability to use	the product	
The product affords the	clinicians (and caregivers)		the ability to use	the product	with children at the early production stage.
The product affords the	clinicians (and caregivers)		the ability to use	the product	with children at the speech emergence stage.
The product affords the	clinicians (and caregivers)		the ability to use	the product	with children at the intermediate fluency stage.
The product affords the	clinicians (and caregivers)		the ability to use	the product	with children at the advance fluency stage.
Intervention Target Requirements					
The product affords the	clinicians (and caregivers)		the ability to intervene	on children's	attention and listening skills.
The product affords the	clinicians (and caregivers)		the ability to intervene	on children's	play skills.
The product affords the	clinicians (and caregivers)		the ability to intervene	on children's	language comprehension skills.
The product affords the	clinicians (and caregivers)		the ability to intervene	on children's	language expression skills.
The product affords the	clinicians (and caregivers)		the ability to intervene	on children's	speech skills.
Teaching Approach Requirements					
The product affords	clinicians (and caregivers)		the ability to adopt	a visual-based teaching approach.	
The product affords	clinicians (and caregivers)		the ability to adopt	an auditory-based teaching approach.	
The product affords	clinicians (and caregivers)		the ability to adopt	a tactile-based teaching approach.	
The product affords	clinicians (and caregivers)		the ability to adopt	a kinaesthetic-based teaching approach.	
Intervention Mode Requirements					
The product affords the	children		the ability to use	the product	on their own.
The product affords the	children		the ability to use	the product	when guided by the CLINICIAN or CAREGIVER.
The product affords the	children		the ability to use	the product	with other children.
Intervention Service Requirements					
The product affords the	CLINICIAN		the ability to perform	intervention	with children face-to-face (live).
The product affords the	CLINICIAN		the ability to perform	intervention	with children remotely (online).
The product affords the	CLINICIAN		the ability to assign	intervention activity/activities	to children to be practiced at home (offline).
Intervention Control element					
Adaptation requirements					
The product affords the	clinicians		the ability to adapt	each intervention activity for Attention and Listening skills	
The product affords the	clinicians		the ability to adapt	each intervention activity for Play skills	
The product affords the	clinicians		the ability to adapt	each intervention activity for Understanding of Language skills	
The product affords the	clinicians		the ability to adapt	each intervention activity for Expressing Language skills	
The product affords the	clinicians		the ability to adapt	each intervention activity for Speech skills	
Personalisation Requirements					
The product affords the	clinicians		the ability to personalise	the themes of intervention activities.	
Customisation (Content Control) Requirements					
The product affords the	clinicians		the ability to customise	the content of intervention activities	by modifying (editing) content.
The product affords the	clinicians		the ability to customise	the content of intervention activities	by modifying which content to show/hide.
The product affords the	clinicians		the ability to customise	the content of intervention activities	by making content appear in a random order.
The product affords the	clinicians		the ability to customise	the content of intervention activities	by making content look realistic, cartoon-like or replaced by words.

Appendix Table B.9 (cont.): Formalisation of the ABRs for the Assessment element

Expansion (Content Addition) Requirements					
The product affords the	clinicians	the ability to expand		the content of intervention activities	by inserting custom content
The product affords the	clinicians	the ability to expand		the content of intervention activities	by installing defined add-ons
Difficulty Adjustment Requirements					
The product affords the	clinicians	the ability to adjust		the difficulty setting	of intervention activities.
The product affords the	clinicians	the ability to adjust	# levels	of difficulty settings	
Activity Duration Requirements					
The product affords the	clinicians	the ability to adjust		the number of turns (duration) of intervention activities.	
The product affords the	clinicians	the ability to adjust		the number of repetitions	that an intervention activity needs to be done.
Language Adjustment Requirements					
The product does not afford the	clinicians	the ability to adjust		the language of intervention activities.	
The product affords the	clinicians	the ability to change		the language of an intervention activity.	
The product affords the	clinicians	the ability to mix		different languages	during an intervention activity.

Appendix Table B.10: Formalisation of the ABRs for the Assessment element

Assessment element				
Assessment Target Requirements				
The product affords the	clinicians	the ability to assess	children	with respect to Play development.
The product affords the	clinicians	the ability to assess	children	with respect to Social and Communication development.
The product affords the	clinicians	the ability to assess	children	with respect to Language Expression development.
The product affords the	clinicians	the ability to assess	children	with respect to Language Comprehension development.
The product affords the	clinicians	the ability to assess	children	with respect to Speech development.
Assessment Type Requirements				
The product affords the	clinicians	the ability to assess	children	with Standardised Assessments.
The product affords the	clinicians	the ability to assess	children	with Dynamic Assessments.
Assessment Languages Requirements				
The product affords the	clinicians	the ability to provide (the provision)	assessments in the _______ Language	
			OR	
The product affords the	children	the ability to be assessed	with an (language) assessment	

Appendix Table B.11: Formalisation of the ABRs for the Reward element

Reward element			
Reward Reinforcement Requirements			
The product affords the	clinicians and caregivers	the ability to provide	both POSITIVE and NEGATIVE REINFORCEMENT rewards.
The product affords the	clinicians and caregivers	the ability to provide	positive reinforcement rewards.
		OR	
The product affords the	children	the ability to receive	positive reinforcement rewards.
The product affords the	clinicians and caregivers	the ability to provide	negative reinforcement rewards.
		OR	
The product affords the	children	the ability to receive	negative reinforcement rewards.
Stimulus Type Requirements			
The product affords the	clinicians and caregivers	the ability to provide	visual stimuli rewards.
The product affords the	clinicians and caregivers	the ability to provide	auditory stimuli rewards.
The product affords the	clinicians and caregivers	the ability to provide	tactile stimuli rewards.
The product affords the	clinicians and caregivers	the ability to provide	olfactory stimuli rewards.
The product affords the	clinicians and caregivers	the ability to provide	gustatory stimuli rewards.
Reward Type Requirements			
The product affords the	clinicians and caregivers	the ability to provide	Physical Salient type of reward.
The product affords the	clinicians and caregivers	the ability to provide	Novelty & Surprise type of reward.
The product affords the	clinicians and caregivers	the ability to provide	Motivation Salience type of reward.
Stimulus Control Requirements			
The product affords the	clinicians and caregivers	the ability to change	between stimuli types.
The product affords the	clinicians and caregivers	the ability to control	the intensity of the stimulus.

