



“Science ... is doing something dangerous”:
an international perspective on science education and teaching

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HÁSKÓLI ÍSLANDS

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**A wise teacher's words spur students to action
and emphasize important truths**

Ecclesiastes 12:11a

The Holy Bible, New Living Translation

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ABSTRACT

Science education and teaching is currently under worldwide scrutiny. Results from international studies, as well as from individual country's own findings, have highlighted the need for such attention. Also, many countries are experiencing difficulties including a decreasing enthusiasm for science amongst students, a decline in the number of students pursuing careers in the field of Science, Technology, Engineering and Mathematics (STEM), and a shortage of science teachers. Furthermore, science education is no longer considered to be important for a minority of students; rather, it is recognised as significant in enabling all citizens to become scientifically literate, empowering them to make informed decisions about issues that affect them individually and as part of a society.

With an international perspective, and using research and reports from a number of countries, this thesis presents, a synopsis of the current state of science education – incorporating information from recent international studies – current issues in science teaching, and recommendations and challenges for the future of science education. Much of the research, although recognising the interaction between numerous factors, highlights the fundamental importance of quality teaching. It was a First Grade student who remarked that 'science ... is doing something dangerous', elaborating his answer with practical examples. In the context of this thesis, however, it is the nature of science education and teaching that is being discussed, something that is cutting edge, relevant and that could even be considered *dangerous*.

Thus, it is intended as a tool for those interested or involved in science education, providing a number of suggestions for improving or consolidating how this subject is taught, from the classroom through to policy-making level, with appropriate references that enable further reading on specific aspects as required. It is a review that is designed, therefore, to make a contribution to educational research in the field of science.

ÁGRIP

**Vísindi ... er eitthvað sem er hættulegt:
nám og kennsla í raungreinum frá alþjóðlegu sjónarhorni.**

Nám og kennsla í vísindum er um þessar mundir undir grannskoðun um allan heim og niðurstöður alþjóðlegra rannsókna, ásamt niðurstöðum frá einstökum löndum, hafa undirstrikað þörfina fyrir slíka skoðun. Víða stendur menntakerfið frami fyrir vandamálum tengdum þessu sviði, svo sem eins og minnkandi áhuga nemenda og vaxandi skorti á raungreinakennurum. Einnig hefur fækkað þeim sem sækjast eftir starfsferli í raungreinum, tækni, verkfræði og stærðfræði. Þessu til viðbótar má nefna að nám í raungreinum er ekki lengur álitid vera einungis mikilvæg fyrir lítinn hluta nemenda, heldur er það viðurkennt sem þýðingarmikill þáttur í að gera öllum borgurum kleift að verða vísindalega læsir. Tilgangurinn er bæði að þeir ráði við að taka upplýstar ákvarðanir varðandi málefni sem hafa áhrif á þá persónulega en einnig þær sem snúa að því að vera hluti af samfélagi.

Í þessari ritgerð er gefið yfirlit yfir núverandi stöðu náms og kennslu í raungreinum, bæði út frá alþjóðlegu sjónarhorni og með því að nota rannsóknir og skýrslur frá nokkrum löndum. Greint er frá nýlegum alþjóðlegum rannsóknum og fræðum um raungreinakennslu og ráðleggingar og áskoranir fyrir raungreinakennara framtíðarinnar. Þótt rannsóknir sýni fram á víxlverkun fjölmargra þátta, setja margar þeirra gæði kennslunnar sem forgangsatriði. Nemandi í fyrsta bekk sagði; vísindi ... er eitthvað sem er hættulegt og útskýrði skoðun sína svo nánar með dæmum. Hér er hinsvegar fjallað um eðli náms og kennslu í raungreinum sem framsækið, mikilvægt og geti jafnvel verið álitid hættulegt.

Ritgerðin er hugsuð sem verkfæri fyrir þá sem eru áhugasamir um, eða í beinum tengslum við, raungreinakennslu. Gefnar eru tillögur að endurbótum til að styrkja það hvernig fagið er kennt, bæði hvað varðar viðfangsefnin í kennslustofunni sem og við stefnumótun. Þegar það á við eru gefnar tilvísanir um ákveðin atriði sem auðvelda frekari lestur ef áhugi er fyrir hendi. Ritgerðin er yfirlit, samin sem framlag til rannsóknar í menntunarfræðum á sviði raungreina.

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1. Introduction

In a science lesson for 5 and 6 year olds, the children were asked what their thoughts were about this subject. For many of them, this was their first ever science lesson, at least in the formal sense, and there were few that raised their hands to respond. One boy, however, was quite confident as he answered, “Science ... is doing something dangerous” – he then went on to give some practical examples of this as he elaborated his response. However, in considering what he said, and in looking at it from the perspective of a science teacher and the state of science education today, it is in my view possible to come to the same conclusion: ***Science is doing something dangerous.***

Why is this so? It is the purpose of this thesis to seek to answer this question. To do so, requires for the current state of science education to be set in context, and for an exploration of the issues that are being faced, along with an analysis of some of the possible solutions. This review presents some international perspectives, as it is recognised that the future of science education is a global concern:

“The world looks so different after learning science.”

Richard Feynman, Nobel Laureate physicist (1968, p.2)

Science education is facing a number of pressing issues. These include a deterioration in student interest in science (Aikenhead, 2003; Bennett, 2003; Fensham, 2006; King, 2009; Osborne & Collins, 2000), declining enrolment in science courses at all levels of education (Coggins, Finlayson & Roach, 2005; Fensham, 2004; Goodrum, Hackling & Rennie, 2001; Harlen, 2010), and a lack of science teachers (Darling-Hammond & Schlau, 1996; Institute of Education Sciences, 2008; Ingersoll & Perda, 2009). These all have implications for the number of students pursuing careers in the field of Science, Technology, Engineering and Mathematics (STEM). Often quoted are results from international studies, which give an overall picture for all those participating, in addition to highlighting issues on an individual country basis.

In many countries, science is no longer limited to an elite, those who would be considered as future scientists or as professionals working in science-related industries, or who require science as part of their entrance to further education. Although this was historically the case, since the 1960s and 1970s the general consensus has been on ***science education for all*** – each student having the opportunity to study science to a certain level as part of their compulsory education. School science should be offering, “... an *education in science* and not a form of pre-professional training” (Osborne & Dillon, 2008, p.7). John Dewey is quoted as saying, “Education is a social process. Education is growth. Education is not a preparation for life; education is life itself” (Dewey, 1938; cited in Grotewell & Burton, 2008, p.30). The emphasis is for all citizens to become *scientifically literate*, a concept that will be examined further in section 2.

Running throughout the discussion on the subject of science education are a number of threads, including political, financial, environmental, and (intrinsically) educational issues, and the role of the media. Each has an influential part to play in affecting the outcome of policy and curriculum decisions on a national and international basis. Political leaders are aware of the role that education plays in their nations – a study of news articles from different countries, particularly around election times, will often find education on the political agenda. This relates particularly to science education as, “Today, many of the political and moral dilemmas confronting society are posed by the advance of science and technology and require a solution which, whilst rooted in science and technology, involve a combination of the assessment of risk and uncertainty, a consideration of the economic benefits and values, and some understanding of both the strengths and limits of science” (Osborne & Dillon, 2008, p.8). The relevance of science education is reiterated in the report issued by the United Nations Educational, Scientific and Cultural Organization (UNESCO): “The quality of school education in science and technology has never before been of such critical importance to governments” (Fensham, 2008, p.4).

This review presents a brief history of science education, followed by an overview of the current state of science education, some issues faced in science teaching, and an analysis and discussion of challenges in improving the future of science education. In doing so, I seek to explain

why science education, a subject that is contemporary and relevant, could even be considered *dangerous*.

2. Brief history of science education in Western countries

This literature review presents developments in science education in the United Kingdom (UK) and the United States of America (US) – the intention is not to exclude other nations, but rather to give an overview from the perspective of two historically influential countries in this field.

Different types of schooling had been in existence in the UK from the late 15th century. It was not until the 19th century, however, that a formal and organised system of education began to be established, culminating in the first Education Act in 1870, which introduced compulsory standardised education for children aged 5-13 years old. The foundational elements of teaching at this time were known as the three R's – *reading, writing and arithmetic* – requiring the provision of reading books. According to Tilleard (1860), over half of the reading books at that time contained considerable science content, due in part to the fact that "... scientific knowledge was believed to be non-inflammatory and suitably neutral" (cited in Layton, 1993, p.3). This is in contrast with previous books which had concentrated on Biblical texts. This is accredited as the first recorded evidence of science material being available as an educational resource throughout the UK.

However, science education became almost immediately a contentious issue. Whilst it was generally accepted that science education was of value, and should be included in the school curricula, the method of teaching that should be used was not agreed upon. Some scholars were already advocating the need for experimental (practical) learning in science rather than theoretical or textbook learning as, in the words of Sir John Lubbock, "... to teach scientific subjects through reading lessons is the worst way they could be taught" (Layton, 1993, p.4).

Similar educational developments were taking place in the US. During the 19th century educational establishments moved away from offering only classical studies, broadening the curriculum to include subjects such as science. However, towards the end of that century it had become

apparent that there were discrepancies between the education that high schools provided and the standards that colleges required. To address this issue, the **Committee of Ten** was set up, with their main objective being to establish what high school students needed to *know or be able to do* in order to fulfil the entrance requirements for college. This Committee, consisting of leading scholars of that time, decided upon nine main subject areas that should make up the high school curricula. Three of these subject areas were in science, divided as follows:

- natural history, including physiology, zoology, and botany
- physics, chemistry and astronomy
- geography, including physical geography, geology and meteorology

As in the UK, the need for practical/laboratory work was accentuated, rather than the traditional approach of learning from the teacher or by using a textbook, with emphasis being placed on the role of the individual in their learning, on knowledge “gained by personal experience” (DeBoer, 1991, p.44), and on developing observational, conceptual and reasoning skills.

Moving into the 20th century, world events had a significant impact on science education. For example, during World War I, science education developed from being an abstract subject to one that provided a contribution to society as a whole. Likewise, that century also highlighted the differences between countries, such as in the race to launch craft and man into space. This race was won by the Soviet Union, and subsequently generated a number of educational reforms in the US, resulting in a significant increase in involvement of science professionals in curriculum-making (Andersen, 1994; Brady, 2008).

Later in the 20th century an increase in the academic study of education (Thomas, 2007) resulted in a substantial number of educational scholars coming from the field of psychology. From the early 1980s, a ‘constructivist’ approach began to have an influence in educational thinking and curriculum development. Constructivism is still a significant learning theory in science education today (Driver, Asoko, Leach, Mortimer & Scott, 1994; Harlen, 2010; Tobin, 1993 & 2008), and has been defined as:

... a theory of learning which holds that every learner constructs his or her ideas, as opposed to receiving them, complete and

correct, from a teacher or authority source. This construction is an internal, personal and often unconscious process. It consists largely of reinterpreting bits and pieces of knowledge – some obtained from firsthand personal experience, but some from communication with other people – to build a satisfactory and coherent picture of the world (Selley (1999), cited in Gunnhildur Óskarsdóttir, 2006, p.4).

Further documentation and legislation in the US, such as *A Nation at Risk* report (1983)¹ and the *No Child Left Behind* Act (2001)², highlighted the poor status of science education and sought to amend this situation. Yet, “despite its own requirement, the law has succeeded in pushing science to the back burner” (Brady, 2008, p.606), due in part to a focus on testing in other core curriculum subjects (Jorgenson & Vanosdall, 2002). More recently, President Obama, introduced the *Educate to Innovate* campaign (2009)³, which states that as a nation they must, “... improve the participation and performance of America’s students in science, technology, engineering, and mathematics”. One initiative that the President has since endorsed is *Change the equation*, which states simply that: “STEM is the future”⁴.

Although science has featured as a core part of the curricula in both the UK and the US for a number of years, the way in which it is viewed, particularly by educators and policy makers, has been changing since the 1960s – as stated earlier, it is no longer seen as just for those who wish to specialise in order to pursue a career in a science-related profession. This change in view is expressed in the Teaching and Learning Research Programme (TLRP) report, as:

*“If the major purpose of science education is to increase the flow of specialist scientists, technologists and engineers, it could be argued that young people with a special talent in science should be identified as early as possible and provided with a separate, specialised, and highly focused science education. We do not agree. Such people share the **general need for a broad science education** and should not be cut off from it. In any case, there are*

¹ <http://www2.ed.gov/pubs/NatAtRisk/index.html>

² <http://www2.ed.gov/policy/elsec/leg/esea02/107-110.pdf>

³ <http://www.whitehouse.gov/issues/education/educate-innovate>

⁴ <http://www.changetheequation.org/why/why-stem/>

no valid and reliable ways in which such young people may be identified. Some who show early promise subsequently fade, whilst the talents of others emerge later on. Young people today show an appetite for a broadly-based education based on themes of proven interest, and developing a range of transferable skills. They would resist any attempt to foreclose their choices"

[emphasis added](TLRP, 2006, pp.4-5).

In response to the different needs and desires of students relating to science education, the University of York and the Nuffield Foundation established a course in England and Wales entitled *Twenty First Century Science*, which consists of:

1. a core curriculum that explores both the major explanatory themes of science and a set of 'ideas-about-science' that all students do;
2. an additional course of academic science which is for those who wish to pursue the study of science at a later stage;
3. an alternative course in Applied Science, for students with a more vocational inclination.

[layout amended](Osborne & Dillon, 2008, p.21)

In this way, the science curriculum is intended to cater for *all students*, and more particularly to develop and nurture scientifically-informed citizens. Within this new curriculum there has also been a shift in emphasis in the way in which lessons and teaching materials are structured – "... there has been a general acceptance that learning science involves more than simply knowing some facts and ideas about the natural world, and that a significant component of science curriculum time should be devoted to providing opportunities for personal inquiry" (Millar & Osborne, 1998, p.2003).

SCIENTIFIC LITERACY

Emphasis is being placed globally on all citizens becoming *scientifically literate* (Leite, 2002). "The main purpose of science education should be to enable every individual to take an informed part in decisions, and to take appropriate actions, that affect their own wellbeing and the wellbeing of society and the environment" (Harlen, 2010, p.7). Although not a new idea, the relevance of being scientifically literate is becoming better recognised. Mullins (1991) identified ten challenges facing schools, one of which was to, "Help students grow into men and women of moral discernment and strength" (p.174), going on to acknowledge

that educators should be compelled to instil moral and ethical values into the students being taught, values that are crucial in bringing about democratic change and growth. Similarly, Schnack (1995) writes, “So you might say that the fundamental challenge to the school is not to make pupils clever but to educate them so that they do not become ‘idiots’. These two aims are not the same” (p.70), written in the context of the translation of *idiotos*, a word used in Ancient Greece to describe “... the opposite of a political [democratic] person ... a man not involving himself in the community” (p.70). Dewey also considered that the community had a duty towards education, believing that, “children needed to understand their roles as active participants in democracy. They needed to learn how to live together and that schools had a responsibility to help students understand moral and ethical dilemmas that they might – and probably would – encounter in the future” (Deblois, 2002, p.2).

There have been many attempts to define this term and there are some differences between scholars as to its meaning. However, for the purpose of this review, the definition provided by the Organisation for Economic Co-operation and Development (OECD, 2007a) is given here. Science literacy is “... the extent to which an individual:

- Possesses scientific knowledge and uses that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues.
- Understands the characteristic features of science as a form of human knowledge and enquiry.
- Shows awareness of how science and technology shape our material, intellectual and cultural environments.
- Engages in science-related issues and with the ideas of science, as a reflective citizen” (p.12).

