Attracting More Students to Opt for Chemistry at Post-Secondary Level: Potential Barriers for Students to Take Up the 'Chemistry Challenge'

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Abstract

This study investigates concerns regarding the perceived decline in number of young people opting to choose chemistry at secondary and post-secondary level of education in Malta. It analyses the trends in numbers of students studying science subjects in local secondary schools. Despite the decreasing number of science candidates at SEC level, there is a gradual progression of chemistry and biology students from ordinary-level to advanced-level courses. This means that there is a good chance of a SEC science student to confirm his interest in science by retaining the subject at post-secondary level.

Literature suggests that students' attitudes to science are multidimensional and are influenced by a number of factors, mostly originating from their life experience. Studies show that whilst students held positive attitudes towards science as a discipline, there was a declining interest by students towards school science. The paper investigates the factors which determined the students' choice to study science and indicates the aspects that made science more appealing and others that hindered the students' motivation to study it at school. Students were found to be disenchanted from school science for a number of reasons such as its perceived difficulty, lack of direct relevance to their everyday life and the demanding examination syllabi, even though they enjoyed carrying out practical work in the school laboratory and were attracted towards the enterprise of science.

Chemistry is the least studied science subject in many countries. The author therefore refers to theories in chemistry education to shed some light on possible underlying issues dissuading students from choosing to study chemistry and any other potential barriers to learning the subject at school.

The study finally proposes a number of measures that could be taken by various educational stakeholders and policy makers to increase the uptake of science / chemistry in both secondary and post-secondary levels of education. These include increasing relevance of the subject, focussing on the language of communication, providing educational outreach programmes, revising the national science curricula to cater for students with different motivations and aptitudes, assisting in career guidance, investing in human resources and increasing international cooperation between science educators.

Keywords: A-level Chemistry, Uptake of Sciences, Chemistry Education, Science Education, Studying Chemistry Post-16

Introduction

There is a complex set of interacting variables governing students' decisions to opt in or out of school science. The paper tries to understand some of these factors in a bid to address national concerns about the uptake of science subjects half way through their secondary education (year 9) and most importantly at the start of their post-compulsory stage of education (year 12).

In order to attract more students to take up sciences (and particularly chemistry) at these levels of education, one has to understand the students' attitudes towards science. One also needs to understand what factors motivate students to study science / chemistry and what are the main barriers in their learning process.

The study finally makes some recommendations in the light of what has been researched so far and how they can be applied to the Maltese context. The idea is to provide food for thought and ideas for a wider discussion involving science educators and education policy makers.

Current Local Trends at Secondary Level

Every year, more than 5,000 Maltese candidates sit for the public SEC examinations marking the end of their secondary education. Local science educators are concerned of an apparent widespread decline in interest to choose to study science at Form 3. This is partly justified when one considers the negative trend in the number of candidates sitting the biology, chemistry and physics exams at this level, over the last 12 years (Figures 1-4).

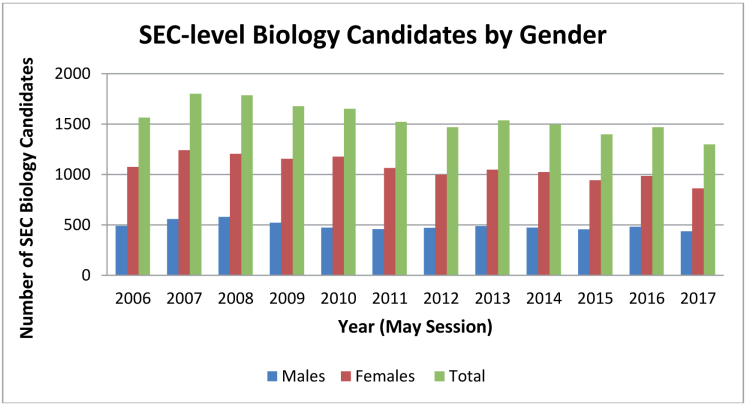

Figure 1
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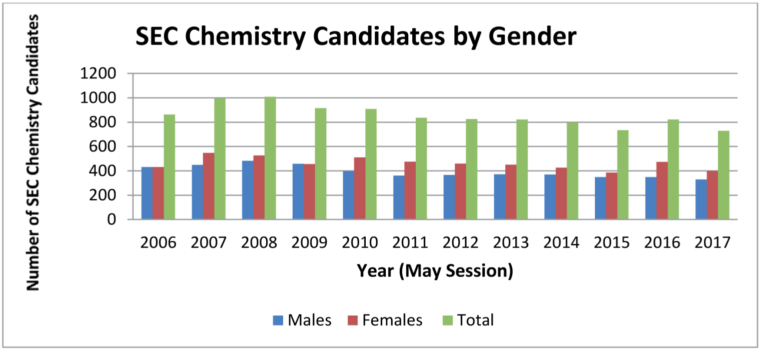