Appendix Table B.12: Formalisation of the ABRs for the Administration element

Administration element					
User Management Requirements					
The product affords the	(caregivers and) children	the ability to use		the product	for their personal use (at home).
The product affords the	clinicians (and caregivers)	the ability to use		the product	with many different children (clients) (in the clinic).
The product affords the	clinicians	the ability to schedule		appointments with clients.	
The product affords the	clinicians and caregivers	the ability to remember		about appointments or children's progress	
The product affords the	clinicians and caregivers	the ability to send		notifications about appointments or children's progress	
The product affords the	clinicians	the ability to control		the product	using a user interface dedicated for clinicians.
The product affords the	children	the ability to use		the product	from a dedicated interface.
The product affords the	caregivers	the ability to control		the product	using a user interface dedicated for caregivers.
The product affords the	children	the ability to use		the product	from a dedicated interface for children.
The product affords the	clinicians or caregivers	the ability to limit (lock)		children access	to certain features of the product.
Intervention Programme Builder Requirements					
The product affords the	clinicians (and caregivers)	the ability to build		a tailor-made intervention programme	for their clients.
The product affords the	clinicians (and caregivers)	the ability to set		goals and objectives.	
The product affords the	clinicians (and caregivers)	the ability to choose		intervention activities	that the client needs to carry out.
Monitoring Requirements					
The product affords the	clinicians and caregivers	the ability to monitor		the child.	
The product affords the	clinicians and caregivers	the ability to monitor		the child's progress.	
The product affords the	clinicians and caregivers	the ability to monitor		how the child	uses the product.
Reporting Requirements					
The product affords the	clinicians	the ability to output		reports.	
The product affords the	clinicians	the ability to output		a report	about the client's progress and interaction with the product.
The product affords the	clinicians	the ability to output		a report	about the client's details, including case history.
Activity Instruction Requirements					
The product affords the	clinicians / caregivers	the ability to understand	how to interact	with the product	through a user guide or by notifications and through examples and tutorials
Tele-Therapy Requirements					
The product affords the	clinicians	the ability to provide	tele-therapy	with the product	
The product affords the	clinicians	the ability to remote-control		with the product	
The product affords the	clinicians	the ability to do	video-calls	with children	

APPENDIX C: MARKETED AFFORDANCES

The marketed affordances of the first fifteen toys in ACQUAINT-SALTT's toy database.

Appendix Table C.1: Marketed affordances for existing toy products suitable for SLT

Toy #	MARKETABLE AFFORDANCES	Attractive	Pragmatic	Adaptive	Affective	Develop-mental
1	Affords children the ability to play with 20 double-sided, sturdy cards		✓	✓		
	Afford adults to ask simple and satisfying questions and prompts to children		✓			
	Affords children the ability to build vocabulary		✓			✓
	Affords children the ability to increase confidence				✓	✓
	Affords children the ability to explore the word around them				✓	✓
	Affords children the ability to discover everyday objects in their home (context)					✓
	Affords clinicians, caregivers, or children usability (ease of use)		✓			
	Affords clinicians, caregivers, or children the ability to see bold and whimsical artwork of Marion Billet	✓				
	Affords clinicians, caregivers, or children the ability to see illustrations of commonly found items around the home	✓				
	Affords children the ability to learn about colours					✓
	Affords children the ability to learn about the concept of size					✓
	Affords children the ability to learn about textures.					✓
2	Affords children the ability to build/stack/construct tall towers and fantastic fortresses		✓	✓		
	Affords children the ability to have limitless fun				✓	
	Affords clinicians, caregivers, or children the ability to see bright primary-coloured blocks	✓				
	Affords children the ability to explore hands-on		✓			
	Affords children open-ended play				✓	
	Affords children long hours of play		✓			
	Affords children the ability to handle big blocks		✓			
	Affords clinicians, caregivers, or children the ability to pack/store the blocks in an eco-friendly, PVC-free packaging		✓			
	Affords clinicians, caregivers, or children compatibility with other Mega Bloks First Builders products.			✓	✓	
3	Affords children the ability to play a fun language activity	✓	✓		✓	
	Affords children the ability to build consonant-vowel consonant (CVC) words		✓	✓		
	Affords children the ability to learn how to read					✓
	Affords children the ability to practice reading and spelling		✓			
	Affords children the ability to handle color-coded foam letters	✓	✓			
	Affords children the ability to develop their phonics skills, including magic words (long vowel words), vowel teams, and words that have blends and digraphs (two consonants next to each other in a word.					✓
	Affords clinicians, caregivers, or children the ability to store the cards and letters in a compartmentalised storage box		✓			
4	Affords children the ability to serve delicious diner classics		✓	✓	✓	
	Affords children the ability to order a meal on a reusable menu		✓	✓		
	Affords children the ability to cook with a durable plastic frying pan and spatula		✓			
	Affords children the ability to serve using a full place setting		✓			
	Affords children the ability to play with seven wooden food pieces that have different food options on either side		✓	✓		
	Affords children the ability to play with a frying pan, spatula, coffee pot, plate, fork, knife, spoon, milkshake cup, straw, mug		✓	✓		
	Affords children the ability to play with double-sided milkshake and hot drink inserts		✓	✓		
	Affords children the ability to play as food servers, chefs or customers		✓	✓		
	Affords children the ability to wear an apron with pockets		✓			
	Affords children the ability to ring a bell when meals are ready		✓			
	Affords children the ability to learn about paying a bill when playing with play money					✓
	Affords children the ability to write on the guest check with a dry-erase marker		✓	✓		
5	Affords children the ability to play with 52-piece set which includes felt salad greens in hinged containers, and slice-able wooden vegetables, proteins, toppings and two salad dressing bottles.	✓	✓			
	Affords children the ability to place an order on a reusable menu card.		✓			
	Affords children the ability to slice ingredients with a wooden knife on a cutting board.		✓			
	Affords children the ability to toss with wooden salad utensils in the bowl.		✓			