Yore & Treagust (2006) seek to combine some of the different understandings of scientific literacy, using science education reform documents from English-speaking countries, expressing these as:

1. The meaningful understanding of knowledge about the big ideas or unifying concepts/themes of science like the nature of science, scientific inquiry, and major conceptual themes in the biological, earth-space, and physical sciences; and,
2. A literacy component that stresses the cognitive abilities, critical thinking, habits of mind, and information communication

technologies (ICT) to understand the big ideas in science; to inform and persuade others about these ideas; and to participate more fully in the public debate about science, technology, society and environment (STSE) issues (p.293).

Reasons given for its importance include that, "... without a scientifically literate population, the outlook for a better world is not promising" (Rutherford & Ahlgren, 1990, p.vii). Similarly, Wang & Schmidt (2001) propose that, "... since every citizen is expected to have informal opinions on the relationships among government, education, and issues of scientific research and development, it is imperative that some appreciation of the past complexities of science and society be a part of the education of both scientists and non-scientists. Because of the increasingly scientific nature of our society and the individual needs of its members, every person must be scientifically literate in order to function effectively" (p.51).

In discussing the history of science education, it is important to be mindful of the fact that this is most seen and documented through the eyes of developed countries. This is not to say that developing countries have had no form of science education, but rather that the science curricula seen around the world today often have their origins in Western culture. Trumper (2010) states that, "In many developing countries ... the local education system remains tied to its original source. In particular, science programs are often taken directly, with little or no adaptation, from Western nations' science programs" (p.234). This situation is changing though, as "Recent decades form a period when a number of countries across the world were coming out of colonisation into self-governance, hereby making this a critical period in terms of educational agendas" (Mutua & Sunal (2004), cited in Earnest & Treagust, 2007, p.3).

Thus, after setting science education in its historical context, this review now focuses on its present situation and future directions.

3. Current state of science education

The issues affecting science education have been addressed at many levels, ranging from local and national feedback within individual countries through to an international response. This section provides an overview of the current state of science education using a selection of available documents and reports, in order to lay an evidential foundation for further analysis and discussion.

3.1 Three recent perspectives on science education

For the purpose of this review, three recent reports have been chosen to illustrate documentary evidence of how the state of science education is currently perceived. The first represents an individual country's findings; the second, a declaration from an international scientific forum; and the third is a report from a component of the United Nations (UN) organization, representing an inter-governmental response. Issues raised by these documents are discussed in section 4, and points pertaining to the future of science education are discussed in section 5.

3.1.1 Science education in UK schools: Issues, evidence and proposals (2006)

This report is a commentary from the Teaching & Learning Research Programme (TLRP) (2006), produced in collaboration with the Association for Science Education (ASE) in the UK. It was published during the *National Science Week* in 2006 and is aimed at all those interested in science education, from those with an individual perspective, such as teaching staff, through to local council and governmental departments.

Issues of concern described in this report are linked to scientific knowledge, or *scientific literacy*, which is identified as playing a

determining role in the future of the country (for example, “... if the UK is to compete successfully in technology-intensive global markets” (2006, p.4)). It is understandable, therefore, that one of the urgent challenges this report addresses is the decreasing number of students who opt to take science courses in school when they are no longer compulsory, and the progressive repercussions of this (for the science industry, for future education and for the economy as a whole).

Concern is expressed about how students perceive science and its relevance. Surveys such as PISA (see section 3.2.2) provide not only statistical data about a country’s performance in science, but also their attitudes towards it. For example, in the PISA 2006 survey UK students generally agree that science is of value to society, but they are less convinced of its personal value to them (Bradshaw, Sturman, Vappula, Ager, & Wheeler, 2007, p.38). However, as the TLRP report states, “... school science education can only succeed when students believe that the science they are being taught is of personal worth to them” (TLRP, 2006, p.6).

With this in mind, the idea of ‘*science education for citizenship*’ is presented. This is conveyed in terms of both a **need** and an **aspiration** for students to come to understand the importance of science:

1. in their personal lives (e.g. so that they can validly identify the components of a healthy life-style);
2. in their civic lives, so that they can take an informed part in social decisions;
3. in their economic lives, where they need to be able to respond positively to changes in the science-related aspects of their employment [layout amended] (TLRP, 2006, p.4).

The report continues by addressing issues such as the way in which science is taught and the environment in which this teaching takes place. Various problems and factors relating to teaching and assessment techniques are discussed, along with how the teaching material is structured and how science curriculum content affects students and teachers alike. After outlining what are considered to be the underlying issues of concern, the document goes on to set out proposals for improving the current state in different spheres – for

example, in the classroom environment (including various aspects of teacher recruitment and training, and the role of assessment), in curriculum content and how it is structured and communicated, and in partnership with outside scientific organisations and industries. These issues and proposals are incorporated into the discussions in sections 4 and 5 respectively.

3.1.2 Perth Declaration on Science and Technology Education (2007)

In July 2007, over 1000 delegates representing 50 countries met at the Annual Conference of the Australian Science Teachers Association (ASTA) (held in partnership with the International Council of Associations for Science Education (ICASE)) in Perth, Australia. These delegates, science teachers and academics, met to "... address the current issues involving science, technology, science teaching and learning and the engagement of student in science" (ASTA, 2007, p.1).

Based on the consensus that throughout the world there is a decline of interest in science, the delegates worked together to distinguish the following 5 key reasons as to why this was so:

- Difficulty finding, training and retaining well-qualified science teachers
- Lack of resources devoted to science and science education globally
- Teaching practice that generally does not reflect new and emerging ways of doing science
- Public misconceptions of science and science careers
- Perceived lack of relevancy of modern science curricula resulting in student disengagement (2007, p.1).

In acknowledgement of these issues, the *Perth Declaration on Science and Technology Education* was put forward. This does not go into more detail, but instead is directed at governments and organizations globally, impelling them to consider a number of ways in which they can seek to arrest and address the problem of declining interest in science. One of these declarations was to, "Call on UNESCO to integrate its science and technology education endeavour

as fundamental to achieving educational, environmental, cultural, social and sustainable development goals” (2007, p.2).

3.1.3 Science education and UNESCO (2008)

This document, entitled *Science education policy-making: Eleven emerging issues*, was commissioned by the UNESCO Section for Science, Technical and Vocational Education. It is a direct response to the *Perth Declaration on Science and Technology Education* (referred to above) and an earlier *Declaration on Science* from the *World Conference on Science* in Budapest 1999, where it was proclaimed that, “Science education in the broad sense is a fundamental prerequisite for democracy and for ensuring sustainable development” (UNESCO, 2000, p.16). As has been mentioned previously, the purpose of education is not for an individual exclusively, but that they might function as part of society.

Currently the United Nations is comprised of 192 member states⁵. The official number of independent countries in the world varies slightly, depending on the source of information, but is stated here as 195 countries⁶. It can clearly be seen, therefore, that the UNESCO document incorporates or represents almost all of the countries of the world.

It is with this international encompassing that the author addresses the current state of science education, giving three essentials or *imperatives* as to why the quality of science education is so important. These are:

- In recognising and facilitating, “the traditional role of science in schooling, namely the identification, motivation and initial preparation of those students who will go on to further studies for careers in all those professional fields that directly involve science and technology [as] **a sufficient supply of these professionals is vital to the economy of all countries and to the health of their citizens... ensuring that industrial**

⁵ <http://www.un.org/en/members/growth.shtml>

⁶ <http://geography.about.com/cs/countries/a/numbercountries.htm>

and economic development occur in a socially and environmentally sustainable way”

- “... that sustainable technological development... require[s] the support of scientifically and technologically informed citizens. ... **All students need to be prepared through their science and technology education to be able to participate actively as persons and as responsible citizens** in these essential and exciting possibilities”
- “**In acknowledging the influence and the effects on education of the times in which we live, namely in the availability of technology and information.** This is antagonistic to some of the foundations of science teaching and learning, which emphasises the need to ‘build up a store of established knowledge’” [emphasis added] (Fensham, 2008, pp.4-5).

To date, although many countries have made varying degrees of effort to improve science education, none of these three imperatives is being achieved.

Reference is made in this report to the evidence of declining interest in science education, science-based careers and science as an area of lifelong interest. The extent of this decline differs between countries, but the trend is widespread, particularly in more developed countries (2008, p.11). This disparity is discussed further in section 4.1.1.1.

This report also recognises that policy decisions and teaching practice are not necessarily in alignment with each another. Fensham notes that, “... the curriculum for school science is a highly contested matter” (2008, p.12), and that there are both visible and hidden political and economical factors that need to be taken into consideration. This is evident in countries where there is no National Curriculum, as regional or local authorities reserve the right to choose what they consider to be important and what should be included in the curriculum, bearing in mind the locality and resources available to them.

The report also highlights the prevailing trends and methodologies in research and their effects on science education. This is illustrated with the way in which the core aspects of *Policy*, *Practice* and

Assessment are treated as separate entities, rather than acknowledging the overlap between them and the implications that they have on one another and, in doing so, causing unnecessary repetition or neglect/oversight.

3.2 How this state is assessed

One of the contributing factors involved in compiling documents such as those outlined in section 3.1 is empirical data, which enables statistical and quantitative assessments to be formed, rather than purely theoretical hypotheses to be purported. This section contains a descriptive summary of two recent studies/surveys, both of which have participation from over 50 countries.

3.2.1 Trends in International Mathematics and Science Study (TIMSS)

Trends in International Mathematics and Science Study (TIMSS) is developed and carried out by the International Association for the Evaluation of Educational Achievement (IEA), "... an international organization of national research institutions and governmental research agencies" (Gonzales *et al.*, 2008, p.1). These studies were initiated upon the tenet that:

"There is almost universal recognition that the effectiveness of a country's educational system is a key element in establishing competitive advantage in what is an increasingly global economy. Education is fundamentally implicated not only in a country's economic and social development, but also in the personal development of its citizens. It is considered one of the primary means whereby inequities, social and economic, can be reduced. Attendant on this growing recognition on the importance and centrality of education has been the recognition, worldwide, of the importance of regular monitoring of educational performance and its antecedents" (Martin, Mullis & Foy, 2008, p.1).

TIMSS was first implemented in 1995, and henceforth carried out every four years, with the most recent study occurring in 2007⁷. Each study places equal emphasis on mathematics and science⁸, and is designed to correspond with the curricula of those countries participating. In doing so, the skills and concepts that the student should have been taught and have learnt are being assessed. Studies are carried out with 2 age groups – fourth grade (9-10 years old) and eighth grade (13-14 years old). As well as the studies themselves, information is also gathered about the students and their educational environments, enabling further analysis and comparisons from the data to be made.

TIMSS 2007

In 2007, approximately 425,000 students from 59 countries⁹ participated in the study (see Table 3.1), with over 180,000 students from fourth grade in 36 countries and over 240,000 from eighth grade in 49 countries. Three science competencies were used at both age groups being studied – *knowing*, *applying* and *reasoning*. For the fourth grade students the content of their study was classified as *Life Science*, *Physical Science* and *Earth Science*, whereas for eighth grade students their content was segregated into *Biology*, *Chemistry*, *Physics* and *Earth Science*.

Appendix I shows the science performance scores for countries participating in TIMSS 2007, along with their Human Development Index (HDI), as calculated by the United Nations¹⁰. As can be seen, in the study carried out with fourth grade students, 21 countries scored significantly above the TIMSS scale average and 13 countries significantly below this average (i.e. at fourth grade the majority of participating countries scored better than the TIMSS average). With eighth grade students, 14 countries scored significantly above the TIMSS scale average compared with 33 significantly below this average (i.e. at eighth grade more than twice as many countries

⁷ A study is currently underway in 2011, but has not yet been completed by all of the participating countries

⁸ A parallel study, Progress in International Reading Literacy Study (PIRLS) is also carried out by the IEA

⁹ Some of the data received from two countries, Mongolia and Morocco, was unable to be used in the analysis

¹⁰ <http://hdrstats.undp.org/en/countries/profiles/IRN.html>

Table 3.1: Countries participating in TIMSS 2007

| | | | |
|----------------------|-----------------------|-------------------------|------------------|
| Algeria | England | Latvia | Saudi Arabia |
| Armenia | Georgia | Lebanon | Scotland |
| Australia | Germany | Lithuania | Serbia |
| Austria | Ghana | Malaysia | Singapore |
| Bahrain | Hong Kong SAR | Malta | Slovak Republic |
| Bosnia & Herzegovina | Hungary | Mongolia | Slovenia |
| Botswana | Indonesia | Morocco | Sweden |
| Bulgaria | Iran, Islamic Rep. of | Netherlands | Syrian Arab Rep. |
| Chinese Taipei* | Israel | New Zealand | Thailand |
| Colombia | Italy | Norway | Tunisia |
| Cyprus | Japan | Oman | Turkey |
| Czech Republic | Jordan | Palestinian Nat'l Auth. | Ukraine |
| Denmark | Kazakhstan | Qatar | United States |
| Egypt | Korea, Rep. of | Romania | Yemen |
| El Salvador | Kuwait | Russian Federation | |

* commonly known as Taiwan

scored beneath the TIMSS average than above it). It is interesting to note that the top four performing countries at both grades in this study are in Asia, where considerable investments are being made into scientific research and development. For example, in a recent report by Professor Sir Chris Llewellyn Smith, “Chinese spending [on research and development] has grown by 20% per year since 1999, now reaching over \$100bn, and as many as 1.5 million science and engineering students graduated from Chinese universities in 2006” (BBC, 2011).

With TIMSS it is possible to compare the results of the fourth grade in one study with the eighth grade in the subsequent study – in other words, fourth grade students who took part in the 2003 study became eighth grade students by the time of the 2007 study. This enables the progress, or lack thereof, of students to be tracked and possible reasons for this to be examined. In the countries who took part in TIMSS 2007 at both grades, all those who had significantly above the TIMSS average in fourth grade also had significantly above this average in eighth grade. This is obviously not a comparison of

students' progression, but rather recognition of the fact that educational standards in science appear to be consistent in these countries.

In analysing the performance of countries in relation to their HDI value it can generally be seen that the higher this value for a particular country, the better that country scored in the study. Hence, of the 21 countries which scored significantly above the TIMSS scale average at fourth grade, 16 of these were considered as having very high human development (HD) in 2007, and 4 with high HD in that year¹¹. The 13 countries which scored significantly below the TIMSS average at this grade were not classified in that year as having very high HD, with the exception of Norway and Qatar – reasons for these discrepancies are discussed in section 3.2.3. The HDI value is calculated using components of health, education and living standards – hence, as a broad assumption, it can be said that the higher the development of a particular country, the better their standards of education and the greater their availability of resources.

3.2.2 Programme for International Student Assessment (PISA)

The Organisation for Economic Co-operation and Development (OECD) is “... a unique forum where the governments of 30 democracies work together to address the economic, social and environmental challenges of globalisation” (OECD, 2007b, p.2).