Figure 2
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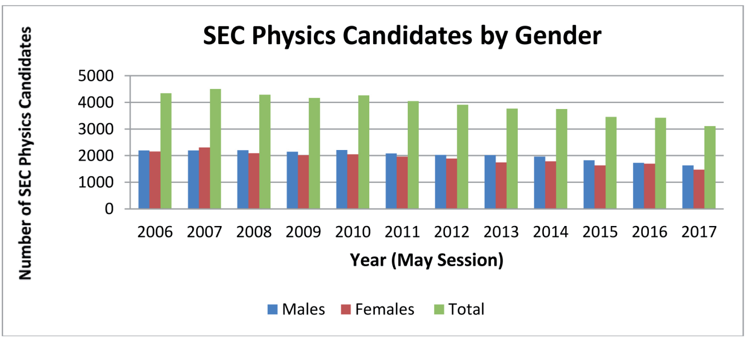

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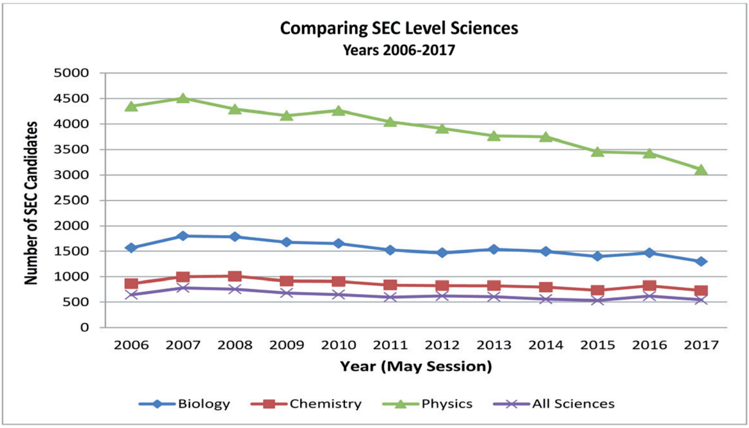


Figure 4
Adapted from University of Malta, Matsec Statistical Reports (2018)

When one takes a closer look at these graphs and considers the various categories of schools of origin of, say, the SEC chemistry students, one would notice that there has been a downward trend in both church and state schools over the last decade (Figure 5).

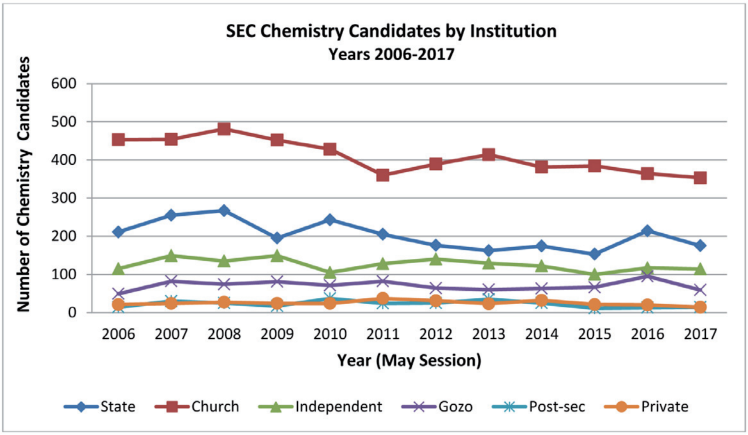
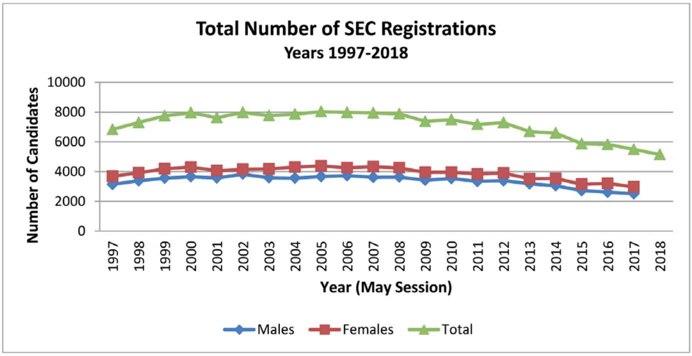


Figure 5
Adapted from University of Malta, Matsec Statistical Reports (2018)

The situation is, however, not as pessimistic as it seems, when it is observed that despite the overall negative trend in the total number of SEC registrations over the past 22 years (Figure 6), there was a recent gradual increase in the proportion of science candidates out of the total SEC cohort (Figures 7, 8 and 9).



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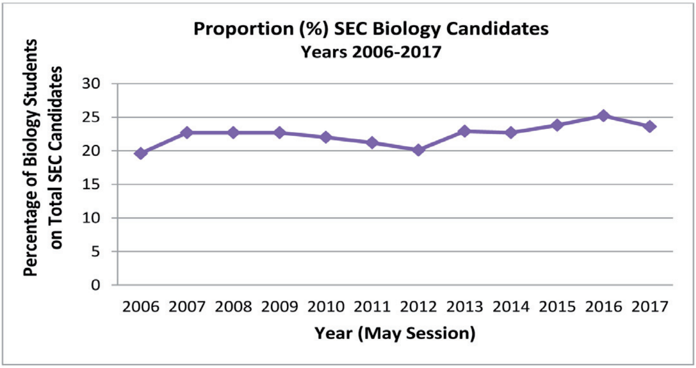