Toy #	MARKETABLE AFFORDANCES	Attractive	Pragmatic	Adaptive	Affective	Develop-mental
	Affords children the ability to enjoy a fresh salad using the fork with self-stick tabs.		✓		✓	
	Self-stick tabs afford children to make a crunching sound when chopping the vegetables.	✓	✓			
	Affords children the ability to pick up vegetable pieces with the fork.		✓			
	Salad dressing bottles afford children the ability to squirt-string when tipped.	✓	✓			
6	Affords children the ability to play with a 15-piece butterfly-themed tea set.	✓	✓			
	Affords children the ability to play with durable plastic components		✓			
	Affords children the ability to play with food-safe plastic components		✓			
	Affords children the ability to pour cold liquids only		✓			
	Affords children the ability to "make-believe" play.		✓			
	Affords children the ability to play with a lid, creamer, sugar bowl with lid, 4 cups, 4 saucers, 4 spoons		✓	✓		
	Affords children the ability to inspire hours of game and imaginative play.		✓	✓		
7	Affords children the ability to create a miniature streetscape, including 12 buildings (fire and police stations, a recycling centre, service station, house, and more), 9 street signs (Stop, One Way, Speed Limit, Yield, etc.), trees, fences, and walls.	✓	✓	✓		
	Affords children the ability to stimulate their visual senses with brightly coloured shaped solid wood pieces	✓				
	Afford children the ability to stimulate their tactile senses with solid wood pieces that are 1-3 inches high.	✓				
	Affords children the ability to stack the pieces		✓			
	Affords children the ability to sort the pieces		✓			
	Affords children the ability to count the pieces		✓			
	Affords children the ability to setup and knock down the pieces.		✓			
	Affords children endless fun				✓	
	Affords children the ability to combine it with other play pieces, toy cars, and figures			✓		
	Affords clinicians, caregivers and children the ability to store the pieces in a divided wooden tray.		✓			
8	Affords children the ability to create freshly-baked pizza.		✓			
	Affords children the ability to put felt sauce and cheese on a wooden crust.	✓	✓			
	Affords children the ability to choose from wooden toppings (pepperoni, olives, mushrooms, and peppers).		✓			
	Affords children the ability to bake in the pizza oven built into the storage and serving counter.		✓			
	Affords children the ability to stick pieces together.		✓			
	Pieces afford other pieces the ability to stock together with self-sticking tabs.		✓			
	Affords children the ability to slice joined pieces with a rolling wooden cutter.		✓			
	Affords children the ability to place an order by using a reusable menu.		✓	✓		
	Affords children the ability to follow instructions for pizza preparation.		✓			
	Affords children the ability to learn about paying a bill when playing with play money.					✓
	Affords children the ability to shake a grated cheese shaker		✓			
	Affords children the ability to lift the pizza with a wooden paddle.		✓			
	Affords children the ability to put the pizza in a pizza box.		✓			
	Affords children the ability to learn/develop counting skills					✓
	Affords children the ability to develop sorting skills					✓
	Affords children the ability to develop fine motor skills.					✓
9	Affords children the ability to lay 52 reusable puffy stickers on double-sided sturdy background board with barn and barnyard scenes.	✓	✓	✓		
	Affords children the ability to build farm characters		✓			
	Affords children the ability to tell stories with the farm stickers and scenes.		✓	✓		
	Affords children the ability to easily lift off stickers		✓			
	Affords children the ability to arrange the scene as they prefer			✓		
	Affords children the ability to express their creativity		✓		✓	
	Affords children the ability to pretend play		✓			
	Affords children the ability to develop fine motor skills					✓
	Affords children the ability to develop hand-eye coordination.					✓
	Affords children the ability to develop narrative thinking skills.					✓
	Affords children the ability to play alone.		✓			
	Affords clinicians, caregivers or children the ability to easily carry the set through a convenient built-in carrying handle.		✓			
10	Affords children the ability to join puzzle pieces.		✓			
	Affords children the ability to spell three and four-letter words.		✓			
	Affords children the ability to gain familiarity with the names and sounds of the letters of the alphabet with more than 50 colourful wooden letters.	✓	✓			✓
	Affords children the ability to develop sight-reading vocabulary					✓
	Affords children the ability to stencil letters	✓	✓			
	Affords children the ability to play lots of learning games		✓			