In 1997 the OECD launched the Programme for International Student Assessment (PISA), which aims to provide data relating to student performance in three specific subject areas – *reading literacy*, *mathematics* and *science*. The OECD member countries work with a defined general framework to assess students at a particular age (15 years old). The acquired results are used to compile statistical information which is analysed, and which provides a platform from which to discuss issues including educational policy and goals, and the quality of education provided. Alongside data on the subject areas being assessed, information about the student and the institution in which they study are also collected to facilitate in the

¹¹ Note: there is no HDI data available for Chinese Taipei

interpretation of results and further analysis. One of the motivating factors behind PISA is the recognised correlation between educational standards and the economic potential of human resources/skills. It is therefore worthy of note that, “The countries participating in PISA together make up close to 90% of the world economy” (OECD, 2007b, p.3).

To date, four PISA surveys have been carried out. Whilst each survey considers all three subject areas, emphasis is placed on one of each of these subjects in turn. The surveys in 2000 and 2009 focused on *reading literacy*; the 2003 survey on *mathematics*, and the 2006 survey on *science*.

PISA 2006

Although the most recent survey was conducted in 2009, as this review is concerned with science education the following discussion focuses in more detail on the results from the 2006 survey, which was carried out by over 400,000 students aged 15¹², from 57 countries – the 30 OECD member countries plus 27 partner economies¹³ (see Table 3.2).

Two aspects of science were assessed – *knowledge about science* (e.g. Physical systems & Technology systems) and *knowledge of science* (e.g. Scientific enquiry & Scientific explanations) – with the aim of defining, “The extent to which an individual:

- Possesses scientific knowledge and uses that knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions about science-related issues.
- Understands the characteristic features of science as a form of human knowledge and enquiry.
- Shows awareness of how science and technology shape our material, intellectual and cultural environments.
- Engages in science-related issues and with the ideas of science, as a reflective citizen” (OECD, 2007b, p.21).

¹² This is recognised as being equivalent to 10th grade in the US education system

¹³ Some of the PISA partners are special administrative regions (SARs) and not independent countries. However, for convenience, the term ‘country’ is used to refer to all participating partners in this review

Table 3.2: Countries participating in PISA 2006

Key: OECD countries / Partner economies

| | | | |
|----------------|-----------------|--------------------|-----------------|
| Argentina | Finland | Latvia | Serbia |
| Australia | France | Liechtenstein | Slovak Republic |
| Austria | Germany | Lithuania | Slovenia |
| Azerbaijan | Greece | Luxembourg | Spain |
| Belgium | Hong Kong-China | Macao-China | Sweden |
| Brazil | Hungary | Mexico | Switzerland |
| Bulgaria | Iceland | Montenegro | Thailand |
| Canada | Indonesia | Netherlands | Tunisia |
| Chile | Ireland | New Zealand | Turkey |
| Chinese Taipei | Israel | Norway | United Kingdom |
| Colombia | Italy | Poland | United States |
| Croatia | Japan | Portugal | Uruguay |
| Czech Republic | Jordan | Qatar | |
| Denmark | Korea | Romania | |
| Estonia | Kyrgyzstan | Russian Federation | |

Using three science competencies (*identifying scientific issues, explaining phenomena scientifically and using scientific evidence*), the responses given by students were categorised into six proficiency levels, with Level 6 depicting advanced scientific knowledge, understanding and application. The results for the participating countries, as percentages of students at each proficiency level, are shown in Appendix II. As can be seen from this graph, there is a wide discrepancy between the participating countries, ranging from Finland, with 96% of students attaining proficiency Level 2 and above, to Kyrgyzstan, with only 14% of students attaining at least Level 2 (and no student attaining Levels 5 or 6). A pattern can be seen emerging, in that 5 of the top 8 performing countries are in Asia, similar to the results found in the TIMSS 2007 study. Some of these results are discussed further in section 3.2.3.

The PISA surveys are designed to be comparable with one another (OECD, 2007b), enabling countries to assess changes in their own performance as well as to compare themselves with the performance of other participating countries. Appendix III compares countries'

science performance between the surveys carried out in 2006 and 2009. Of the 57 countries participating in both surveys, 31 showed improvements in 2009, 4 countries showed no change in their performance score, and 22 countries saw a decline in their performance in the 2009 survey. Two countries, Turkey and Qatar, saw an increase in score of 30 points, which is the equivalent of almost half a proficiency level or one school year. Austria saw the biggest decrease in score (17 points), equivalent to approximately half a school year.

Appendix IV shows the science performance of countries' and economies' in PISA 2006 & PISA 2009, along with their corresponding HDI values for those years. It can be seen generally that, as with the TIMSS 2007 study, the higher this value for a particular country, the better that country scored in the survey. Notable exceptions to this are again Norway and Qatar (discussed in section 3.2.3), who scored statistically below the OECD average, despite having very high HD. Other countries with very high HD that scored below the OECD average are Iceland, US, Slovak Republic, Luxembourg, Italy, Greece, Israel and Portugal.

3.2.3 Comparison of these two studies

Both PISA and TIMSS are international evaluations of students' performance, with a large overlap in the countries who took part. Appendix V gives a list of countries participating in TIMSS 2007 and PISA 2006 – as can be seen, 82 countries or economies participated in either one or both studies. There are, therefore, over 100 countries from which there is no comparable data regarding their science performance. Figure 3.1 shows a map of the countries not involved in either PISA 2006 or TIMSS 2007 studies. Here can be noted that the majority of these are in Africa and Central America, along with parts of Central Asia. Of these countries not involved, a large number have medium or low HD – that is not to say, though, that the educational systems in these countries are unable to participate in international assessments. The new countries participating in PISA 2009 and TIMSS 2011 include South Africa and Honduras which both have a medium HDI.

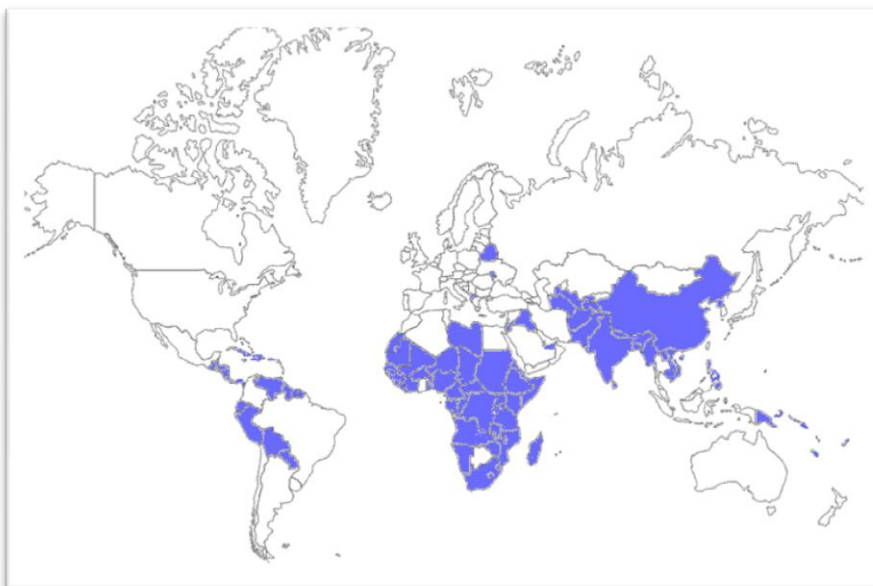


Figure 3.1: Map showing countries not participating in either TIMSS 2007 or PISA 2006 studies

Non-participating countries are highlighted blue

There are several obvious differences between these studies, such as the age of students being assessed, and that TIMSS assesses two year groups in each survey. On the whole, there is a broad similarity or emphasis behind these studies – to establish the knowledge and skills that students have, to be able to evaluate and draw comparisons between different participating countries, to be able to critically analyse educational systems and curricula, to make note of external information about participating students and to find out what perceptions students themselves hold towards their studies.

However, one distinct difference is in the concepts underpinning the tests. TIMSS tends towards a traditional approach, taking more conventional aspects from the curricula, whereas PISA questions include more application of these aspects, requiring students to show their understanding of the subject content and their skills in manipulating this. One international educator who has been involved in both PISA and TIMSS projects, “... characterised TIMSS as testing what students **know** (or **remember**) from their school science, while PISA tests what students **can do** (or **understand**) with the science

knowledge they have” (Fensham, 2008, p.29). The author continues by stating that, “TIMSS tests students in Years 4 and 8 in the curriculum knowledge of science that is common across the participating countries for these years. PISA (Science) has a different purpose, namely, providing the educational systems in its participating countries with information about *how well 15 year olds have been prepared for life in the 21st Century* in the domain of Science. The PISA Framework documents make it quite clear that this project is concerned with a level of learning that involves the transfer of knowledge, that is, the application of what science is known to new situations of relevance in the today’s world” [emphasis added](p.30). This has been alternatively expressed as:

“TIMSS is a major source for internationally comparative information on the mathematics and science achievement of students in the fourth and eighth grades and on related contextual aspects such as mathematics and science curricula and classroom practices across countries. PISA is the primary source for internationally comparative information on the mathematics and science literacy of students in the upper grades at an age that, for most countries, is near the end of compulsory schooling. The objective of PISA is to measure the “yield” of education systems, or the skills and competencies students have acquired and can apply in these subjects to real-world contexts by age 15”

(US Department of Education, 2007, p.2).

In light of the inherent differences between TIMSS and PISA assessments, direct comparisons are deemed not to be beneficial.

There is a general pattern for both PISA and TIMSS studies of high HDI value and high scores. Figure 3.2 shows the relationship between student performance on the PISA 2006 science scale and national income, one of the components used to compile the HD index. As can be seen, there is a positive correlation between these two factors.

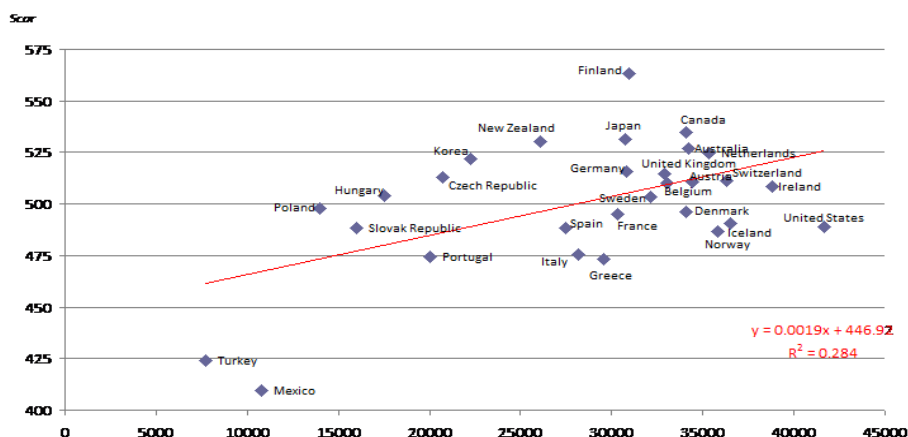


Figure 3.2: Student performance on the 2006 PISA science scale and national income

Relationship between performance in science and GDP per capita, in US dollars, converted using purchasing power parities (PPPs). [Source: OECD PISA database 2006, Tables 2.1c and 2.6]

A positive correlation is also seen in Figure 3.3, between the relationship between student performance on the science scale and spending per student. It can be hypothesised, therefore, that the higher the development of a country, the greater its national income and the greater its spending per student, the better the score it is likely to obtain in PISA surveys. A similar relationship could be expected in TIMSS studies too, although this data is not available.

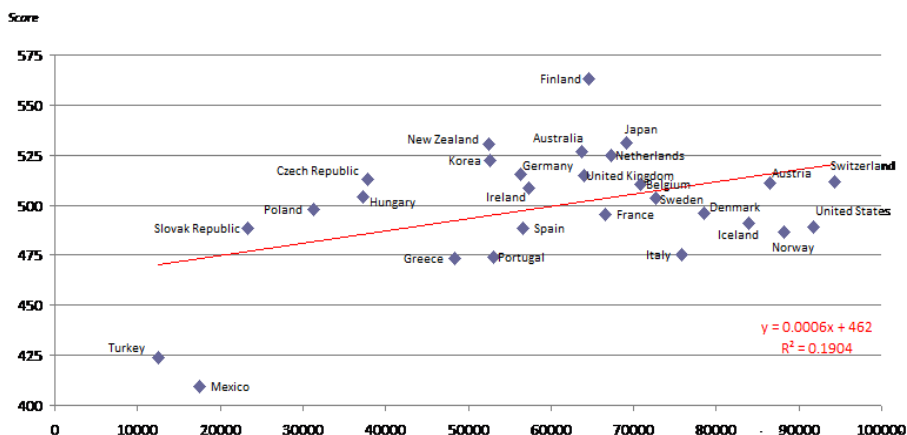


Figure 3.3: Student performance on the 2006 PISA science scale and spending per student

Relationship between performance in science and cumulative expenditure on educational institutions per student between the ages of 6 and 15 years, in US dollars, converted using purchasing power parities (PPPs). [Source: OECD PISA database 2006, Tables 2.1c and 2.6]

One of the countries showing results that did not follow the general pattern of higher HDI value and higher scores in PISA and TIMSS studies was Qatar – attaining almost the lowest scores in both tests. It is, however, worth noting that in the 2009 PISA study, the science score had risen by 30 points from the 2006 PISA study, yet this score of 379 was still way below the OECD average of 500. Although countries which have higher national incomes do tend to perform better in science (Figazzolo, 2009), Qatar is an example of a country where income does not reciprocate with its scores. Specific reasons for this could not be found – the only point of note is that the country has undergone educational reforms since their participation in the first of these surveys.

The other country showing results different from the general pattern was Norway, who scored significantly lower than the OECD average. This is not attributed to language (Kjærnsli, Lie, Olsen & Roe, 2007), although there are 2 main languages, *Nynorsk* and *Bokmaal*, nor to gender differences. One suggestion given was regarding a low level of ‘test motivation’ – “Why should [students] bother to struggle on the test, if they did not get anything back, not even their personal result as a test score?” (p.23). Another reason for such a result was associated with the low score attained for the competency *Using scientific evidence*, which was significantly different from the other two competencies in the PISA surveys. Kjærnsli & Lie (2009) refer to the way science testing is carried out in Norway (and many other countries), where emphasis is more on content knowledge and less on the ‘process’ aspects of science, which is in contrast to the PISA method of questioning.

However, the main reasons for these results are attributed to a number of other factors, including the decline in reading skills (see section 5.1), and the way in which teaching is organised – “Not many years ago, teaching was basically given by one teacher teaching one class in one classroom and with one timetable. The word ‘class’ is not any longer so relevant. Now students may be organized in small groups and these groups might be quite flexible, both regarding hours used on a task, and also regarding how the teachers organize students across different grades” (Kjærnsli *et al.*, 2007, p.31). This change, along with the work plans used by teachers and students, is a matter of concern, as weaker students seem to struggle with the

‘self-regulating’ learning approach. These authors continue that, “We are sure that the weak pedagogical leading in classrooms are one main concern for interpreting the decline in the subject achievement level” (p.34).

Concerns relating to poor student performance in TIMSS and PISA studies raised by countries such as Norway, and possible solutions for dealing with these aspects of science education, are discussed further in sections 4 and 5.

4. Current issues faced in science teaching

This section looks at the science teaching issues faced at present, firstly from the perspective of students, and secondly from the perspective of teachers.

4.1 Students and science

One of the key ways of identifying issues faced in science teaching, as perceived by students, is in monitoring their attitudes. This enables not only the current situation to be assessed, but also for changes over time to be analysed and interpreted, and the effects of any changes implemented to be considered.