Figure 7
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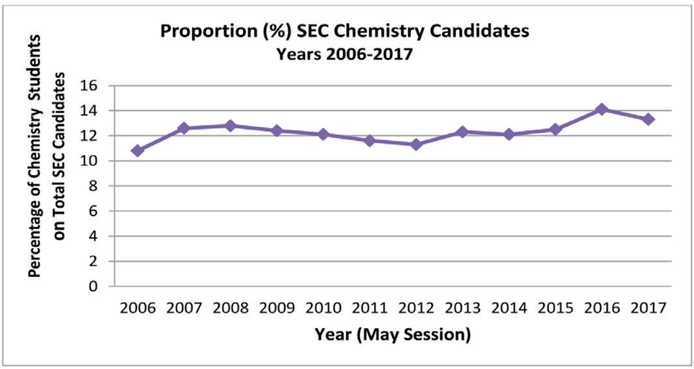

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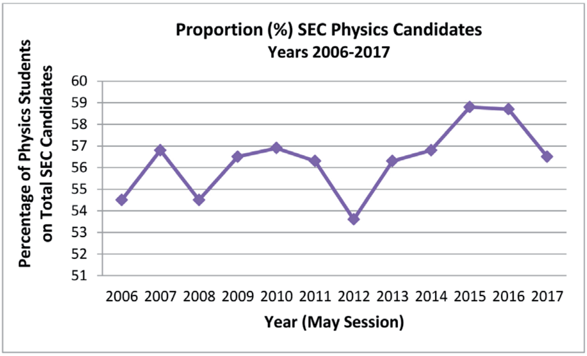

Figure 9
Adapted from University of Malta, Matsec Statistical Reports (2018)

One other point worth referring to is the comparison between the number of students studying each science subject at this level. When one analyses the figures available from state and church schools for year 2017-18 (Figures 10 and 11), it emerges that

- the number of students studying physics in state schools is almost three times those studying either chemistry or biology;
- the number of students studying physics in church schools is almost the same as the total number of chemistry and biology students in the same schools;
- the numbers of chemistry and biology students in church schools are substantially higher than those in state schools;
- the number of physics students in state schools is almost double that in church schools;
- in both church and state schools, the ratio of chemistry to biology students is approximately 3 to 5.

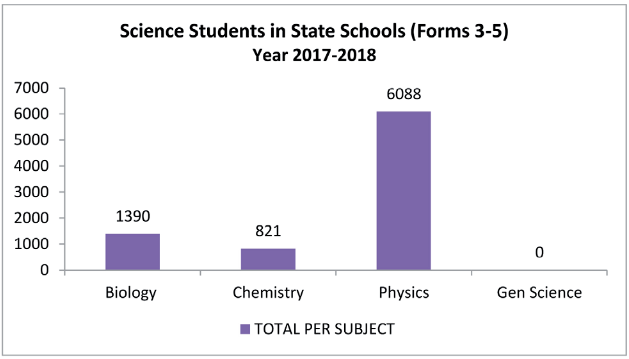

Figure 10
Source: Department for Curriculum, Lifelong Learning & Employability, Education Division (2018)

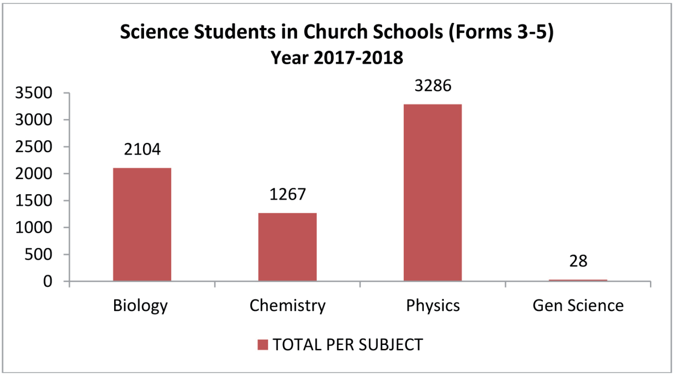

Figure 11
Source: Directorate for Curriculum & Standards, Secretariat for Catholic Education (2018)

There is no reliable data available comparing the number of students studying a single science subject, those studying two sciences and those studying all three sciences simultaneously.

Current Trends at Post-Secondary Level

In the meantime, some 3,000 Maltese students register yearly for the Matriculation certificate exams (IM and AM level) marking the end of their post-secondary phase of education and a stepping stone to higher education.

The feeling shared among science educators at a local post-secondary college is similar to that experienced by their counterparts in secondary schools. However, even though some sciences are currently experiencing what appears to be a slight negative trend (Figures 12 and 13), the situation is again not alarming.