Toy #	MARKETABLE AFFORDANCES	Attractive	Pragmatic	Adaptive	Affective	Develop-mental
	Affords children the ability to fit the letters into eight two-sided cut-out boards		✓			
	Affords children the ability to develop fine motor skills.					✓
	Affords clinicians, caregivers or children the ability to store all the pieces in a compact wooden storage case.		✓			
11	Affords children the ability to create a world of imaginative adventures.	✓	✓	✓	✓	
	Affords clinicians and caregivers the ability to machine-wash the soft and durable activity rug.		✓			
	Affords children the ability to play with 49 wooden play pieces, including construction vehicles, cars and trucks, play people, buildings, farm equipment and structures, animals, traffic signs, and people.		✓			
	Affords clinicians, caregivers and children with skid-proof backing and reinforced border binding.		✓			
	Affords multiple children the ability to play together.		✓			
12	Affords children the ability to let their imagination and creativity sprout.		✓	✓	✓	
	Affords children the ability to put body parts and accessories anywhere.		✓			
	Affords children the ability to create different fun combinations with the provided accessories.		✓	✓	✓	
	Affords children the ability to promote thinking and imagination.					✓
	Affords children the ability to develop fine motor skills.					✓
	Affords clinicians, caregivers and children the ability to open the back of the potato body.		✓			
	Affords clinicians, caregivers and children the ability to store the pieces in a compartment on the back of the potato body.		✓			
13	Affords children the ability to count 90 rainbow bears.		✓			
	Affords children the ability to sort bears in 6 sorting cups.		✓			
	Affords clinicians, caregivers and children the ability to store all the pieces in a plastic box.		✓			
	Affords children the ability to play math games with 11 laminated, double sided activity card.		✓			
	Affords children the ability to engage in logical thinking and critical thinking.		✓	✓		
	Affords children the ability to develop fine motor and grip skills using tweezers.					✓
	Affords children the ability to develop hand-eye coordination.					✓
	Affords multiple children the ability to play together or against each other.					✓
	Affords children the ability to obtain teamwork ability through completing the tasks on the cards.					✓
14	Affords children the ability to build phonemic awareness skills.					✓
	Affords children the ability to build letter/sound recognition skills.					✓
	Affords children the ability to engage in discriminating sounds, from easier rhyming and beginning sound contrasts to more difficult Vowel and consonant digraph.		✓			
	Affords children the ability to connect sounds to letters.		✓			
	Affords children the ability to learn about sounds made by one syllable sounds.					✓
	Affords clinicians or caregivers the ability to learn how to set up, manage, and assess sound sorting activities with children with the included guidebook.		✓			✓
	Affords children the ability to learn about rhyming, blends and digraphs.					✓
	Affords children the ability to play sorting activities with two, three, four, and five groups of objects.	✓	✓			
	Affords clinicians, caregivers and children the ability to store the 83 objects by individual sound.					
15	Affords children the ability to build a solid foundation for literacy.					✓
	Affords children the ability to place a letter sound in one of the play board wells and fill the others with pictures of words that contain the sound.		✓	✓		
	Affords children to learn about the sounds that a word makes in the beginning, in the middle and in the end through 3 wooden play boards.					✓
	Affords 40 rectangular picture tiles and 31 puzzle-shaped letter-sounds tiles the ability to fit in the wells.	✓	✓			
	Affords children the ability to learn about letter sounds.					✓
	Affords children the ability to find relationships between familiar words and letter sounds.		✓			
	Affords clinicians and caregivers the ability to use the kit with children as it was developed in consultation with education experts.		✓			
	Affords clinicians the ability to tailor gameplay to any age with the provided tips.			✓		
	Affords children the ability to learn about phonics and spelling.					✓
	Affords children the ability to learn how to say each sound.					✓
	Affords children the ability to learn which words contain a sound.					✓
	Affords clinicians or caregivers the ability to discuss phonics and spelling with children.		✓			✓

APPENDIX D: UNDERSTANDING THE DESIGNER'S NEEDS FOR THE DEVELOPMENT OF THERAPEUTIC TOYS.

Introduction

The aim of this questionnaire is to understand whether designers need any type of support in designing therapeutic toys. This questionnaire is part of an ongoing research lead by Mr Emanuel Balzan for his PhD studies.

Through toys and play, children learn all sorts of things about their environment and develop their skills. Toys are also used by clinicians in therapeutic activities such as Speech and Language Therapy. A constant challenge that clinicians have to deal with is attention span. Engagement and attention span can be very short with pre-schoolers, especially if they have conditions such as Autism. Among other reasons, the design of toys can be pretty challenging when specific skills and behaviours need to be promoted. The overall aim of the PhD study is to develop a framework and a computer-based decision support system that proactively guides designers during the early stages of design.

Questions

Section A – Demographic information

1. Professional background information: ________________________________
2. Position: ________________________________
3. Years of Experience in the toy industry: ________________________________
4. Current key responsibilities: ________________________________

Section B – Current Practices in toy design

5. The process of designing toys is identical as designing other consumer products. Do you agree and why?

6. With reference to the Pahl and Beitz Design process model (see below), at what design stage would the toy designer interact with the following people? You may select more than one design stage.

	Task Clarification	Concept Design	Embodiment Design	Detail Design
Marketing	☐	☐	☐	☐
Manufacturing	☐	☐	☐	☐
End-Users	☐	☐	☐	☐
Graphic Designer	☐	☐	☐	☐
Product Manger	☐	☐	☐	☐
Tool Makers	☐	☐	☐	☐
Sakes	☐	☐	☐	☐
Lab Testing	☐	☐	☐	☐
Psychologists / Children Experts	☐	☐	☐	☐
Suppliers	☐	☐	☐	☐

7. What is the most challenging task during the design process? (select 1 or more activities)
   - ☐ Understanding requirements
   - ☐ Coordinating activities with team members
   - ☐ Translating requirements
   - ☐ Generating concepts
   - ☐ Choosing the definite design
   - ☐ 3D modelling
   - ☐ Prototyping and testing
   - ☐ Designing for mass production
   - ☐ Adhering to standards (e.g. EN71)

Please provide any comments for your choice(s):

____

____

8. To what extent do you find it difficult to satisfy all the requirements when designing a new toy product?

1 (Easy)	2	3	4	5 (Hard)
☐	☐	☐	☐	☐

Please provide any comments for your choice(s):

____

____

9. To what extent do you think that computer-based decision support tools are useful in the design process of a new toy product?