As already mentioned, concern has been expressed regarding the decreasing interest in science amongst students and the decline in those choosing to continue with further education in science. One of the implications that arises from this is described by Fensham (2004): “As far as the future supply of scientists is concerned the problem suggests that without substantial changes the supply will be from a small minority of senior students ... while the majority will, to all intents, have ‘disowned’ science” (p.2). It is important, therefore, to consider that, “... recent research evidence... strongly supports the idea that the majority of children are making up their minds about whether to follow a STEM related career before the age of 14” (R. Tytler, Osborne, Williams, K. Tytler, Cripps Clark, 2008, p.86; also OECD, 2007b). Similarly, in a study of over 3000 eighth grade students in the U.S., it was found that, “students with expectations of a science-related career [when aged 13/14] were 3.4 times more likely to earn physical science and engineering degrees than students without similar expectations” (Tai, Qi Liu, Maltese & Fan, 2006, p.1144). In her research study, Dr Elbanowska-Ciemuchowska, has pointed out that life choices can be dependent on children’s experiences even as early as kindergarten (Jabłońska, 2010, p.1). Also of note, some studies suggest that students’ interest or

engagement in science deteriorates between primary and secondary education – Lyons & Quinn (2010), however, challenge this suggestion, as “92% of students [in the *Choosing Science* survey] believed their secondary school experiences had had the greatest influence” (p.102) upon their opting to continue with science education.

4.1.1 Why do students not choose science?

So why is it that fewer students are choosing to continue with science when this subject becomes optional rather than compulsory? In seeking to answer this question, the results from some different studies have been combined to give an overview of current attitudes expressed. It is important to acknowledge, however, that, “Currently, we know little about the factors that lead children under the age of 14 to be interested in science or not. How much it is a factor of school or outside influences is, for instance, one critical issue” (Osborne & Dillon, 2008, p.19). This is reinforced by evidence showing that a significant proportion of learning takes place outside the classroom: “Students of school age spend about two-thirds of their waking lives outside formal schooling. Yet science educators tend to ignore the crucial influences that experiences outside school have on students’ beliefs, attitudes and motivation to learn” (TLRP, 2006, p.6). This is, therefore, an area where further research is needed. It is also worth considering, what subjects *do* students choose if they are not choosing science, as examining their preferences may give an understanding of what they perceive as of value in further study.

Also important to consider is the role of the teacher. If students choose not to continue with science, is it because of the way it is taught, or is it the subject itself? Would a ‘good teacher’ be influential in students’ decisions to continue with science? Research has emphasised the part of teachers in helping students engage with a subject (Glasgow, Cheyne & Yerrick, 2010).

Both PISA and TIMSS studies incorporate questions about students’ attitudes to science and other personal details which may have an effect on their achievement. In light of research evidence regarding the age by which students express interest in pursuing

careers in STEM subjects, it is fair to suppose that the majority of students participating in these studies have already made up their minds in this respect. Moreover, attitudes expressed in these studies are not only indicators of the current situation, but also for the immediate future.

As well as these studies (PISA and TIMSS), this section incorporates findings from two other studies. The first of these is the Relevance of Science Education (ROSE) international project¹⁴, which seeks to determine students' views about science, and to highlight factors which are important to them. ROSE currently has over 40 partnering countries (see Table 4.1)¹⁵. This project, aimed at 15/16 year olds, does not test students' aptitude in science, but instead uses a questionnaire to obtain students attitudes and motivations towards different aspects of science and technology. The second is the *Choosing Science* study carried out in Australia between 2007 and 2009, also with 15/16 year old students, which sought to determine what factors influenced students as they chose the subjects they intended to study further in their education (Lyons & Quinn, 2010).

Table 4.1: Countries currently partnering in the ROSE project

| | | | | |
|----------------|---------|-------------|--------------|-------------------|
| Australia | Estonia | Israel | Philippines | Sweden |
| Austria | Finland | Italy | Poland | Trinidad & Tobago |
| Bangladesh | France | Japan | Portugal | Turkey |
| Botswana | Germany | Latvia | Russia | Uganda |
| Brazil | Ghana | Lesotho | Slovakia | UK* |
| Brunei | Greece | Malawi | Slovenia | Zimbabwe |
| Czech Republic | Iceland | Malaysia | South Africa | |
| Denmark | India | Netherlands | Spain | |
| Egypt | Ireland | Norway | Swaziland | |

Key: Countries who did not participate in either PISA 2006 or TIMSS 2007 are highlighted blue

* UK: England, Northern Ireland, Scotland

¹⁴ <http://www.uv.uio.no/ils/english/research/projects/rose/> (Retrieved 24th February 2011)

¹⁵ Note: ROSE includes 9 African nations and 12 countries not included in either PISA 2006 or TIMSS 2007

It is mainly from these four studies (*Choosing Science*: Lyons & Quinn, 2010; *PISA*: OECD, 2007b; *ROSE*: Sjøberg & Schreiner, 2010; *TIMSS*: Martin *et al.*, 2008) that the following attitudes towards science, from a student perspective, have been compiled. In this context, various issues as to why it is difficult to engage students' interest and active participation in science are discussed – for as Fensham (2004) writes, “International concern is mounting about the failure of recent school science curricula to foster interest in science as a career or as a lifelong personal interest” (p.1).

4.1.1.1 General

BORING AND IRRELEVANT

One of the most common responses found was that science was boring and irrelevant – students do not see the utility of it in their own lives and consider it unnecessary for the future. For example, in the PISA 2006 study, although over 90% of students seemed to agree that science was important for understanding the world around them and for improving living standards, only 57% of the students participating thought that science was very relevant to them individually (OECD, 2007b, p.27). Results also showed that those who had a more positive attitude towards science tended to do better in it than those with less positive attitudes (Martin *et al.*, 2008, p.7). Furthermore, it has been noted that, “School science, particularly at secondary level, fails to sustain and develop the sense of wonder and curiosity of many young people about the natural world” (Millar & Osborne, 1998, p.2005).

This highlights a paradox – students consider science to be *irrelevant* at a time when governments (and subsequently curricula) are seeking to promote its *relevance*. As has already been stated, the importance of scientifically literate citizens has been recognized on a national and international level. “Young people need to see science as relevant to the identities that they are building, or wish to build for their future selves, and they need to develop this insight against an international backdrop of global issues and concerns” (Bolstad & Hipkins, 2008, p.15).

It is important to note though, that not all evidence supports the idea that students are disinterested in science (Jenkins & Nelson, 2005). Results from the ROSE questionnaire indicate a stark/significant difference between the participating countries – for example, although Japan and Nordic nations show scepticism or ambivalence to many aspects of science, less developed countries who participated in this survey showed *considerable interest* in learning about almost all the topics included (Sjøberg & Schreiner, 2010). Analysis of this data showed, “... a 0.92 negative correlation between students’ attitude towards school science and the United Nations Index of Human Development” (Osborne & Dillon, 2008, p.11). An earlier TIMSS study from 1999 also showed a negative correlation between students’ performance and their attitude towards science – the higher their attainment in the test, the less positive their attitude (Ogura, 2006)(See Figure 4.1).

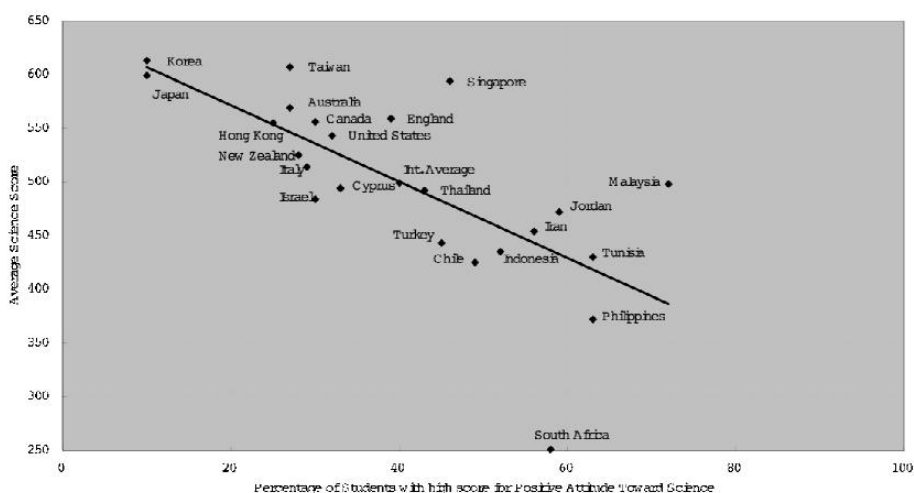


Figure 4.1: Relationship between student achievement and student attitudes to science for TIMSS data

Source: Osborne & Dillon (2008, p.14)

http://www.pollen-europa.net/pollen_dev/Images_Editor/Nuffield%20report.pdf

Fensham (2004), however, suggested using caution when interpreting such results, warning that, “... these declines in interest may be some sort of rebellion of adolescents against schooling generally, and not against science in particular” (p.1), although

various factors tend to confirm this negative perception of science, which is not seen in other subject areas.

One possible reason for the difference in attitude is in how students perceive their education generally. In some countries, education is a privilege that is not available to all students, hence any opportunity to study is considered beneficial, and subject matter itself is not so great a concern. In other countries, this 'right' or access to education is perhaps taken for granted.

The boredom expressed by students is considered to be due in part to the way in which science is taught. This is often with an emphasis on transmission from teachers and textbooks (Fensham, 2006), rather than practical or interactive with the students themselves. Moreover, the content of much of the teaching material is seen as decontextualised, which neither captivates students' interest nor encourages their participation (Lindahl, 2003). According to Towne, a (*former*) school dropout, "Lecture is dead. It's boring and ineffective. Instead, [teachers should] find ways to make the lesson fun, engaging, and, most important, relevant to students' lives" (2009, p.1). In particular, teachers are encouraged to involve students more in various aspects of the lesson. For example, using debate in teaching environmental education, with students researching and presenting viewpoints from different stakeholders etc.

Added to this, not all teachers of science are well equipped to teach these subjects (BBC, 2010a; DEST, 2002; Fensham, 2004), and many lack confidence (Goodrum *et al.*, 2001) resulting in them avoiding certain aspects altogether or using curricula and teaching methods that are perceived as being out of touch with modern science (ASTA, 2007; Keys, 2005). Many students also expressed difficulties with the conflicting information that they gather from their lessons and from other sources, such as the television or the internet. They are not aware of the activity or nature of science, which involves ongoing research, often leading to changes in our existing understanding and new discoveries. In fact, "... science is by no means static; theories are dependent on available evidence and as such may change as new evidence emerges" (Harlen, 2010, p.11). Moreover, this report continues, "Science seen as the creation of

understanding about the world is more likely to appeal to and excite learners than when seen as a set of mechanical procedures and established ‘right answers’” (p.12).

DIFFICULT AND ASSESSMENT INTENSE

Approximately two thirds of students participating in the PISA 2006 study did not picture themselves as scientists or with a science-related career. School science has historically been geared towards those students who *do* require science for their future, thus appealing to only a narrow range of students. It is suggested that many of the students who do not require science for their further education or future occupation choose not to continue with this subject as it is difficult in comparison with other subjects available. This is often exacerbated by the wider variety and greater choice of what are regarded as less academic courses now offered by many educational establishments (Lyons & Quinn, 2010).

Some studies remark on an apparent lack of knowledge about science in careers. It is not that students perceive science careers to be less well-paid, or that they think it is difficult to find work in a science-related career. The lack of knowledge comes in their awareness and understanding of transferable skills that are considered necessities for a wide range of jobs in the 21st century. According to the National Research Council (2010), “Research suggests that these five skills are increasingly valuable in the workplace:

1. adaptability
2. complex communication/social skills
3. nonroutine problem-solving skills
4. self-management/self-development, and
5. systems thinking” (p.2).

Figure 4.2 illustrates how the demand for certain skills in the workplace has changed since the 1960s, with a significant increase in demand for nonroutine analytic and interactive skills. Moreover, it is acknowledged that these skills, in varying degrees, are learnt and cultivated as part of science education. The extent to which this occurs is influenced by the science curriculum requirements of a particular country and the teaching methods used by individual schools.

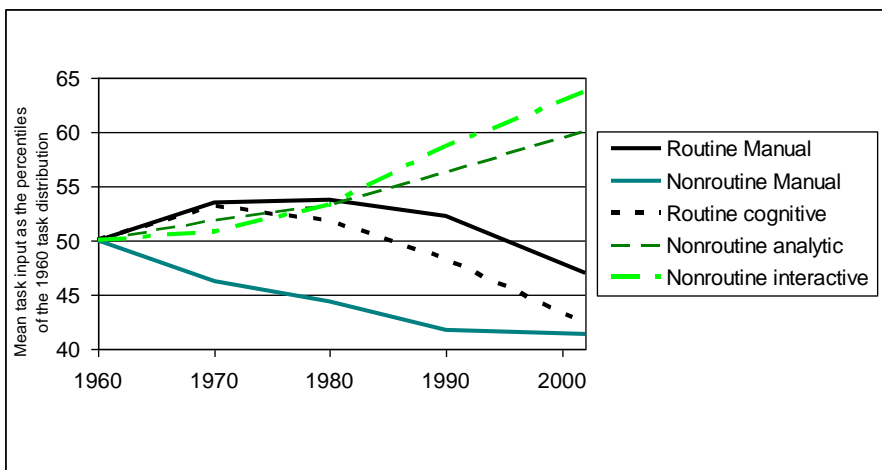


Figure 4.2: How the demand for skills has changed: economy-wide measures of routine and non-routine task input (US)

Taken from: Schleicher, A. (2007). *Europe's Skills Challenge*. Presentation held during the Lisbon Council, (October 2007). OECD. Available online:

www.lisboncouncil.net/component/downloads/?id=96

Coupled with its perceived difficulty, science is also seen to be a time-consuming and assessment intense subject. The tasks that students are required to do are seen as too rigorous, and the amount of effort and input needed is a detracting factor when students consider their subject choices. In addition, students' motivation in science seems to be driven more by achievement than by interest in the subject (Coggins *et al.*, 2005).

SELF-ESTEEM AND SELF-EFFICACY

How students perceive themselves and their own capabilities is another influencing factor that could apply to all subjects, but has specific relevance to science in light of the issues discussed above. Bandura (1997) made the distinction between self-efficacy and self-esteem: "Perceived self-efficacy is concerned with judgments of personal capability, whereas self-esteem is concerned with judgments of personal worth" (p.11). He considered both factors, though different from one another, to be important in understanding how students learn. In particular he noted that students who have a sense of efficacy in mastering academic tasks are able to learn better both in formal school environments and in informal environments outside of school.

Further research shows that, “It may even be reasonably argued that teachers should pay as much attention to students’ self-beliefs as to actual competence, for it is the belief that may more accurately predict students’ motivation and future academic choices ... For example, unrealistically low self-efficacy, not lack of capability or skill, can be responsible for maladaptive academic behaviours, avoidance of courses and careers, and diminishing school interest and achievement” (Pajares & Schunk, 2002, p.18). They also state that, “Many students have difficulty in school not because they are incapable of performing successfully but because they are incapable of believing that they can perform successfully” (p.17). It is recommended that teachers who seek to develop self-worth and self-confidence in their students should provide, “... challenging tasks and meaningful activities that can be mastered” (p.17), with appropriate assistance and encouragement when and where required.