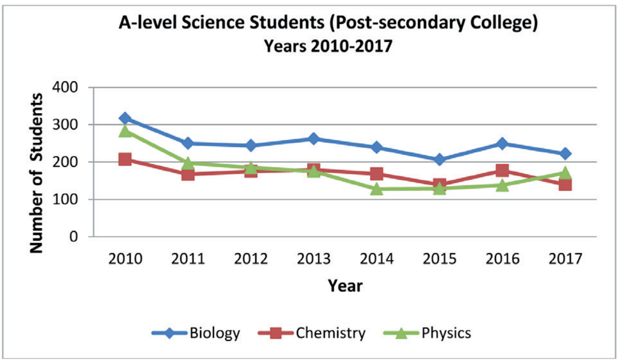

Figure 12
Source: The Administration, Post-secondary College, Malta (2018)

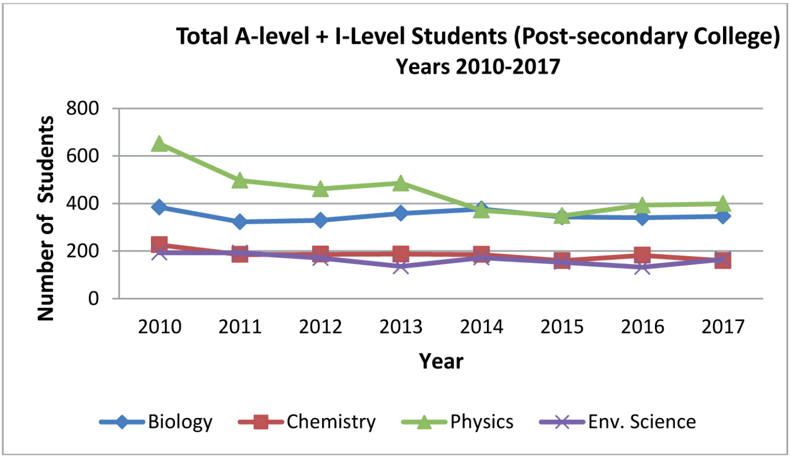

Figure 13
Source: The Administration, Post-secondary College, Malta (2018)

In fact, it can be shown that the number of candidates sitting AM biology and AM chemistry have in fact progressively increased over the last 12 years, while numbers dropped in Physics (both IM and AM) and environmental science (IM only) during the same period of time (Figures 14 and 15).

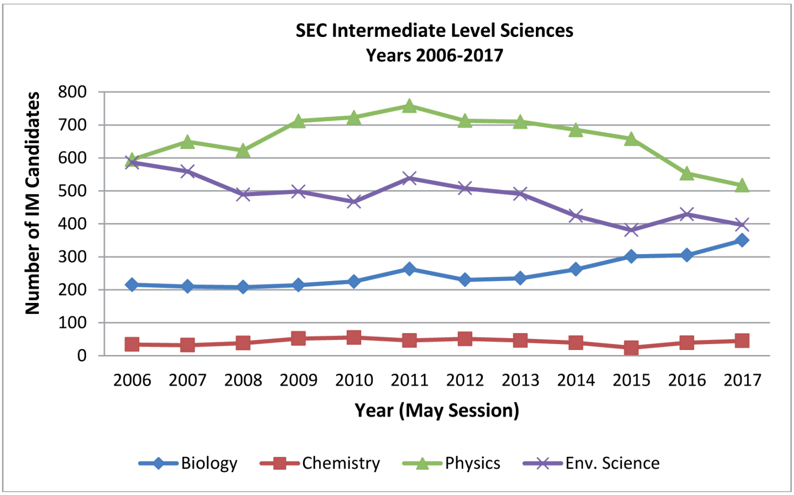

Figure 14
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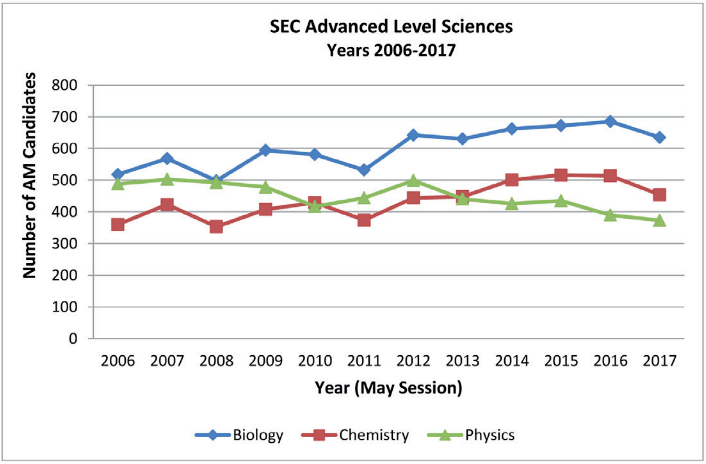

Figure 15
Adapted from University of Malta, Matsec Statistical Reports (2018)

It is worth pointing out that unlike in the case of SEC, there was a recent significant overall positive trend in the total number of candidates attempting AM level exams (Figure 16).