1 (Not Useful)	2	3	4	5 (Very Useful)
☐	☐	☐	☐	☐

Please provide any comments for your choice(s):

____

____

10. At which design stage do the most important decisions take place? Please rank the design stages.

	1 (Most Important)	2	3	4 (Least Important)
During problem analysis (task clarification) stage	☐	☐	☐	☐
During concept stage	☐	☐	☐	☐
During embodiment stage (generating the first prototype)	☐	☐	☐	☐
During the final stages of design	☐	☐	☐	☐

Please provide any comments for your choice(s):

____
____

11. Please specify at which stage(s) decision support tools, if any, are used in your organisation.
    - ☐ Task clarification stage
    - ☐ Conceptual design stage
    - ☐ Embodiment design stage
    - ☐ Detailed design stage
    - ☐ Not used

Please provide any comments for your answers:

____
____

12. At which design activity, if any, are end-users (e.g. children, parents) involved?
    - ☐ Gathering of requirements
    - ☐ Defining specifications
    - ☐ Generating concepts
    - ☐ Choosing principal solution (best concept)
    - ☐ Producing the prototypes
    - ☐ Testing the prototypes
    - ☐ Testing the final solution
    - ☐ Never involve

Please provide any comments for your answers:

____
____

Section C: Identifying requirements of toys

13. How are product requirements obtained?
    - ☐ Market research
    - ☐ Observations
    - ☐ Ideas from Investors
    - ☐ Competition
    - ☐ Others: ___________________________________

14. How are requirements communicated to the designer?

____
____
____
____
____

15. How are product requirements (e.g. easily opens) translated into product specifications (e.g. Force = 1-3N)?

____
____
____
____
____
____

16. Besides the requirements, what other resources do the designer resort to, when designing the first concepts?
    - ☐ Past products
    - ☐ Experience
    - ☐ Creative thinking
    - ☐ Tacit knowledge and skills
    - ☐ Other: ________________________

17. Please rate the following design factors that you consider most important when designing toys

	1 (Most Import ant)	2	3	4	5	6	7	8	9 (least Import ant)
Function	☐	☐	☐	☐	☐	☐	☐	☐	☐
Target Skills	☐	☐	☐	☐	☐	☐	☐	☐	☐
Aesthetics	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ergonomics	☐	☐	☐	☐	☐	☐	☐	☐	☐
Play Value	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety	☐	☐	☐	☐	☐	☐	☐	☐	☐
Durability	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cost of Manufacturing	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ease of Manufacturing	☐	☐	☐	☐	☐	☐	☐	☐	☐

18. Toy products can be more effective if:

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Customer requirements are better understood	☐	☐	☐	☐	☐

End-users are involved more often in the design process	☐	☐	☐	☐	☐
Experience gained from previous products is retained	☐	☐	☐	☐	☐
The design process is improved	☐	☐	☐	☐	☐
The designer has tools that support decision making	☐	☐	☐	☐	☐

Section D: Support for toy design

19. To what extent do you agree with the following statements?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Toy designers need support in translating product requirements (e.g. rotating arms) into specifications (e.g. revs/min) .	☐	☐	☐	☐	☐
Toy designers need to know children's preferences in advance and not wait until prototyping stage.	☐	☐	☐	☐	☐
A computer-based tool that supports a toy designer's decision making process before the conceptual stage could potentially reduce design iterations.	☐	☐	☐	☐	☐

Please provide any comments for your answers:

____

____

20. Should a decision support system be computer-based or paper-based?
    - ☐ Computer-based
    - ☐ Paper-based

21. In your case, what would you wish for in a decision-support system to design better toys?

____

____

____
____

Section E: Therapeutic Toys

22. In your opinion, were would a support tool be needed to help you design therapeutic toys?
    - ☐ Task Clarification Design Stage
    - ☐ Concept Design Stage
    - ☐ Embodiment Design Stage
    - ☐ Detailed Design Stage

Please provide any comments for your answers:

____
____

23. How much do you agree with the following statements?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The design process for therapeutic toys should be the same as the design process for normal toys.	☐	☐	☐	☐	☐
Therapeutic toys should be aesthetically different than normal toys.	☐	☐	☐	☐	☐
Therapeutic toys should be functionally different than normal toys	☐	☐	☐	☐	☐
Identifying requirements for therapeutic toys is more difficult than identifying requirements for general toy products.	☐	☐	☐	☐	☐
A computer-based tool for decision making is more suitable for general toy products only.	☐	☐	☐	☐	☐
A computer-based tool for decision making is more suitable for therapeutic toys only.	☐	☐	☐	☐	☐
A computer-based tool for decision making is suitable for both general toy products and therapeutic toys.	☐	☐	☐	☐	☐

Designers of therapeutic toys should consult with clinicians or therapy-related standards	☐	☐	☐	☐	☐

Please provide any comments for your answers:

____
____

24. Suppose you are designing a therapeutic toy, and an end-user requirement is in conflict with an established health-related standard for such toys (e.g. to carry out a remote speech therapy session requires an in-built camera in the toy. But this has a lot of cyber security concerns.)
    - ☐ Implement end-user requirement
    - ☐ Follow the established related standard
    - ☐ Consult with stakeholders and policy makers
    - ☐ Reach a compromise between end user requirement and the established standard

Please provide any further comments:

____
____

APPENDIX E: FOCUS GROUPS QUESTIONS

FOCUS GROUP A: SLPs

Engagement Questions

1. How long have you been working with children as an SLP, and approximately how many children do you have on your workload currently?
2. Describe a typical day of your work.
3. Do children look forward to the speech-language therapy session? How do children feel during therapy sessions? In your opinion, should children be aware of their speech and language condition? Do you think that the therapy sessions should be conducted only in the clinic?