4.1.1.2 Gender differences

Both PISA and TIMSS studies report on gender factors. With regard to achievement, TIMSS 2007 found that on average, female students at both age levels scored higher than male students; in contrast, in the PISA 2006 & 2009 studies, the overall results for many of the participating countries do not show a significant difference between the sexes. However, it was noted in the PISA 2006 study that, “females are stronger in *identifying scientific issues*, whereas males are stronger at *explaining phenomena scientifically*” (OECD, 2007b, p.114) (see Figures 4.3 & 4.4). Similar differences were seen in the ROSE study, which reported on the responses given by girls and boys as being context-dependent.

Another observation made was regarding the difference in attitudes between male and female students – in particular, with male students in 22 of the 30 OECD countries, who “... thought more highly of their own science abilities than did females” (OECD, 2007a, p.30). This finding concurs with recent literature on the subject by Bennett (2003), for example, who writes, “... gender appears to be an influential factor in determining attitude [to science]” (p.198); and, “Even though girls generally achieve as highly as boys they are less

likely to rate themselves as successful learners of physics” (Ponchaud, 2008, p.62).

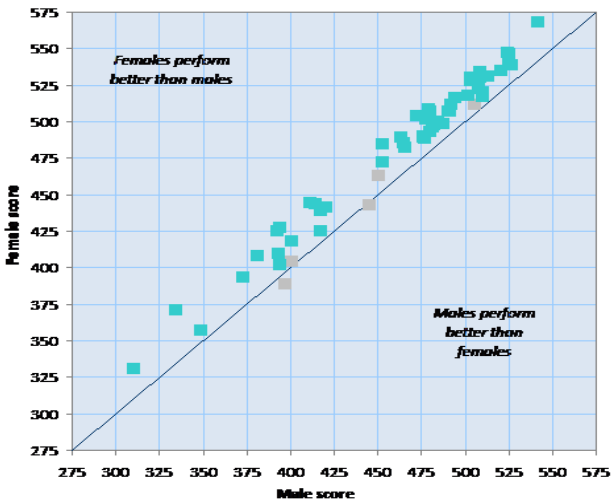


Figure 4.3: Performance of males and females on the *identifying scientific issues* scale

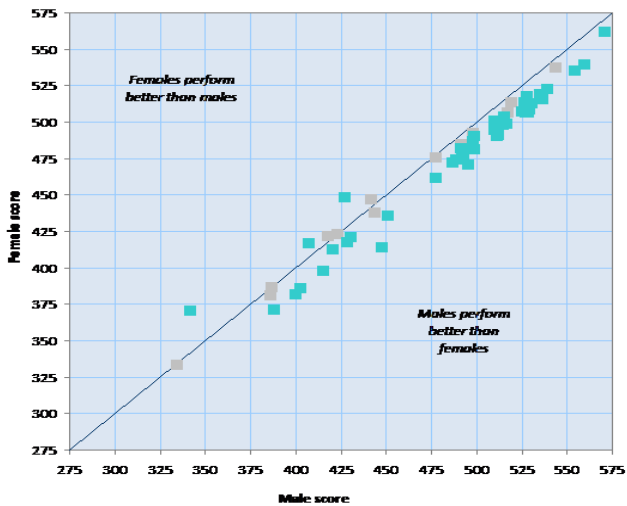


Figure 4.4: Performance of males and females on the *explaining phenomena scientifically* scale

Note: Gender differences that are statistically significant are marked in darker colour.
 Source: OECD PISA 2006, Chapter 2, Figures 2.15 & 2.16
http://www.oecd.org/document/2/0,3343,en_32252351_32236191_39718850_1_1_1_1,00.html

Moreover, science continues to be seen as a masculine discipline. According to Kelly (1985), there are four main reasons for this:

- The attitudes of teachers and pupils
- The image presented by books and other resources
- Practitioners of science are overwhelmingly male
- Scientific thinking embodies an intrinsically masculine world view (cited in Whitelegg, 2001, p.379)

Crossman (1987) gives a further explanation for the lack of girls studying physical sciences – “While acknowledging that the reasons for girls choosing not to study physics are many and varied, it struck me forcibly that most physics lessons were directed at the boys, and that relatively little communication went on between girls and their teachers” (p.58).

Blickenstaff (2005) identified that women are under-represented in STEM university courses and careers. Correll (2004) believes it may be because, “Cultural stereotypes about gender have an impact on students’ career aspirations and subject choices” (cited in Tytler *et al.*, 2008, p.93). Smail (1987), moreover, noted that, “... girls who do physics see their future in applied fields, particularly medicine and the biological sciences, rather than as pure physicists” (p.118). In addition to these explanations, Kelly (1987) wrote that, “Boys may be more willing than girls to continue science even though they find it difficult because they see it as relevant to their future careers” (p.14). These differences are more acute when considering developing countries, and the traditional role of women in many of these societies (UNESCO, 1995).

An illustration of male-domination can be seen in student enrolment in the Department of Physics at the University of Iceland: “In the autumn of 2006 ... sixty-four students were registered in the BS physics programme, 17 females and 47 males. In the master’s programme fourteen students attended physics, 4 females and 10 males. Nine PhD students were registered in the programme, 2 females and 7 males” (Guðrún Geirsdóttir, 2008, p.163). This is of particular note as within the Science faculty as a whole, the ratio of females to males is approximately equal. This example is by no means unique to Iceland – similar scenarios are seen in other countries within the European Union (Osborne & Dillon, 2008).

Dweck (2002) points out that, “Girls, especially bright girls, have traditionally underestimated themselves and shied away from challenges”. However, “... the way to motivate [them] and to give them more lasting motivation and confidence is not by telling them they’re smart, but by focusing them on the processes that create achievement” (p.56). This highlights the need for appropriate teaching practices that engage both sexes – Barbara Gross Davis states that, “Research has shown that good everyday teaching practices can do more to counter student apathy than special efforts to attack motivation directly” (cited in Ericksen, 1978, p.3).

4.1.1.3 Other factors affecting students’ performance in science

There are a number of other factors that are considered to affect students’ performance. On average, better achievement was seen in students who had a socio-economic advantage (found, for example, amongst students who had regular access to computers at school and at home), who had and read more books, who attended urban schools, and whose parents had themselves attained higher levels of education.

Also important is language - those students who spoke the language of the test in their home attained better scores in both PISA and TIMSS studies. According to PISA 2009 results, “... first-generation students – those who were born outside the country of assessment and who also have foreign-born parents – score, on average, 52 score points below students without an immigrant background” (OECD, 2010a, p.10). This is the equivalent of almost one whole proficiency level or nearly two school years. Likewise, TIMSS results show that “... achievement was highest amongst students attending schools with more than 90 percent of students having the language of the test as their native language” (Martin *et al.*, 2008, p.8). This has implications for the way in which lessons are taught – “... classroom observation studies conducted in several countries in Africa (Benin, Burkina Faso, Guinea-Bissau, Mali, Mozambique, Niger, South Africa, Togo, Tanzania, Ethiopia, Ghana, and Botswana) reveal that the use of an unfamiliar language such as English often results in traditional and teacher-centred teaching methods” (Alidou *et al.* (2006), cited in Webb, 2009, p.330).

Language factors are quite complex – for example, consideration needs to be given to the languages spoken in the home, those spoken by the teacher (both in teaching and in general communication), those of the texts being used, and indeed those of countries where subjects are taught in more than one language – e.g. Finland, the top scoring country in 2006 PISA, where science is taught in Suomi (Finnish) or Swedish (Hautamäki *et al.*, 2008). There are also cultural aspects related to language – ethnic minorities, although perhaps speaking the language of the teaching and texts, are shown to achieve widely different results (Hastings, 2006).

4.1.2 How would students like science to be taught?

“Tell me and I forget. Show me and I remember. Involve me and I understand”.

— Chinese proverb

Research has also been carried out to not only find out why students’ do not do science, but also to establish how they would like science to be taught. Aikenhead (2005) promotes the idea of *Humanistic Science Education*, which is seen as different from traditional teaching of science in that it includes both the learner and the nature of science. He describes positive student response to the following approaches of teaching:

- Science as a Story involving persons, situations and actions
- Real-world situations of S&T that students can engage with
- Focal questions that attract interest
- Contexts as the source and power of concepts in science
- Clearly presented science – related issues of personal and social significance
- Personally engaging, open problems for investigation

(cited in Fensham, 2006, p.71)

These approaches have been incorporated into the PISA assessment tests, and a positive response to questions in this style has been seen. Various reports comment on students’ desire to have science in context – not sets of isolated facts, but teaching that presents interconnected concepts and ideas. In essence, students want to know how or where a scientific idea can be seen, and why it is important for them to learn and understand it. Thus, students can

engage with science and it becomes something that they can actively participate in.

Similar responses have been noted by Lyons & Quinn (2010), who also remark on students' desire for practical/experimental work rather than an emphasis on the theoretical aspects of science. In addition, they reiterated the need for relevant and applicable teaching that should be made interesting and enjoyable for students. However, they go on to say that, "The first step to developing effective policy to increase enrolments [in science subjects] is to appreciate the complexity of interrelationships between systemic, societal, school and student factors associated with the declines" (p.110). In other words, a change in teaching approach *alone* is not likely to produce the sought after upturn in student enrolment.

Another factor commented on is the material traditionally used in science lessons. School textbooks are considered, by students and teachers alike, as consisting of too much surface detail and not enough in-depth information and explanation. Textbooks are, "... full of facts and names of mixed importance... devoid of the most interesting things... like how we know what we do, and what we don't know" (Singer, 2010, p.2). This also has a direct relationship with a students' ability to read, recognised by both PISA and TIMSS (and the associated PIRLS) studies. Students also perceive that what is required of them is often repetition of facts or giving the correct answer, rather than an understanding of how that fact or knowledge can be applied (Fensham, 2004; Osborne & Collins, 2001).

In addition, Bartley, Mayhew & Finkelstein (2009) report that, "Students are now provided less opportunity to learn science. ... formal science educational settings face several challenges including: large student-to-teacher ratios, time constraints, mandated testing, insufficiently trained and under-qualified teachers, and lack of financial and community support" (p.93). At a time when the global economy is placing strains on government budgets and funding, some of these factors are likely to become amplified.

4.2 Teachers and science

There has been considerable research into the current issues faced by teachers of science. The situation has been assessed by different methods including direct questioning, online forums, workshops and conference sessions. As already mentioned, one area of particular concern is the lack of science teachers. Other factors include aspects of teacher training and teaching capabilities, available materials and curriculum issues. These are explored in more detail below.

4.2.1 Teacher shortage

There is a shortage of teachers, especially in STEM subjects. This is seen not only in developed countries, but also in those described as developing or transitional. For example, Tanzania faces a general shortage of qualified teachers, but particularly maths and science teachers. Such is the problem that they are considering looking, “beyond Africa for an immediate solution to the teacher shortage crisis” (Tagalile, 2010). Another developing country facing an immediate shortage of science teachers is Guyana, which has previously hired teachers from Sri Lanka and Sudan and is considering hiring overseas teachers again. Moreover, they are looking into retaining teachers beyond retirement age to meet the current demand (Kaieteur News Online, 2011). This migration of educated workers, especially from countries of lesser income to those offering higher wages, creates a so-called ‘brain-drain’.

Ingersoll & Perda (2009) found that the issue was not so much one of teacher shortage, but rather that of teacher turnover: “Our analyses revealed that pre-retirement teacher turnover – the departure of teachers from their schools – is a significant factor behind the demand for new hires and the accompanying difficulties that schools encounter staffing classrooms with qualified teachers” (2009, p.5). According to the U.S. National Centre for Education, “In a typical year, an estimated 6 percent of the nation’s teaching force leaves the profession and more than 7 percent change schools” (cited in NSEA, date unknown)¹⁶. In other words, the problem is not simply

¹⁶ <http://www.nsea.org/policy/salaries/index.htm>

a shortage of teachers being recruited into science, but also *retention* of science teachers already in place.

Which begs the question, why do teachers leave? According to research by the Institute of Education Sciences (2008), the most influential reason, other than retirement, given by science and mathematics teachers for leaving their teaching employment, was a better salary (25%). Smith (2010) illustrates this with a joke that is told by teachers: “*You know the difference between a large pizza and a teacher? A large pizza can feed a family of four!*” (p.5). Whereas 14% of teachers of other subjects left as they were dissatisfied with teaching as a career, this figure rose to 18.4% for maths and science teachers. Also, Darling-Hammond (1997) reports that for teachers beginning their careers, “... more than 30% ... leave within the first five years of teaching” (p.21).

Another issue raised is regarding why so few undergraduates are choosing to train to become science teachers. For example, in 2010 there were 210 teachers who graduated as compulsory school teachers (grunnskólakennari) from the University of Iceland (Háskóli Íslands), with only *ten* of these specialising in science (Anna Kristín Sigurðardóttir, 2011; see Appendix VI). A contributing factor is in the reciprocal effect of having fewer students who choose to continue with science beyond compulsory schooling to graduate level. Some multi-national projects have been set up to try to address this issue, and to learn from one another – for example, the Improving Quality of Science Teacher Training in European Cooperation (IQST) project, which recognises the “... need for the exploration, discussion and exchange of educational ideas, analysis of common problems, implementation of European dimension in initial science teacher training, with the aid of joint projects”¹⁷.

4.2.2 Teacher training

A factor contributing to the number of science teachers who leave the profession has been that of teacher training. TIMSS 2007 results showed that only 39% of students had teachers who had specialised in science subjects and/or science education. Furthermore, “teachers

¹⁷ <http://www.iqst.upol.cz/>

of the fourth grade students in a number of countries reported little specific training or specialized education in science” (Martin *et al.*, 2008, p.10). Dr Hilary Leever of the Campaign for Science and Engineering (CASE) states that, “People signing up to start a textiles teaching course were being hailed as new [science] classroom teachers” (BBC, 2007). Fensham (2006) believes that the problem is compounded by the fact that, “Undergraduate studies in the sciences have... been primarily introductory to careers in scientific research, leaving graduates for other careers, such as school teaching, deficient in aspects other than foundational conceptual knowledge” (p.72).

Garner (2008)¹⁸ cites a report from OFSTED, the UK *Office for Standards in Education, Children’s Services and Skills*, stating, “Many science teachers lack the confidence to teach the subject because they have had little or no training in it” (p.1), going on to say that, “Science is a fascinating subject... Yet for many pupils it lacks appeal because of the way it is taught” (p.1). This was a problem highlighted in the 1978 *HMI Primary Survey*¹⁹ – “The most severe obstacle to the improvement of science ... is that many existing teachers lack a working knowledge of elementary science appropriate to children of this age. This results in some teachers being so short of confidence in their own abilities that they make no attempt to include science in the curriculum” (p.62). Recent research suggests that this situation has changed little (Murphy, Neil & Beggs, 2007; Lee, Wu & Tsai, 2009). Harlen (2010), for example, identifies that, “Primary teachers face particular challenges [including] a lack of confidence in teaching science as a result of little personal experience and understanding of scientific activity” (p.48). Similarly, Fensham (2004) highlights the discrepancy between secondary school science teachers, who are specifically trained to teach their subject, and primary school teachers, who have a broad overview of many subjects rather than a deep understanding, which can result in a lack of confidence. However, as Bower (1996) writes, if the focus shifts from scientific content knowledge – where teachers may well feel inadequate – onto that of scientific processes, teachers are much more assured in their capabilities to teach science.