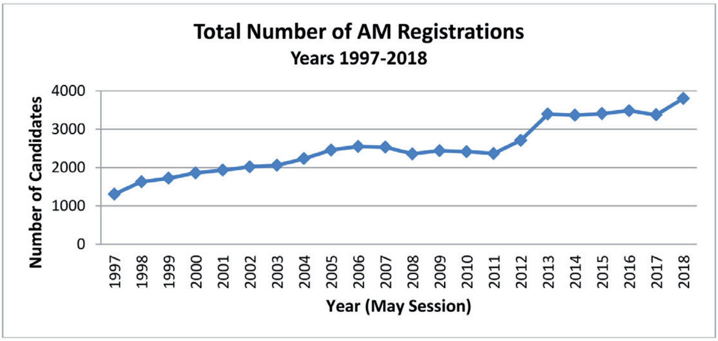

Figure 16
University of Malta, Matsec Statistical Reports (2018)

Progression from SEC to Matriculation (IM and AM) Level

Using statistics published by the Matsec Board, one can measure the progression of Maltese students in each of the 3 science subjects over a period of time. This involves a simple calculation of the percentage of intermediate (IM) or advanced (AM) candidates in one session, over those sitting the ordinary (SEC) level exam, two years earlier. Such a metric indicates the percentage of students attempting SEC exam in the science subject who continue studying the subject at post-secondary level.

Results show that biology showed the highest progression to intermediate level over the period 2006-2017, while chemistry students registered the highest progression from SEC to AM level (Figures 17 and 18).

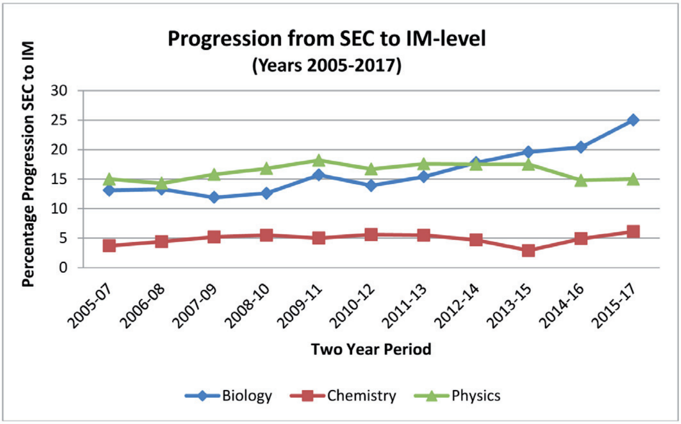

Figure 17
University of Malta, Matsec Statistical Reports (2018)

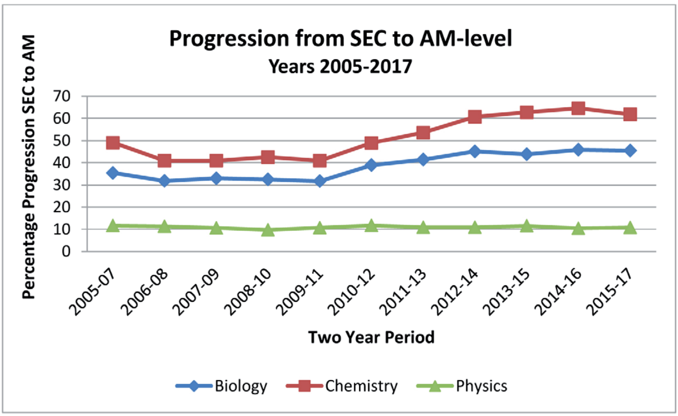

Figure 18
University of Malta, Matsec Statistical Reports (2018)

When the IM and AM numbers are combined, it seems that biology and chemistry students undergo the same progression from secondary to post-secondary level, with physics (still compulsory in most state schools) ranking a significantly lower third. One could note an almost identical positive trend in the progression of chemistry and biology students over the last 7 years, with that of physics students remaining virtually constant (Figure 19). It is very evident that an increasing number of students studying science to SEC-level continue their science study at AM-level.

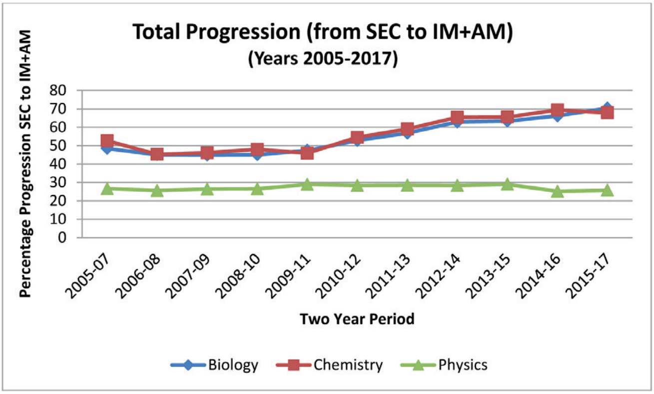

Figure 19
University of Malta, Matsec Statistical Reports (2018)

This means that in the case of chemistry and biology, a SEC student stands a good chance (currently 7 out of 10) to further his/her studies in these subjects at intermediate or advanced level. The chances of SEC students to continue studying physics at post-secondary are much lower (currently less than 3 out of 10).

Students' Attitudes towards Science

Students' attitudes towards both societal science and school science get shaped by various factors originating from their life experience.