Transition Questions

4. Do children ever bring their own toys at the clinic or do they use only the toys at the clinic? Which toys do they tend to like most?
5. How do you start to assess a child for speech-language impairment? What tools do you use for assessment? How often do you repeat assessment?
6. How does a speech-language therapy session vary among children with different developmental levels and children that have bilingual or multilingual exposure? How long does a typical therapy session last?
7. In your opinion, which speech-language activities work best with children for intervention? How are they best motivated to engage in the activity? Are there any special multi-modal toys/games /activities (e.g. colours, gestures, light, etc.) that entice children with speech-language impairment?

Key Questions

8. How long and how many times should children practice daily/weekly? In your opinion, do you think that the parents/guardians follow your suggestions properly at home (in terms of frequency and knowledge?
9. How do you measure improvement in children's speech and language skills? How do you continuously monitor the child's progress from one session to another?
10. In your opinion, how can speech and language be promoted during play? Further to play, are there any other activities which you suggest to parents/guardians, educators, etc. to facilitate children's speech and language development?
11. Can you mention any technology products (incl. tablet applications) which can be used by children for speech and language therapy? Are there any limitations in these products?

Ending Question

12. Are there any aspects/activities of your job which could be facilitated through technology?

FOCUS GROUP B: ACTU

Engagement Questions

1. Describe a typical day of your work. What kind of Assistive Technology do you use?
2. Should technology facilitate assessment or intervention? What aspects/activities of your job which could be facilitated through technology?

Transition Questions

3. In your opinion, which activities work best during intervention with children with language impairment? How are they motivated to engage in the activity? Are there any special multi-modal toys/games/activities (e.g. colours, gestures, light, etc.) that entice children?
4. Are High Tech methods better than Low Tech methods? What are the benefits and drawbacks of both technologies?
5. Do you think that speech recognition technology would be useful when working with language impaired children or do you find text-to-speech more relevant?

Key Questions

6. From your experience, what other developmental skills should be enhanced through play in order to improve their speech and language skills?
7. Further to play, are there any other activities which you suggest to parents/guardians, educators, etc. to facilitate children's speech and language development?
8. Can you mention any technology products (incl. tablet applications) which can be used by children for speech and language therapy? Are there any limitations in these products?
9. Are High Tech methods better than Low Tech methods? What are the benefits and drawbacks of both technologies?

Ending Question

10. In your opinion, what would be the ideal price range for assistive devices/toys that will help children improve their speech and language skills?
11. Keeping in mind that the toy will be used by children, pathologist/therapist and child, and parents and child, should the toy be different depending on the user and location to be used, or the same toy? What kind of features should a toy/device have such that it promotes speech and language practice?

End Of Focus Group

FOCUS GROUP C: STAKEHOLDERS

Design Questions

1. How can a toy remain attractive (and in use) to children for a number of years?
2. What is the ideal packaging design for a toy/device that needs to appeal clinicians, parents and children?
3. Parent's main concern about toys is **safety**. What safety characteristics do you consider as most important for a technological toy/device for children?

4. How can the device be developed such that children can interact with it through play?

Manufacturing Questions

5. What are the ideal materials and material properties for children's toys? Painted vs. coloured material?
6. What manufacturing considerations are required when producing for low and high volumes? Should one opt for a tool for each component or a family mould?
7. Apart from undercuts, what kind of features should be included in the design in order to reduce manufacturing costs?
8. What kind of product manufacturing defects should be avoided/are allowed (if any) in toys?

Marketing Questions

9. Should the toy/device's form be gender-neutral or stereotyped? Or should customers be allowed to customize the final look of the product?
10. One main drawback of technological products is cost. Considering the fact that the toy will provide a number of functions and it can be used by different people, which of the following is the best marketing strategy?

- One product (all features)
- Product line (different features)
- Customisation (user selects features)

11. What is the best pricing strategy for Product-Service System, keeping in mind that the toy's software (and hardware) can be upgraded?
12. For an unknown brand, what would be the ideal marketing strategy?

Ending Question

As a spin-off of this research, we intend to develop a structured methodology, which would guide designers to take a user-centred design approach to develop a Product-Service System to support children with Language Impairment.

From your area of expertise, are there any other considerations which you think are relevant during the development of a toy for children (with Language Impairment)?

End Of Focus Group

<u>FOCUS GROUP D: CAREGIVERS</u>

Engagement Questions

1. (*Ice breaker*) What was your favourite toy during childhood? Do you still have it? What is your favourite toy/gadget today?

2. What is your child's favourite toy? What makes him/her be attracted to it? Material/colours/size/sounds/light/portability? Has it changed over the past few days/weeks/months? How much do they last before breaking or lose interest?

Exploration Questions

3. Do children take their favourite toy wherever they can? Which toy?
4. What considerations would you make before purchasing a toy for a child?
5. What do you think of today's educational toys? Should toys be interactive and pose as stimulus to their senses?
6. Which technology products are being used by children aged 3-6 years nowadays?
7. Do you spend time playing with your child? What kind of play activities do you do and how often?
8. Do children enjoy sounds and music? How do they act when they hear music or games which make sounds?
9. Other than playing, what do children enjoy doing? Do they enjoy listening to stories?
10. Are the tools and methods used by teachers at school enough to help the child improve? What would you do different if other tools were available?
11. How can today's technology be used to meet children's needs? What would you like to see in an interactive device?
12. How do you know whether a child is making improvement or not?