¹⁸ <http://www.independent.co.uk/news/education/education-news/science-teachers-suffering-lack-of-confidence-848483.html>

¹⁹ <http://www.dg.dial.pipex.com/documents/hmi/7805.shtml>

Yet Duit (2007) expresses that, “For teachers to know science well is not sufficient to teach this subject. At least basic knowledge on the nature of science provided by philosophy of science and history of science as well as familiarity with recent views of efficient teaching and learning provided by pedagogy and psychology are necessary” (p.4). As the intended overall aim is to improve students’ learning in science and technology, UNESCO reports that the fundamental factor required in achieving this is, “... the quality (knowledge, skills and enthusiasm) of their teachers” (Fensham, 2008, p.39). This factor has perhaps been underestimated in the drive to recruit more teachers to the profession – however, it is my personal opinion that high teaching quality is crucial for a positive future in science education.

Science lessons require ‘clear explanations at appropriate junctures’ (Weiss & Pasley, 2004). They also require a coherent transmission of information – not disjointed and detached facts and theories that students are unable to connect and contextualise. Also, teachers need to promote the art of interaction, helping students to develop meaningful scientific talk and the art of thinking, engaging the ability of students “... to successfully explain and manipulate complex systems” (Roberts & Billings, 2008, p.33). These skills are crucial as, “We have yet to succeed in persuading all children of the relevance of science to their daily lives and to see themselves as critical guardians against the use and abuse of science and misinformation parcelled out by politicians and the media. Maybe this is the task for the teachers of the new century” (de Boo & Randall, 2001, p.120). This is an aspect of scientific literacy – enabling students to calculate or discern for themselves. Statistical results are often used to prove a desired fact, and yet that same data could be interpreted differently and used to prove an alternative. For example, some of the same statistics given in the documentary *An Inconvenient Truth*²⁰, highlighting global environmental issues, are used in the opposing production, *A Convenient Fiction*²¹, to dispute the original arguments being presented.

Another observation is that teachers of science subjects lack variety in their teaching and learning experiences. For example,

²⁰ <http://video.google.com/videoplay?docid=8847562857479496579#> (Retrieved 5th May 2011)

²¹ <http://video.google.com/videoplay?docid=7593305076218696987#> (Retrieved 5th May 2011)

amongst teachers with varying levels of science education in Australia, Fensham (2006) reports that, "... many of them are seriously deficient in *having any science stories to tell*, in *communicating within and from science*, in *knowing science as a way of thinking* and in *applying science in real-world applications*" (p.72). Professional development is often available for science teachers, but for differing reasons these support services and networks are not used to their full advantage. Additionally, the quality of this development offered varies greatly, with some services being rather inadequate and of little benefit. This exacerbates the fact that science teachers can feel very isolated and have little contact, mentoring or even accountability with fellow teachers in their own subject field (Eisner, 1992).

4.2.3 Curriculum factors

Teachers cite a number of reasons as to why teaching science is difficult. One such complaint relates to the continual changes and requirements in curricula and assessments: "The majority of teachers need a sustained period of stability in which they can refine, reflect and develop their practice within a framework that is relatively constant and secure" (Millar & Osborne, 1998, p.2028). Windschitl confirms the need for time in, "... planning and enacting new practice" (National Research Council, 2010, p.63). In the same discussion, Carvellas adds, "Although teachers are willing to teach in a different way, they need time and support to do so" (2010, p.66).

There is an over-emphasis on content in the science curricula of many countries, being dominated in particular by topic-knowledge (Hafþór Guðjónsson, 2008). This has led to science curricula being compartmentalised, 'disconnected' from the context, and 'overloaded', as curricula have so far not been able to, "... resist the temptation to include too much, and so avoid ending up with content-dominated curriculum" (Millar & Osborne, 1998, p.2007). Harlen (2010), writes of the need to, "... conceive the goals of science education not in terms of the knowledge of a body of facts and theories but a progression towards key ideas which together enable understanding of events and phenomena of relevance to students' lives" (p.2). However, warnings have also been sounded about

straying away from establishing knowledge and facts – science is based on fact (as it is known at that time). New-style curricula are seen as providing a ‘watered-down’ version.

Science curricula are seen to be assessment-driven. Although it is recognised as being necessary, there are issues relating to the method and frequency of assessment. For example, “Assessing science through paper-and-pencil tests is akin to assessing a basketball player’s skills by giving a written test. We may find out what someone knows about basketball, but we won’t know how well that person plays the game” (Hein & Price (1994), cited in National Academy of Sciences, 1997, p.100). As science is considered by a number of students as being too intense, this is an area where careful consideration should be given as to how not to ‘put them off’.

A survey by the Science Learning Centre (BBC, 2010b) found that 96% of teachers faced obstacles to doing practical lessons. Reasons for this included curricula and assessment requirements, badly behaved students, a lack of equipment and fears over health and safety. Professor Sir John Holman, in the same article, states that, “Learning science without practicals is the equivalent of studying literature without books”.

It is also important to consider the number of hours given to science instruction per week. TIMSS 2007 found that on average fourth grade students received almost 2 hours of science instruction per week, rising to 3 and a quarter hours in eighth grade. In the US, “As a result of the *No Child Left Behind* legislation, general science curriculum in formal settings has been displaced in favour of additional focus on reading and math skills (Bartley *et al.*, 2009, p.93).

One final aspect to mention is the perceived lack of coherence and overlap with other departments. This, for some teachers, can be not only frustrating, but also belittling. Networking is considered fundamental in business, and yet within a school environment there can be little communication or sharing of information. Benefits of knowing what other teachers and departments are teaching include preventing unnecessary repetition of material for students, providing a coherent teaching curriculum that builds on what is taught by one another, and generally learning from one another.

4.2.4 Information and Communication Technologies (ICT)

Rapid and extensive changes have occurred in recent years relating to ICT, which are having far-reaching consequences for education. No longer is the sole source of material for students provided by teachers, textbooks and practical experiments. ICT provides resources for teachers and students alike. For teachers there are numerable websites offering preparatory material, such as lesson plans, worksheets, and simulations (of experiments or in providing virtual environments) etc. For classes where restrictions on practical experiments apply, these tools can provide an alternative method of visualising the material being taught.

ICT can also be incorporated into the lesson itself – a review carried out by Hogarth, Bennett, Lubben, Campbell & Robinson (2006) shows some of the effects of using ICT in lessons, assessing the impact that it has on students' learning and understanding of science. Although the sample size for this review was small, below are 3 of the initial conclusions that they were able to draw:

1. Students' use of ICT simulations helped to improve their understanding of science ideas significantly more effectively compared with their use of non-ICT teaching activities (based on 6 studies).
2. Students' significantly better understanding of science ideas when using ICT simulations versus their use of traditional (non-ICT) activities can lead to understanding of science knowledge (based on seven studies) and to understanding of scientific approach (3 studies).
3. [7.] The gains from the students' use of ICT simulations were even further increased when teachers actively scaffolded or guided students through the ICT simulations (2 studies).

(2006, p.3)

This review highlights a lack of research in the area of ICT in science teaching, and cautions against generalisations until further evidence is available.

Giovannini *et al.* (2010) state that, "Teaching with ICT requires many skills" (p.2). A study of teaching using ICT in Iceland identified that, "Technical difficulties can hinder the use of ICT in subject-based classes and many teachers need support from teaching advisers,

library specialists or computer specialists in order to use ICT in their classroom teaching” (Eggert Lárusson, Meyvant Þórólfsson, & Allyson Macdonald, 2009, p.219). Furthermore, in research with science teachers, they found that when ICT was used it was often to support or extend learning, rather than bringing a change in the way the core material was traditionally taught.

The use of ICT outside of the classroom has also been shown to have an effect on students’ abilities in science. Kubiak & Vlckova (2010) examined the results of PISA 2006 for the Czech Republic, and found that there was a significant relationship between science knowledge and ICT. Higher scores were attained by students who had used computers than by those who had not. They attributed this positive relationship to the fact that, “... students using ICT have access to more information from a variety of sources related to science and human activity. Whilst textbooks might not be as attractive to different groups of students for various reasons, the interactive nature of the Internet holds their attention so that the content is better absorbed” (p.536). Moreover, their “... results support empirically not only the use of computers at school but also the educational effectiveness of their use at home when used for educational purposes” (p.538). Similarly, it has been suggested that online learning environments, “which engage students in developing, warranting, and communicating a persuasive argument and in critiquing arguments developed by others [...] develop students’ adaptability to uncertain, new, and rapidly changing conditions” (National Research Council, 2010, pp.86-87).

ICT has changed the way many subjects, including science education, have been taught in recent years. In particular, it has been observed that many of the skills obtained by using ICT are transferable between subjects, and are useful for future workplaces. It has also been noted that students show a great adaptability and awareness in using ICT, often more than teaching staff themselves.

4.3 Discussion

Section 4 has outlined various current issues being faced in science teaching, with many of these discussed within the text. This section concludes with a summary discussion of some of these issues.

From the perspective of students, the most important factors to them are to make the lessons more interesting, interactive and relevant to their lives. In my view, the adage, “You can drag a horse to water but you can’t make it drink unless it’s thirsty”, applies to students and science. Unless students know why science is important for them to learn, how it is relevant to their lives, and what transferable skills they can acquire, it is difficult for them to engage with the subject. As a teacher it is important to consider the whole class – not just the brightest or the weakest students, not just the males or the females, not just those who know that they require science for their futures – as science education is for all students, and the way it is taught needs to provide for all students.

From the perspective of a teacher, it is my opinion that the quality of teaching is of paramount importance. A ‘good’ teacher can take a difficult subject, find innovative and interactive ways of teaching it, and in doing so make science ‘alive’. High quality teaching involves a thorough understanding of the subject being taught, adequate preparation for the lesson, suitable materials and resources made available, and an enthusiastic approach to the subject and the students. It also involves treating each student as an individual and helping them to develop to the best of their ability. Teachers do, of course, have to work within the constraints of the curriculum and the school environment, but science need not be boring for students to learn – on the contrary, it is better to teach less material, but to teach it well, giving students good foundations in core aspects of sciences and seeking to resolve any misconceptions. Furthermore, with the development and availability of ICT, teaching practice and materials are being enhanced, aiding both student and teacher.

Part of this training should equip teachers to devise their teaching plans, using the curriculum that they are guided or ‘bound’ by, learning where emphasis should be given, and how and where assessment would

be appropriate. Training should include assisting teachers to see how their subject overlaps or interacts with others, and where appropriate, how science activities could take place outside of the classroom.

It is important to address the issue of teacher shortage and recruitment, but the emphasis should be on training teachers well – *quality not quantity* is the key. Once this has been addressed, the aim should be to then retain these teachers, with due consideration of the factors that contribute to teachers leaving the profession. Some countries, for example, offer financial incentives to encourage teachers to remain in their posts, and to new teachers as a start out package.

Promoting science teaching as a career should begin no later than when students start their secondary education – awareness of the benefits and the privilege of being a teacher should be emphasized. In this respect, governments and media should address the status of being a teacher. It is not ‘just a job’ for those who haven’t found a desired career path, but a profession which is both challenging and rewarding.

5. Analysis of recommendations and possible solutions for improving the future of science education

This section examines and discusses recommendations for the future of science education. Many of these proposals relate to issues discussed in section 4 – here, the emphasis is on future perspectives.

Individual countries and the international community aim to improve the status of science education, as society becomes increasingly dependent on numerous aspects of science and technology. This has been expressed by nuclear physicist Edward Teller as, “The science of today is the technology of tomorrow”²², and by Carl Sagan, astronomer and astrophysicist, as, “We can do science, and with it, we can improve our lives”²³. A fuller definition is given by the United Nations Educational, Scientific and Cultural Organization²⁴:

Science, technology, engineering and mathematics education (STEM) is important for developing and developed countries alike, to increase public awareness, understanding and literacy regarding science, engineering and technology, and also to enable developing countries to build up a critical mass of scientists, researchers and engineers to enable them to participate fully in the global economy.

Two of the reports used to illustrate the current state of science education in section 3 are referred to again here: *Science education in schools: Issues, evidence and proposals* (TLRP, 2006) and *Science education policy-making – Eleven emerging issues* (Fensham, 2008). These are supplemented with recommendations from other documents – in particular, *Science Education in Europe: Critical Reflections* (Osborne & Dillon, 2008) and the *Principles and big ideas of science education* (Harlen, 2010). As before, this represents an individual country’s findings

²² <http://www.famousquotesabout.com/quote/The-science-of-today/606133>

²³ <http://www.symphonyofscience.com/>

²⁴ <http://www.unesco.org/new/en/natural-sciences/priority-areas/science-education/>

(TLRP, 2006), an inter-governmental response in a report on behalf of UNESCO (Fensham, 2008) and, with the additional documents, contributions from seminars involving a number of European science educators (Osborne & Dillon, 2008) and internationally renowned experts in science education (Harlen, 2010).

The structure of this section follows a similar layout to that of section 4, looking firstly at factors relating to students, and then to those concerning teachers and teaching.

5.1 Students and science

Recommendations regarding students include a plea for policy makers to heed how students would like to be taught science (see section 4.1.2). This includes the proposal that science teaching should move towards being context-based and relevant to everyday life, whilst still retaining scientific concepts which provide essential foundations to the subject (Bennett, Lubben & Hogarth, 2007). One way this can be done is by promoting collaboration between schools and scientific establishments. The involvement of science professionals in teaching can have a number of positive effects, including enabling students to connect science to the real world (Brady, 2008; Harlen, 2010). Evidence suggests that, "... clearer links between school science and science as it is encountered out of school lead to greater student interest and involvement" (TLRP, 2006, p.11). Other outcomes of developing cooperation and relationships with science professionals outside of school include an engagement of the local community, and an opportunity to learn of careers *in* and *about* science. Furthermore, in some countries media efforts try to educate and enthuse the public in certain areas of science have resulted in programmes presented by scientists such as *David Attenborough*²⁵ (translated into many languages) and documentaries fronted by 'modern' scientists like Professor Brian Cox²⁶.

²⁵ For example, the *Life* series: *Life on Earth*, *The Living Planet*, *The Trials of Life*, *Life in the Freezer*, *The Private Life of Plants*, *The Life of Birds*, *The Life of Mammals*, *Life in the Undergrowth*, and *Life in Cold Blood*

²⁶ <http://www.dailymail.co.uk/home/moslive/article-1360281/Brian-Cox-Life-Mars-2nd-law-thermodynamics-date-world-end.html>

Linked with this is the need to understand the educational purposes of science education for *all* students – not just for those who intend to pursue a scientific career, so that all students have the opportunity to partake in and respond to everyday aspects of science and technology. Students want to know what they will need science for – “By making science more relevant to a broader audience we can prepare prospective science degree students and professionals, as well as contribute to improved scientific literacy for all students” (King, 2009, p.13). Policy makers are also asked to consider the relationship and response of girls to science, ensuring that contexts relevant to them are developed and incorporated into new curricula. PISA, TIMSS and ROSE studies all highlight gender differences in some form, ranging from the scores attained to the desired subject items students would like to learn about – ROSE identifies 80 out of 108 topics where female and male students in England respond significantly differently from one another (Jenkins & Nelson, 2005). Osborne & Dillon (2008) observe the following differences: “Percentages of female maths, science and technology graduates vary from 19.5% in the Netherlands to a maximum of 42% in Bulgaria, with an average of 31% across Europe” (p.16). These gender differences are also important considerations for teachers in preparing the content and method of teaching their material.