Studies and surveys show that students' attitudes towards science itself are generally positive, with students viewing it as useful and interesting (Jenkins & Nelson, 2005). This is confirmed by the ROSE (Relevance of Science Education) study which discovered that young people view science and technology as important means to make their lives healthier, easier and more comfortable (Sjøberg & Schreiner, 2010).

By contrast, literature shows that school science is viewed by students as unattractive, as it lacks topics of interest, does not allow them to be creative and does not connect with society. It also fails to relate with the progress of research work in science and is often perceived as fragmented in different isolated disciplines which prevents students from having a coherent picture of science (Christidou, 2011; Siegel & Ranney, 2003; McSharry & Jones, 2002). Students' interest in school science declines significantly during the period of compulsory education (Bennett & Hogarth, 2009; Christidou, 2011).

This contradiction between the students' interest in science as a discipline and their growing lack of interest to school science confirms that science appears to be a 'love-hate' subject that has a strong influence on the students' feelings, particularly at the secondary level of education (Osborne et al, 2003; Hendley et al, 1996).

Students' Attitudes towards School Chemistry

The fact that chemistry is the least studied science subject and is not so popular in Maltese schools at both secondary and post-secondary level does not make Malta an exceptional case (Kracjik et al, 2001). Physical sciences are, in fact, among the least popular school subjects in several other countries as well (Bennett, 2008).

It was found that negative attitudes towards school chemistry result from a combination of factors, such as the perception that chemistry is a rather dirty discipline, the abstract concepts and theories which make it hard to understand (De Jong, 2000) and the subject's lack of relevance to the student's everyday lives (Holbrook, 2005).

Other important aspects of school chemistry that influence the students' attitudes towards the subject are the applied method of teaching and the laboratory experience.

Factors Determining Students' Choice to Study Science

It is known that the students' interest to pursue further study in science becomes largely set in stone by the age of thirteen or fourteen (Lindahl, 2007; Osborne & Dillon, 2010). The following are some of the features which students find interesting and uninteresting in science in general, and in chemistry in particular, at such an important phase in their education.

• What makes science more appealing

There is sufficient evidence showing that students, especially girls, are more attracted towards biology than to the other sciences (Bybee & McCrae, 2011).

In chemistry, students were particularly interested in aspects that were concrete, observable and manipulable, such as mixing of chemical reagents, odours associated with chemical changes and other observations from practical work. Students were stimulated when exposed to hazards such as toxic and explosive substances, which renders the laboratory experience even more memorable (Collins, 2011).

Students feel more engaged in relevant topics concerning contemporary issues or others that dealt with the existence of man. Students' interest also depended on teaching, with the most effective teachers being the ones that maintained order in class, were less didactic, used different resources and activities, had a sense of humour and built a good relationship with students, involving them frequently during lessons (Hampden-Thompson & Bennett, 2013; Lyons, 2006).

Researchers found that practical work helps students understand and retain better the scientific concepts (Abrahams & Millar, 2008). It also facilitates learning, resulting in a greater sense of enjoyment and a deeper understanding (Cerini et al, 2003).

One main motivation to learn science remains the prospect to land a science-related career (Osborne & Dillon, 2010), which can be a prestigious and well-paid profession.

• **What makes science less appealing**

Factors making science so difficult and hence less appealing include the use of language full of unfamiliar terms, the complex concepts involved, irrelevant topics, the mathematical aspect of physics and chemistry, and the need to memorise so many facts for exams (Collins, 2011). Students may also be influenced badly from people with a negative viewpoint on the subject.

Students also dislike the rushed and overburdened curriculum which they experience at school. The common feeling among students is that material is too crammed, allowing no room for reflection, participation and questions. Students feel deprived of having their own say in their own learning experience and therefore cannot express their creativity and imagination.

It is argued that the school science curriculum is failing to give students a coherent picture of the subject by providing them with fragmented pieces of knowledge usually dealt with separately under one of the three sciences, viewed by students as being so distinct from each other (Osborne and Collins, 2001).

Studies show that students often experienced a pedagogy described as condescending, patronising and dogmatic, which again did not allow sufficient space for discussion. It often created a competitive atmosphere and assumed that students cannot act as autonomous intellectual agents (Donnelly, 2001; Tobias, 1990).

Chemistry was singled out by students to be the least relevant of the three sciences, with certain aspects regarded as being unimportant and outdated. Chemistry curricula tend to put more emphasis on the subject matter than on its applications (Holbrook, 2005).

Students' Understanding of Chemistry Concepts

A significant amount of research addressed issues related with students' understanding of key chemistry concepts. Research findings indicate that problems arise from a number of potential learning difficulties:

- Students learn most things by heart in order to create their own meanings of the material being taught.
- Many students have an initial poor understanding of basic chemical concepts, making it harder for them to understand completely more advanced concepts.
- Many ideas remain vague and students are unable to identify key concepts required to understand the subject content.
- Teaching may not present the key concepts or relationships between different concepts in a sufficiently clear way for better understanding.

(Nakhleh, 1992; Pendley, Bretz & Novak,1994).