Exit Question

13. Do you think that children make decisions based on colours when it comes to choosing toys? If you had to define a neutral colour for children what would be?

End Of Focus Group

APPENDIX F: UNDERSTANDING THE LOCAL CAREGIVERS' PERSPECTIVE ON SLT

Section A: Understanding caregivers' views with respect to the Speech and Language Therapy service

1. Which kind of speech and language therapy does your child receive?
   - ☐ Speech (pronunciation, intelligibility)
   - ☐ Language (sentence construction, vocabulary)
   - ☐ Both

2. Does your child look forward to his/her speech therapy session?
   - ☐ Yes
   - ☐ No

Can you mention a reason for your answer.

____

____

3. Where does your child's speech-language therapy session take place?
   - ☐ Home
   - ☐ Clinic
   - ☐ School
   - ☐ Other: ________________________________

4. Would you prefer to have speech therapy for your child at home, if this is not already taking place?
   - ☐ Yes
   - ☐ No
   - ☐ Maybe
5. Do you manage to find time to practice with your child according to the Speech-Language Pathologist's (SLP's) recommendations?

Always	Frequently	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

How is your child motivated to practice speech/language exercises given by the pathologist?

____

____

6. How long do the child's speech-language therapy sessions normally take?
   - ☐ 20 minutes
   - ☐ 30 minutes
   - ☐ 45 minutes
   - ☐ 1 hour
   - ☐ Other: ________________

7. Do you think that the duration of your child's sessions is appropriate?
   - ☐ Too short
   - ☐ About right
   - ☐ Too long

8. Can you mention a speech-language therapy activity that your child particularly likes? Please, describe briefly.

____
____

9. Would you be interested in seeing a visual indication of your child's progress/improvement in speech therapy?
   - ☐ Yes
   - ☐ No
   - ☐ Maybe

10. Is there anything that you would like to see new or different during speech therapy sessions?

____
____

Is there anything that you would to see in a toy which would allow you to practice speech and language therapy with your child?

____
____

Section B: A child's favourite toy

11. Which statement best describes you?
    - ☐ Parent/guardian of a 3-5 year old child
    - ☐ Parent/guardian of a child older than 6 years old
    - ☐ Parent/guardian of a child younger than 3 years old

12. Please choose the general form of your child's favourite toy.
    - ☐ Human form (doll/cartoon character)
    - ☐ Animal (dog, teddy bear, fish, turtle, owl, etc.)
    - ☐ Robot
    - ☐ Monster
    - ☐ Vehicle (truck, helicopter, boat, etc.)
    - ☐ Musical Instrument (drums, trumpet, piano, etc.)
    - ☐ Object (star, telephone, ball, hammer)
    - ☐ Play set (Kitchen set, Doll house, castle, Tool work bench, etc.)
    - ☐ Video game
    - ☐ Boardgame

13. Does the toy have facial features (e.g. eyes, mouth)?

- ☐ Yes
- ☐ No

14. In your opinion, what is your child's favourite colour in the items s/he plays with?

____

15. How often does your child take this toy around with her/him?

Always	Frequently	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

16. In your opinion, which are the two most important criteria that seem to influence your child in preferring a particular toy? Tick only 2 boxes.
    - ☐ Influence from friends/TV/YouTube
    - ☐ Aesthetics (form / colours)
    - ☐ Generation of music/sounds
    - ☐ Interactive features (moving/sliding parts)
    - ☐ Dimensions
    - ☐ Versatility (options for play made available)
    - ☐ Texture/feel
    - ☐ Gender stereotypes (e.g. dolls for girls, cars for boys)
    - ☐ Other: ________________

17. In your opinion, does your child prefer soft/hard/mixed materials in toys?
    - ☐ Soft (plush/rubber/etc.)
    - ☐ Hard (plastic/wood/etc.)
    - ☐ Mixed (different materials)

18. Where does your child prefer to play most with his favourite toy?
    - ☐ Outdoors
    - ☐ Indoors

19. In your opinion, which type/s of toys is/are preferred by your child?
    - ☐ Intellectual and creative toys (games which require mental activity)
    - ☐ Physical and active toys (games which require physical activity)
    - ☐ Digital 'toys' (video games and smartphone/tablet applications)
    - ☐ Analogue toys (castles, doll houses, planes, etc.)

Section C: Choosing Interactive Toys

20. How much importance do you give to the following considerations when choosing a toy for your child?

	Not Important	Slightly Important	Important	Very Important	Essential
is worth the cost	☐	☐	☐	☐	☐
has educational-value	☐	☐	☐	☐	☐

fun/enjoyability	☐	☐	☐	☐	☐
developmental value	☐	☐	☐	☐	☐
is durable	☐	☐	☐	☐	☐
level of interaction	☐	☐	☐	☐	☐
is safe to use	☐	☐	☐	☐	☐
is washable and easy to clean	☐	☐	☐	☐	☐
is portable	☐	☐	☐	☐	☐
has novel technology	☐	☐	☐	☐	☐
has a good build quality	☐	☐	☐	☐	☐
child's wishes	☐	☐	☐	☐	☐
number of features (buttons, light, movement,...)	☐	☐	☐	☐	☐
online reviewers' ratings	☐	☐	☐	☐	☐
advice from relatives / friends / educators / clinicians	☐	☐	☐	☐	☐
features in advertisements	☐	☐	☐	☐	☐
is age appropriate	☐	☐	☐	☐	☐
stimulates the imagination and creativity	☐	☐	☐	☐	☐
fits the child's abilities	☐	☐	☐	☐	☐
fits child's developmental level	☐	☐	☐	☐	☐
is right for the child's sex	☐	☐	☐	☐	☐
matches own (parent/guardian's) interests	☐	☐	☐	☐	☐
is aesthetically appealing (colour, form, dimension, etc.)	☐	☐	☐	☐	☐
has replacement parts	☐	☐	☐	☐	☐
supports add-ons or can be upgraded for prolonged usage	☐	☐	☐	☐	☐
encourages thinking and problem solving	☐	☐	☐	☐	☐