Cultural differences can present disadvantages for students in learning science. This has been specifically observed in the area of language, and can be understood on two levels. Firstly, as seen in section 4.1.1.3, where the language used by students in the home is different from that in school, or where the official teaching language is one that is not the most familiar to either student or teacher. Secondly, the language of science is distinct in itself from ‘everyday’ language. As Bennett (2003) writes, “In order to understand science subjects, pupils need to become familiar with a wide range of specialist vocabulary” (p.147). Thus, according to Wellington & Osborne (2001), “... one of the major difficulties in learning science is learning the language of science” (p.8). They go on to emphasise that:

1. Learning the language of science is a major part (if not *the* major part) of science education. Every science lesson is a language lesson.
2. Language is a major barrier (if not *the* major barrier) to most pupils in learning science. (p.9)

Furthermore, language in the science classroom context should not be confined only to the traditionally understood methods of reading, writing, speaking and listening, but should incorporate symbolic, graphical and tactile communication, where relevant to the content being taught. Also recognised is the need for building 'key scientific skills', encompassing factors such as numeracy and mathematical understanding, and problem solving skills. Roberts & Billings (2008) argue that learning is an integrated process, "The more fluent students become as readers, writers, speakers, and listeners, the clearer, more coherent, and more flexible their thinking will become", and that "... learning to think requires frequent, deliberate practice" (p.33).

Teachers are therefore encouraged to acknowledge the diversity that exists between students of different gender and cultural backgrounds, and the way in which they learn and understand science. This is summed up by Yore & Treagust (2006), "Immigration worldwide has resulted in multicultural classrooms where the language of instruction is not the dominant home language. By necessity, teachers have had to address the three-language problem and help students navigate among home language, instructional language, and science language" (p.310). As stated earlier, language is a complex factor. One of the key connections for improving a student's ability in science is to improve their ability to read – this is all the more so if the instructional language is different from the one they are used to reading in.

In seeking to eliminate students' perception that science is boring and irrelevant, another key issue that science educators need to address is that of engagement. Osborne & Dillon (2008) report that, "... data strongly suggest[s] that efforts should be expended to ensure that children's early encounters with science before the age of 14 should be as stimulating and engaging as possible. Some messages from the research for policy-makers and educators are relatively clear – the experience should:

- be rich in opportunities to manipulate and explore the material world
- use a pedagogy that is varied and not dependent on transmission
- offer some vision, however simplified, of what science offers both personally in satisfying material needs and as a means of realising an individual's creative potential

- be provided in both formal and informal contexts for learning. A single encounter with a science-based activity post-14 is unlikely to have a significant impact. What is required is a continuum of educational experiences of science from an early age” (p.19).

Fensham (2004) concurs with this view, suggesting a curriculum that for, “the first three years would focus on a students’ sense of curiosity and be a rich exposure to the beauty, wonder and fascination of the natural world. The next three years would focus on the excitement of creative problem solving. In both these stages asking questions and exploring alternative ways of pursuing them, rather than ‘correctly’ answering them, should be the outcome” (p.9).

Closely linked to the issue of engagement is that of motivation. Transforming the attitudes of students towards science may seem an impossible task, but each of the reports referred to in this section impels policy makers to make this a priority. “If education is sufficiently challenging and interesting, genuine high achievement will become more widespread and will become apparent through students’ creativity, lateral thinking, and persistence” (TLRP, 2006, p.5). Further research is encouraged in investigating factors affecting students’ persistence in science.

Dweck (1998) outlines two motivational patterns that affect the response and attitudes of students towards challenges. Some students exhibit a pattern of *learned helplessness* and, “... avoid challenges that pose the risk of errors or failure, and show self-blame (denigration of their intellectual ability), negative effect, and impaired problem-solving strategies in the face of difficulty” (p.258). Others exhibit a *mastery-orientation* pattern, “... in which students confront challenge with relish, and show intensified effort, sustained optimism, and effective strategizing when they confront obstacles” (p.258). Further research showed that these patterns do not pertain to a students’ intelligence or achievement, but gender differences are quite pronounced, with females who are far more likely to exhibit the helplessness pattern (Dweck, Davidson, Nelson & Enna, 1978). With this evidence in mind, policy makers are called to make careful consideration of how students’ engage in science and what factors discourage them from continuing. In my view, this is an area where different teaching and assessment techniques can play an important role. For example, working in small groups and using peer assessment have been shown to build up

confidence in students who find it difficult to express themselves in front of a whole class.

An important observation seen by a number of researchers is in the change of attitude towards science between primary and secondary stages of education. For example, TIMSS studies identified a significant difference in attitudes between students in the fourth grade and eighth grade. Fourth grade students were generally more positive about science, with an average of 77% of students having very positive attitudes towards science. By eighth grade, the number of students showing a very positive attitude towards science had decreased to a 65% average in countries where science was taught as a single subject; in countries where science was taught as separate subjects, these averages were 66% in biology, 58% in earth sciences and only 50% in chemistry and physics (Martin *et al.*, 2008). A similar decline in students' interest has been documented in England, beginning even in children of primary school age. Evidence suggests that this is due to 'overemphasis on revision' that is carried out in preparation for Standard Assessment Tests (SATS) taken at the end of Key Stage 2, aged 11 (TLRP, 2006, p.7). This is of relevance when considering the fact that, "... for the majority of students, interest in pursuing further study of science has largely been formed by the time children are 14" (Osborne & Dillon, 2008, p.18). This observation of attitude change is one that requires further monitoring – the results seen by different countries have highlighted certain trends, but there is still quite a lot of contradictory evidence.

Another of the issues affecting students is described by TLRP as science education for citizenship. Many of the students involved in the quantitative studies are of the age when their compulsory schooling is coming to an end – some of them will continue in further education, whilst others will enter the workforce. All of them will be exposed to situations involving science and technology – such as health, energy or environmental issues, economic factors – some of which will require them to make informed decisions. Scientifically literate students are much more able to contribute and respond to these situations in an informed manner. Astrophysicist, Neil DeGrasse Tyson, expressed it like this: "If you're scientifically literate, the world looks very different to you

and that understanding empowers you”²⁷. This is, in my view, another important consideration for the future of science education – equipping an individual with the knowledge and ability to make their own choice, rather than having to guess or be guided by others. As already discussed, statistical data can be ambiguous, and science, or scientific literacy, enables an individual to make an educated reasoning or decision as required.

5.2 Teachers and science

The majority of the recommendations and proposals fall into the category of teachers and science. These are examined here under the headings used in section 4: teacher shortage, teacher training, curriculum factors and ICT.

5.2.1 Teacher shortage

Issues of teacher supply and retention can vary considerably between countries. For example, “In countries such as Cyprus, Finland and Portugal, teachers still have high status and there is much competition to enter the teaching profession. The contrast is in England, where there is a shortage of science and mathematics teachers despite considerable financial inducements and an extensive public recruitment campaign” (Osborne & Dillon, 2008, p.24). The situation in England, however, has changed in some respects – whilst there is still a shortage of teachers, particularly in maths and physics, a positive change in attitude towards teaching has been seen, along with an increase in the enrolment of mature students looking for a new profession (OECD, 2010b).

Problems have been exacerbated by recruitment to other countries – for example, “German schools are recruiting science teachers from Poland with excellent pay offers at a time when Poland has a shortage of such teachers” (Filipowicz, 2007). The key, therefore, is for individual countries to identify their own specific

²⁷ Tyson, N.deG. (date unknown). Symphony of science – The poetry of reality (An anthem for science). Retrieved 23rd March 2011 from: <http://www.symphonyofscience.com/>

requirements, and to initiate policies accordingly. Suggestions vary for how to tackle these issues, including reviewing pre-service training, and establishing or strengthening local and national science education support networks. For newly qualified teachers or for teachers who join a new school these support networks are particularly useful, as research highlights the isolation and vulnerability that can be felt in 'unfamiliar territory'.

One possible solution is to give students who are majoring in STEM subjects the opportunity to tutor in schools as an introduction to life in the teaching profession. Thornton & Reid (2001) state that, "Ideally it would seem best to 'pull' recruits towards teaching, as a positive career choice, rather than to 'push' them. The best way of accomplishing this appears to be positive work experience in schools" (cited in Smith, 2010, p.29).

In a presentation on behalf of the American Association for the Advancement of Science (AAAS), Abdallah (2007) highlights two aspects of teacher shortage, giving the following recommendations:

1. RECRUITMENT: Strengthen teacher recruitment policies in mathematics and science.
 - Implement a comprehensive package of mathematics and science teacher education recruitment strategies that include incentives such as scholarships, signing bonuses, and differential pay.
 - Strengthen the content and pedagogy of teacher preparation programs to ensure a national mathematics and science teacher workforce capable of preparing students for success in higher education and the workplace.
 - Expand strategies to attract talented individuals in STEM related professions to teaching, and ensure that they are adequately trained for the classroom.
2. RETENTION: Improve the retention of both new and experienced teachers, and address the causes of teacher dissatisfaction.
 - Develop and implement research-based induction programs for all new mathematics and science teachers.

- Implement comprehensive policies and programs that address the leading causes of teacher job dissatisfaction, including inadequate compensation, lack of administration support, and professional isolation.²⁸

(Slides 22 & 23; [layout amended])

These points summarize some of the recommendations from a number of sources being used in this review.

5.2.2 Teacher training

It is desired that all students should be taught STEM subjects by good quality *science* teachers, both at primary and secondary levels of education. This is essential as, "... the most significant determinant of the quality of school science education was the quality of the teaching that students experienced" (Osborne & Dillon, 2008, p.25). George Bernard Shaw once said, "He who can, does. He who cannot, teaches". Whilst recognising that this is not true, it is important to understand that teachers do not know everything and, "... like all learners, [have to] ultimately build their understanding of any new information or experiences based on prior knowledge or experience" (McCutchen & Berninger, 1999, p.221). Yet, it is also "... without question, [that] teachers need to have sufficient knowledge of the mathematics and science content that they teach" (Weiss & Pasley, 2004, p.28).

One persistent theme is that priority be given to ongoing professional development (or *renewal*). The recommendations given by Abdallah (2007) outlined above, continue with:

3. RENEWAL: Ensure that all mathematics and science teachers participate in renewal activities that support their effectiveness in the classroom.
 - Provide ongoing, research-based professional development programs, focused on both content and pedagogy, for all mathematics and science teachers.
 - Revamp teacher license renewal programs to incorporate measures of teacher effectiveness.

²⁸http://www.aaas.org/spp/dser/02_Events/Lectures/2007/20070623_stem/abdallah_presentation.pdf

- Establish comprehensive [...] data collection systems that track student progress, teacher effectiveness, and employment trends of mathematics and science teachers.

(Slide 25)

Harlen (2010) writes that, “Teacher education courses, pre- and in-service, should recognise that teachers as learners also need to experience scientific activity and discourse at their own level. Courses should include conducting different kinds of scientific inquiry followed by reflection on the conditions and role of the teacher that supports understanding both in science and about science” (p.14). Pre-service teachers should be assisted in translating their knowledge in science subjects into ‘pedagogical content knowledge’, i.e. how to effectively teach what they themselves know (TLRP, 2006). These views are similar to those of Yore & Treagust (2006) who advocate for interactive and informative professional development programmes for teachers involving all areas of the curriculum including instruction and assessment.

Teachers in many countries are encouraged to engage in continuous professional development. Osborne & Dillon (2008) warned though that, “In Denmark, teachers who gain further qualifications are paid more. However, there is a risk that gaining such qualifications often leads to able and enthusiastic teachers being promoted to managerial positions where they are removed from the place where they are most needed – the classroom” (p.25). It is recommended that in the desire for quality teachers with up-to-date knowledge and skills, these same teachers are not ‘lost’ from everyday teaching situations,

Finland was the top-performing country in the PISA 2006 science study, obtaining an average of 563 score points (OECD average is 500). One factor contributing to this achievement is perceived to be the number of highly-educated and qualified teachers who have “... deep subject matter and pedagogical knowledge” (Hautamäki *et al.*, 2008, p.96). More than 97% of schools in Finland reported that there was no serious lack of teachers for the separate science courses, compared with the OECD average of 81.9%.

For many teachers, the problem is not that they do not wish to participate in any kind of professional training. It is rather that, as this

is a time- and effort-consuming activity, it should be meaningful and productive, offering a wide range of opportunities for developing and honing skills, and for learning from the expertise and experience of others.

5.2.3 Curriculum factors

There is a general consensus in the recommendations set out regarding curricula. This section starts, however, with the one major difference in opinion seen, which relates to the curricula for primary and secondary education. It is followed by other recommendations and proposals from the different reports that are more in accordance with one another.

UNESCO recommends that the curriculum for science and technology in primary education should be *quite different* from that of secondary education, emphasising that it should provide students of this age “... with a series of positive and creative encounters with natural and human-made phenomena, and builds their interest in these two areas of learning” (Fensham, 2008, p.39). Similarly, Osborne & Dillon (2008) recommend that the emphasis for students under the age of 14 be placed on engagement in science, through investigative and ‘hands-on’ assignments, accentuating the practical rather than the theoretical aspects of science. In contrast, Harlen (2010) refers to a science education programme for *all* compulsory schooling that aims “... systematically to develop and sustain learners’ curiosity about the world, enjoyment of scientific activity and understanding of how natural phenomena can be explained” (p.6). This is a similar viewpoint to that found in the TLRP document (2006) which, along with research provided in the *Beyond 2000: Science education for the future* report, recommends a *seamless* curriculum, from Early Years Foundational Stages through to the end of formal schooling²⁹.

In Scotland, for example, where curricula have been centred on integrated education, a strategy known as *Storyline* was developed, challenging the traditional role of the teacher – the emphasis

²⁹ Note: these two publications were written regarding science education in the UK

changed from the teacher having all the knowledge and transmitting this to the students, to a process or 'journey' that teacher and students take together with the teacher acting primarily as a facilitator³⁰. This idea of storytelling, providing a framework for understanding an area of experience through an inter-related set of ideas, is advocated by UNESCO. A corresponding recommendation by Millar & Osborne (1998) is that, "... case-studies of historical and current issues should be used to consolidate understanding of the 'explanatory stories', and of key ideas-about-science, and to make it easier for teachers to match work to the needs and interests of learners" (p.2023).

Whether the science curriculum is different depending on the age of the student, or seamless throughout a students' school education, the question remains as to what purpose this curricula serves. According to Millar & Osborne (1998), "The purpose of science education, as a component of young people's whole educational experience, is to prepare them for a full and satisfying life in the world of the 21st century. More specifically, the science curriculum should:

(1) sustain and develop the curiosity of young people about the natural world around them, and build up their confidence in their ability to inquire into its behaviour. It should seek to foster a sense of wonder, enthusiasm and interest in science so that young people feel confident and competent to engage with scientific and technical matters.

(2) help young people acquire a broad, general understanding of the important ideas and explanatory frameworks of science, and of the procedures of scientific inquiry, which have had a major impact on our material environment and on our culture in general" (p.2012).

They go on to argue that this cannot be fixed by 'quick' solutions or patching up of the existing curriculum, but that this requires going back to the drawing board in order to develop and rethink how the curriculum should be constructed for the desired outcomes to be achieved.

³⁰ <http://www.storyline-scotland.com/whatisstoryline.html>

The goal of science education has been described as equipping students with meaningful scientific knowledge and abilities that are transferable outside of the school environment. This resembles other recommendations, which differentiate between established facts in science and the nature of science, and promote the need for scientific inquiry. Furthermore, it is proposed that, “We should ... attempt to see if pupils can understand not only *what* an idea is but also *why it is important*” [emphasis added] (Millar & Osborne, 1998, p.2027).