There are other possible barriers to the learning of chemistry (Gabel, 1999). These may be summarised as follows:

- Chemical concepts tend to be abstract and cannot be completely explained with the use of analogies or models.
- Learning chemistry occurs at three different levels: the **macroscopic** level; the **microscopic** level; and the **symbolic** level (Figure 20). Students find it hard to transfer readily from one level to another, while instruction usually occurs at the most abstract level, that is, at the symbolic level (Johnstone, 1991).
- During practical work, students are often expected to make observations at the macroscopic level but then they have to interpret results at the microscopic level.
- Students may perceive chemistry as being unrelated to their lives and more related to strangely named toxic or hazardous chemicals.
- The type of language and terminology used during chemistry lessons could also complicate matters.
- The chemistry curriculum is not always structured in a logical sequence that is suitable for instruction.

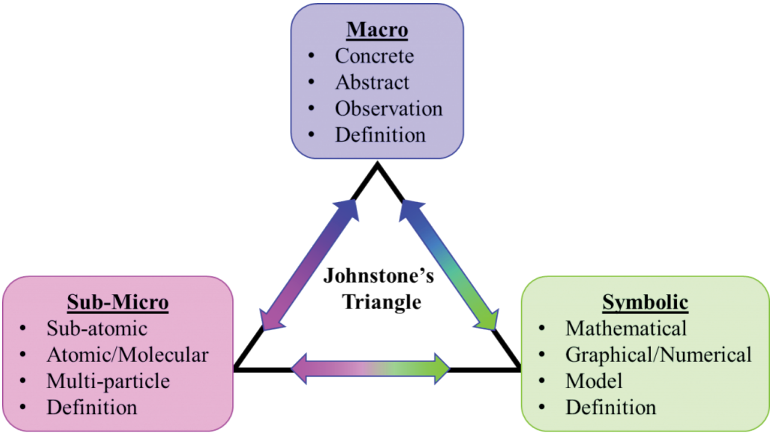

Figure 20: Johnstone's triangle of chemistry learning
(Source: Seery, 2016)

These barriers to chemistry learning need to be identified and addressed accordingly in order to facilitate the learning process and address misconceptions. For example, many chemistry teachers are not able to distinguish clearly between the three types of knowledge. This explains why students find it hard to build meaningful connections or transfer rapidly from one level to another for a given chemical system (Talanquer, 2013). Such difficulty to continuously integrate these different levels of understanding results in a fragmented picture of chemistry made up of disjointed parts that do not seem to fit together (Gabel, 1999).

In order to stress the importance of the human aspect in the learning of chemistry, Mahaffy (2004a; 2004b) added a fourth dimension, "the human element", to Johnstone's three learning levels of chemistry, to put emphasis on scientific literacy and understanding of the role of chemistry in everyday life (Figure 21).

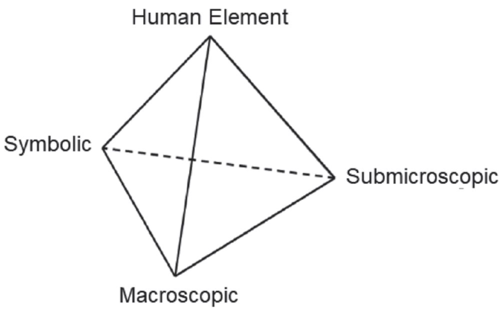

Figure 21: Tetrahedral chemistry education
(Source: Mahaffy, 2004b)

Later on, Mei-Hung Chiu (2012) added also a "language" dimension (Figure 22) to highlight the importance of teaching and learning the language of chemistry within chemistry contexts. One has to realise that although language attempts to help students understand scientific concepts more clearly, it is the same medium that sometimes hinders students' understanding.

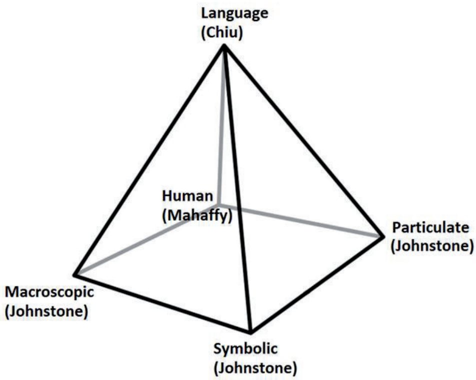

Figure 22: The revised model of key factors influencing chemistry learning (Source: American Chemical Society, 2012)

Other authors indicate that there are additional areas which need to be explored further in chemistry education. These include further work on curriculum development (in view of increased use of technology), problem-solving, the type of chemistry required by different students with different career aspirations and addressing different levels of motivation (Beasley, 2009).

Implications for Policy and Practice

In the light of the abundant research and the current trends in science, one can safely conclude that there is a realistic chance of attracting more students to choose to study science at secondary level and further their studies at post-secondary level and beyond. The following are some points worth considering in any future updates of the local science education policy and teacher training programmes.

- **Increase relevance of the subject**

Science education needs to emphasise those aspects which are valued by students in everyday life and in different contexts, such as health and environment (Christidou, 2011). One may consider also applying inductive methods such as guided inquiry and problem-based learning with the use of real-world problems to provide more context for all course material (Felder & Brent, 2009).