promotes communication and interaction	☐	☐	☐	☐	☐
involves the use of both hands	☐	☐	☐	☐	☐
encourages activity and movement	☐	☐	☐	☐	☐
has a screen	☐	☐	☐	☐	☐
appeals to several senses (visual/tactile/auditory interaction)	☐	☐	☐	☐	☐
can be used in more than one position and in different ways	☐	☐	☐	☐	☐
provides online help from manufacturer	☐	☐	☐	☐	☐
can be easily used	☐	☐	☐	☐	☐
promotes cooperative play	☐	☐	☐	☐	☐
is manageable by the child (dimensions)	☐	☐	☐	☐	☐
is waterproof	☐	☐	☐	☐	☐
is free of gender stereotyping	☐	☐	☐	☐	☐
is appropriate for both indoor and outdoor play	☐	☐	☐	☐	☐
has rechargeable battery	☐	☐	☐	☐	☐
is recyclable	☐	☐	☐	☐	☐

21. In your opinion, which of the following toy options would you rate as the best toy 'companion' for a child?
    - ☐ An autonomous toy (high-tech robot)
    - ☐ A handheld toy
    - ☐ A mountable toy (can be ridden, e.g. tricycle)
    - ☐ A table-top toy
    - ☐ A wearable toy (e.g. watch)

22. Please rank the following that you would like to see in a toy for your child.

	1 (Most Important)	2	3	4 (Least Important)
Visual	☐	☐	☐	☐
Auditory	☐	☐	☐	☐

Tangible	☐	☐	☐	☐
Olfactory	☐	☐	☐	☐
Gustatory				

23. In your opinion, how much do you agree with the following statements?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
An interactive toy should have a touch screen.	☐	☐	☐	☐	☐
Battery life is important.	☐	☐	☐	☐	☐
A toy should be intelligent and able to interact with my child.	☐	☐	☐		☐
A toy should have LED lights and sounds/voice prompts which respond to my child's interactions.	☐	☐	☐	☐	☐
Toys should be controlled by parents through their smartphone for better interaction.	☐	☐	☐	☐	☐

Section D: Background Information

24. How old is your child?
    - ☐ 3 years - 3 years 6 months
    - ☐ 3 years 6 months - 4 years
    - ☐ 4 years - 4 years 6 months
    - ☐ 4 years months - 5 years
    - ☐ 5 years - 5 years 6 months
    - ☐ 5 years 6 months - 6 years
    - ☐ Other: ______________________________

25. What is your child's gender?
    - ☐ Female
    - ☐ Male
    - ☐ Other

26. Was your child exposed to two or more languages throughout his/her early childhood?
    - ☐ Yes
    - ☐ No

27. Please specify which languages your child is exposed to.
    - ☐ Maltese only
    - ☐ Mostly Maltese with some English words
    - ☐ Maltese and English (in equal proportions)
    - ☐ Mostly English with some Maltese words
    - ☐ English only
    - ☐ Matese, English and additional language/s

28. Who is answering this interview?
    - ☐ Mother
    - ☐ Father
    - ☐ Both parents
    - ☐ Guardian(s)
    - ☐ Other

29. Age of the person answering this interview
    - ☐ 18 - 25 years
    - ☐ 26 - 35 years
    - ☐ 35 - 45 years
    - ☐ 46 - 55 years
    - ☐ Other: __________________

30. Marital Status
    - ☐ Single parent (not married, separated, divorced, widowed, etc.)
    - ☐ Married with spouse living at home.

Please provide any further comments:

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APPENDIX G: LIST OF PUBLICATIONS

Balzan, E, Farrugia, P., Casha, O., Wodehouse, A., and Engineering, M. (2018). Evaluating the Impact of Design Affordances in Preschool Children's Toy Preferences. *Proceedings of International Design Conference, DESIGN*, (pp. 2165–2176). Dubrovnik, Croatia.

Balzan, E, Farrugia, P., Casha, O., Camilleri, L., and Wodehouse, A. (2019). Design considerations for therapeutic devices - An investigation of Preschoolers' Preferences for an Artefact's Basic Characteristics. *Proceedings of the International Conference on Engineering Design, ICED*, (pp. 877–886). Delft, The Netherlands.

Balzan, E, Farrugia, P., and Casha, O. (2021). A User-Centred Design Framework for the Development of Speech and Language Therapeutic Toys. *Proceedings of the International Conference on Engineering Design, ICED*, (pp. 303–312).

Balzan, E, Farrugia, P., and Casha, O. (2022). Evaluation of an Affordance-Based Requirements Generation Tool for Speech and Language Therapeutic Toys. Proceedings of International Design Conference, DESIGN. (pp. 1221 -1230).

Balzan, E., Farrugia, P., Casha, O., Frendo Wirth L. and Gatt D.: 'An Affordance-Based Requirements Approach for Developing Therapeutic Artefacts - A case study of Speech and Language Toys', UX4V Rehab 2022, 13-14 October 2022, Pisa, Italy, 2022.