The local A-level chemistry curriculum lacks relevance and needs updating to illustrate the progress made by chemistry and its impact on contemporary society. A revamped curriculum should attempt to make it more relevant by bringing chemistry into the students' everyday experience. However one should not assume that whatever appears as topical or noteworthy is necessarily 'relevant' too.

- **Improve communication via better use of language**

Misconceptions in chemistry may arise with the inappropriate use of chemistry language in class. Language used in chemistry may be quite different from that used outside of chemistry. Hence efforts have to be made to ensure that students learn chemistry within chemistry contexts (Chiu, 2012).

- **Educational outreach programmes**

There is a strong need to organise educational outreach programmes aimed at both secondary and post-secondary science students to stimulate the learners' interest in chemistry. Such initiatives should establish contact between students and professionals or scientific researchers and increase the students' awareness of such job opportunities and ongoing research in our country. One could also explore the possibility of linking learning at school with organised school visits to industry.

- **National curriculum in science**

Future revisions of the national curriculum in science should continue aiming at putting less pressure on the curriculum material, allowing greater flexibility on choice of topics and putting more emphasis on practical applications (Munro & Elsom, 2000).

- **Specialised science vs 'science for all' curricula**

Any development in the science curricula has to address the dual objective of training a scientific elite and preparing the rest of the population, who are not interested in becoming professional scientists, to be scientifically literate citizens. Hence, the need for a specialised science curriculum starting from Form 3, which allows a smoother transition to further study and a broader curriculum serving a wider treatment of scientific knowledge, is indicated.

It is good to note that science has now been promoted to a core subject at primary level and that integrated science has returned as part of the secondary curriculum for non-science students. The next logical step is to introduce core science SEC exam for those wishing to include it in their secondary school leaving certificate. This move could attract more students to consider retaining science subjects at least up to the intermediate post-secondary level.

• **Addressing the chemistry uptake problem**

Special attention is needed in the case of chemistry, which is perceived as one of the hardest A-level subjects. Indeed, some schools struggle to find qualified teachers in the subject. One needs to explore, for example, the possibility of attracting students who are less gifted in sciences and those who are late developers or late learners, but who are still interested in science despite having underachieved up to SEC level for a variety of reasons. Any initiatives taken to address this problem should always fall within an overall national strategy for developing science education in schools.

• **Science education for all**

There is a need to organise a strong educational campaign to promote the broader values of science subjects as being important aspects of a person's general education and career, and for the flexibility and transferability of skills at work (Munro & Elsom, 2000).

• **Career advice**

Attention should also be paid on the way parents and students are advised on the choice of subjects at years 9 and 12. For example, one has to highlight the implications of dropping career-relevant subjects and explain how continuing to study science does not limit students to a science career.

• **Invest in human resources**

One has to secure an adequate supply of properly qualified teachers of science, particularly in view of the academic reform affecting the qualifications required for the teaching of sciences. The state needs to invest in science teacher training, and possibly create more science learning centres, to enhance the continuous professional development of science educators, always keeping a balance between subject knowledge and pedagogical skills. Jenkins and Donnelly (2006) suggest that students need to enjoy learning science and this will happen if they are taught by teachers who enjoy teaching it.

• **International cooperation**

There is a strong need for science (including chemistry) educators to involve themselves at the international level by participating in conferences and/or other initiatives to share and disseminate research findings in science education. Cross fertilisation of ideas and experiences in education would certainly contribute to enhance the teaching and learning processes, despite cultural and other limitations.

Conclusion

The aim of this paper was to evaluate the concerns regarding what appears to be a lack of interest by students to take up sciences, particularly chemistry, at post-secondary level and try to find what factors might be contributing to such a disenchantment among teenagers to school science.

The concerns are not fully justified, as the declining numbers of science students at secondary level in a way reflects the decreasing numbers of SEC candidates at the end of secondary education. It was also noted that there is a positive trend by secondary students studying science subjects to continue doing so at post-secondary education, thus increasing their chances to pursue further science-related studies.

The students' choices at secondary and post-secondary levels of education depend on a number of variables; it is not simply a question of convincing the most gifted students to commit themselves to become scientists at an early age. There are several stakeholders involved in the education of adolescent students, each of which can play an important role in affecting the students' decision and motivation to study science.

The paper aimed at trying to analyse these variables and inform these stakeholders, including science educators and career guidance professionals, about the complexity of students' choices at this level of education.

Chemistry is the science subject with the lowest uptake at secondary level; however, it then registers a high progression to AM level. This means that the problem of chemistry uptake mostly concerns choosing the subject half way through secondary education.

There are many initiatives and decisions that can be taken to improve the uptake of sciences in secondary education. Such initiatives should involve action from curriculum designers, policy makers, educators and scientists. Malta needs to 'catch them young' in science if it wants to increase the number of local undergraduates studying science or science-related disciplines and attract more Maltese graduates to undertake post-graduate research or follow a science-oriented career path.

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