One of the international reports used in this section describes the *Big Ideas* of science education, listing 14 big ideas, ten of which are ideas *of* science and four are ideas *about* science (see Appendix VII). These were constructed on the premise that, “The goal of science education is not knowledge of a body of facts and theories but a progression towards key idea which enable understanding of events and phenomena of relevance to students’ lives during and beyond their school years” (Harlen, 2010, p.2). It has been suggested that it is better to teach less material and teach it well, than to teach more and teach it too quickly/badly. In identifying only 14 big ideas it is inevitable that some scientific content is not covered – however, the author argues that in order for science education to meet the requirement that all students leave school with at least a basic level of scientific literacy, this will entail a trimming down of the existing curricula as well as an endeavour to unify the components or themes of the curriculum together.

In the National Research Council (2010) summary, Windschitl suggests that for curricula to incorporate the learning goals of 21st century skills (outlined in section 4.1.1.1), which, “... can be taught in the context of scientific inquiry or project-based learning ... [it] will require ‘ambitious’ teaching which:

- features learning how to solve problems in collaboration with others;
- engages students in productive metacognitive strategies about their own learning
- places some learning decisions and activities in the hands of students that were formally determined by the teacher; and

- depends for success on monitoring of student thinking about complex problems and relies on ongoing targeted feedback to students” (p.61).

An inquiry-based approach is being used to teach science in many countries, and is a recommended approach in combating the lack of interest seen in students. “Inquiry, well executed, leads to understanding and makes provision for regular reflection on what has been learned, so that new ideas are seen to be developed from earlier ones. It also involves students working in a way similar to that of scientists, developing their understanding by collecting and using evidence to test ways of explaining the phenomena they are studying” (Harlen, 2010, p.3).

Arthur Eisenkraft, Professor of Science Education, noted however that in his experience teachers may, “... embrace the notion of inquiry ... [yet don’t use] an inquiry approach as he understands it” (National Research Council, 2010, p.7). Similarly, Anderson (2002) argues that, “... in spite of its seemingly ubiquitous use, many questions surround inquiry. What does it mean to teach science as, through, or with inquiry? Is the emphasis on science as inquiry, learning as inquiry, teaching as inquiry or all of the above?” (p.1). It is necessary that science teachers undertake measures to ensure that they use this approach to its full potential.

Much is also written about using projects or topics to study science. As part of the big ideas of science education described above, international science experts recommend that students study topics of interest and relevance to them (Harlen, 2010). It is suggested that this would be better suited to periodic, longer ‘science events’ rather than frequent, short science classes. This approach has been used to energise science learning, enabling students to use certain techniques which enhance one another – for example, thinking skills have been shown to improve “... students’ content understanding and learning” (Swartz, 2008, p.26). This method of topical studies can be beneficial to teachers who lack confidence in certain areas of the science curriculum. For example, in the Australian Citizen Science program, which initiated national projects such as *Operation Possum*, *Bluetongue*, and *Magpie*, involving, amongst others, “... school groups and parents, who participate by collecting data in collaboration with scientists and

professional bodies” (Alexander & Russo, 2010, p.47). This method of teaching science through projects may incur some organizational complexities, but is a preferable way of studying a number of topics.

Another proposal is that of curriculum trialling – rather than implementing and investing in a National Curriculum that does not work, the suggestion is to carry out trials in different parts of the country and with different types of schools, using the outcome of these trials to make changes that are seen to be beneficial. Eisner (1992) supports this method of curriculum reform, advocating for ‘empowering’ teachers, giving them authority and influence over the educational processes in their schools. An observation from the PISA 2009 study affirms the benefits of this: “In countries where schools have greater autonomy over what is taught and how students are assessed, students tend to perform better” (OECD, 2010a, p.15). This is another recommendation that I support, as it gives teachers flexibility over what is taught, rather than having to struggle to ‘cover the material’. Furthermore, this method enables individuals to teach to their strengths, making the best of their abilities and allowing them to defer to other teachers in weaker areas.

In some countries, such as those in the former Soviet Union, students who showed aptitude in science were often singled out for special attention, based on the potential of what their knowledge and future work/research could provide for the nation. Their contributions and achievements in the world of science can be well-illustrated in the field of space exploration, with the Soviet Union being the first nation to successfully launch a satellite into orbit, *Sputnik 1*. This was followed a few years later by the accomplishment of Russian cosmonaut, Yuri Gagarin, becoming the first man in space. In recognition that some of the more able students are not sufficiently challenged by the general science education curriculum, a ‘specialized science-enriched’ secondary school has been established in the Netherlands. Here the structure and focus of the material taught prepares students for further studies or careers in scientific research (Osborne & Dillon, 2008). Similar reasons are given for the *Super Science High Schools* that have been established in Japan (Fensham, 2004). These schools are for the elite student. Competition is high to obtain a place, and the results achieved by

these students are significantly better than the average in those countries.

5.2.3.1 Assessment

The final curriculum factor discussed is that of assessment. The importance of assessment, in its different forms, is widely accepted to be a key factor in science education. As such, each of the reports includes a number of recommendations regarding this.

Before considering the different forms of assessment, it is important to be aware of what is being assessed. As mentioned in section 3.2.3, there is a difference in what the TIMSS and PISA studies are assessing – TIMSS is described as testing what students *know/remember* about science, whereas PISA tests what students *can do/understand*. These distinctions are characteristic of different assessment systems throughout the world. According to UNESCO, “... *having knowledge of science and being able to make use of it* has been prominent in discussions and studies” (Fensham, 2008, p.30). Parallels have been drawn with different levels of understanding – using, for example, *Bloom’s Taxonomy of Cognitive Objectives* (see Pohl, 2000), knowledge of science is the lowest level of intellectual behaviour in learning, whereas application (being able to make use) of science is at a higher level.

The collective aim internationally is for students to have higher learning levels – evidence of this can be seen in the way and frequency that PISA studies are referred to. The results obtained are benchmarks. Individual countries examine the scores from ‘their’ students, relating how they compare with previous PISA studies, how they compare with other countries, and what percentage of students attain the different proficiency levels. Not one document or report has been found suggesting a country was satisfied to stay as they were, in terms of science education, even when that country was one of the top performing countries. For example, the Minister for Education in Finland, who were the highest performing country on the PISA 2006 science scale, states that, “We must turn our eyes

forwards and see to the prerequisites of quality education and to its development also in the future” (Hautamäki *et al.*, 2008, p.3).

In a school context, assessment itself usually falls into two categories – formative, assessing a student’s ongoing progress, and summative, which is usually carried out at a particular time, often the end of a course or school year. It has been recognised that the assessment techniques or tools being used by many countries provide unreliable and inaccurate measures of students’ abilities – the recommendation is for *authentic assessment*. One method of formative assessment commonly used is that of simple multiple choice testing. Although these are able to check, “... the extent to which students can recall conceptual and definitional science content and low levels of application of this knowledge ... [they are] very limited in extent to which they can monitor other aspects of science learning, that are intended in the science curriculum” (Fensham, 2008, p.34). As an alternative, the TLRP report (2006) recommends four areas of formative assessment: classroom dialogue, interactive feedback on written work, involving students in working in small groups to assess each others’ work, and making use of the formal tests that teachers regularly apply to add extra value to learning.

Relevancy and effectiveness are two key components of assessment, both for the student and for the teacher. Tests should not be carried out just for the sake of it or because that is the way things have always been done. Assessment should be something that assists learning, and that is incorporated in an ongoing manner into teachers’ planning. “What is assessed and reported is assumed to reflect what it is important to learn, so it is essential that this is not limited to what is more readily tested” (Harlen, 2010, p.15). Millar & Osborne express this as, “The assessment approaches used to report on pupils’ performance should encourage teachers to focus on pupils’ ability to understand and interpret scientific information, and to discuss controversial issues, as well as on their knowledge and understanding of scientific ideas” (1998, p.2025). This correlates with *Bloom’s Taxonomy of Cognitive Objectives* already mentioned, assessing basic skills through to higher order levels of thinking (Pohl, 2000).

Targets are another component of assessment. For a teacher, the targets that they set for their students may seem self-explanatory and are often derived from curriculum targets and goals. However, in order for assessment to be relevant to students, "... they [need to] have a sufficiently clear picture of the targets that their learning is meant to attain" (Black & Harrison, 2000, p.27). Moreover, the tasks that they are set "have to be justified in terms of their learning aims that they serve..." (p.35). This view is shared by Harlen (2010), who writes that, "Students find it very difficult to learn with understanding from tasks which have no apparent meaning to them" (p.11). Students need to have clear and feasible goals for assessment to be meaningful, and they need to understand what the teacher is looking for. Some students, for example, think that the effort they put into their work is of greater significance than the content and its accuracy. Moreover, they are conscious of the fact that, "... they are required not to think out their own answers but to guess at the answer that the teacher expects" (Black & Harrison, 2000, p.37).

Another recommendation in assessment is to recognise what pupils already know. Many assumptions are made about students understanding based on schooling and textbooks, yet 'outside school' learning has not been taken greatly into consideration (Wilson, 2009). Indeed, Millar & Osborne (2005) noted that, "Science is, however, fundamentally about interpreting the implications of, and assessing the validity of, knowledge. It also identifies, and then pursues, what is unknown" (p.8). Using the acquired knowledge from assessments carried out, "... can inform science teachers as they plan how to tackle difficult content in a way that their students understand, and can help guide their conversations with pupils during teaching" (TLRP, 2006, p.8).

However, a caution is given in an article entitled *Assessing Student Achievement* under the heading of *What STEM faculty should know*:

- students know and understand less when they emerge from courses than most faculty think they do
- that what we teach, despite our best efforts, is not what students learn or how they learn

- there are a lot of good ideas about assessment out there, and we should be borrowing them from each other, not reinvent the wheel
- student achievement can be increased with effective assessment
- you can teach better and enjoy it more if your students are demonstrably learning better

(Project Kaleidoscope, 2006, p.1)

Caution is also expressed regarding how national and international league tables are interpreted and used. Instead of the emphasis being on students, facilitating and developing their abilities, knowledge and understanding, focus is often turned towards schools and individual teachers and their capabilities. Whilst it is necessary for teachers to evaluate their own teaching practices, concentrating on this can detract from the original purposes of the assessments themselves. Also, when comparing results between different countries, it is good to remember that individual nations place emphasis on teaching and assessing the material and the skills that they consider of value, and that this has been found to be quite different between developed and developing countries (Trumper, 2010).

When choosing what methods of assessment to use, it is important to consider first what students already know, and then how this assessment can extend and apply that knowledge. As mentioned in the Project Kaleidoscope report above, it is advisable to note that if students can visibly see that they are learning, this is of benefit to both them and the teacher.

5.2.4 Information and Communication Technologies (ICT)

According to Fensham (2008), “Across the world we all now live in a Global Communications society, in which knowledge and information are the currency. The possibilities for exchange and interaction of knowledge are regularly being redefined and extended, as new scientific principles and materials are being, ever more rapidly, put into application” (p.31). With this in mind, policy makers are urged to consider how they can provide ICT that will facilitate science and

technology education. This includes considering equipment available to students and to staff, ongoing maintenance for this equipment, and professional development programmes for how these technologies can be used.

The role of ICT should not be underestimated in the future of science education. The way that students learn and play is continually changing, as more varied and different opportunities are made available to them, and as technology is constantly being updated. There are many implications for teaching from this. For example, as one fourth grade student stated: “I like to play indoors better ‘cause that’s where all the electrical outlets are” (Louv, 2005, p.10). This illustrates how, although students may have access to a vast amount of ‘theoretical’ information through the internet etc, their practical experience of science and of nature in general is often being depleted.

These recommendations should be considered in the light of what is known as *knowledge society*, “... which places an explicit and principal value on knowledge as the means to achieve economic and social well being. It is one which features knowledge prominently among the basic needs of all of its citizens and wills all citizens to engage productively with knowledge” (Mallalieu, 2006, p.2). This is different from an *information society* which, “... is one which happens to strongly feature information-based innovations as tools for productivity and entertainment, [whereas] a knowledge society is one which additionally counts these tools among the basic needs of all citizens (p.2). As one world leader, Yoweri Museveni of Uganda, writes, in order for a country to be able to assert itself globally it requires, “An educated population that will have the capacity to utilize technology in order to transform our natural resources into wealth” (Gardels, 1997, p.56). Teaching for a knowledge society affects the way in which subjects, including science, are taught, requiring an, “... approach that turns academics themselves into reflective practitioners with respect to their teaching” (Laurillard, 2002, p.20).

The value of ICT in science education has been highlighted here, and also in section 4.2.4. Its role has developed at a rapid pace, changing the way lessons are taught, material is prepared, homework

is carried out, information is gathered and presented and much more. This is an area which is likely to change and evolve more quickly than any of the other factors discussed in this review, by very nature of the fact that technology is itself constantly updated and improved.

5.3 Discussion

Section 5 has considered the future of science education, identifying and discussing some of the possible solutions to the issues raised in section 4. This section concludes with a summary discussion of a number of these recommendations and possible solutions.

In my view, the key factor when discussing students and science is to consider how they would like science to be taught. Many of the suggestions put forward by students are not complicated or unrealistic, but rather they are ideas that enable students to connect science with the real world and to begin to visualise and experience the relationship between ‘classroom’ science and everyday decisions. In order to put in the effort deemed necessary, students want to know why science is an important subject for them to learn. They need to be given the opportunity and experience to understand that, as Richard Feynman (1968) states, *“The world looks so different after learning science”*, as quoted in section 1. Engaging students in science and motivating them to continue must be a priority for teachers and policy makers alike.

A further key factor is for policy makers and educators to recognise the importance of language. If a student cannot understand the language of the material being taught, it is not possible for them to fully participate in the lesson, or the subsequent assessments etc. Similarly, a students’ reading ability will have great implications for their understanding and comprehension of what is being taught.

From a teachers’ perspective, I agree with the recommendation to teach science as inquiry – not that the teacher sits at the front of the class and transmits all the required information, but that the students, through an inquiry approach, learn to investigate and to work as a team. When the teacher facilitates lessons, it enhances their ability to

differentiate between the needs and understanding of the students, one of the attributes of quality teaching. It also encourages skills recognised as being adaptable for different workplaces to be developed in students, equipping them for their future, regardless of whether this is in a science profession or not.

The ideas presented of recruitment, retention and renewal provide a number of recommendations for consideration. Of most importance, in my opinion, is the preparation of teachers in their pre-service training, and the establishing of effective professional development programs. Pre-service teachers invariably have little teaching experience, but through their studies they are aware of available technology and resources, and are taught current trends and practices in teaching. In contrast, teachers who have been in the profession for a number of years have the experience, but often they are less familiar with what is available to them, and how thinking regarding teaching has been developing etc.

One of the differences seen between countries is highlighted in the way in which their students are assessed. In reporting on how international tests are put together, authors from a number of countries remark that this may be favourable to one country more than another. In my opinion it is likely that, in order to improve their test scores, countries will seek to develop their assessment techniques, which will result in students being taught how to answer questions in the style of these international tests. As well as producing the desired improvements, this should also equip students to apply the knowledge they have acquired.

Finally, it is important not to overlook the role that ICT will play in the future of science education. From a students' perspective, both PISA and TIMSS showed better performances for students who had access to computers. There are also benefits for teachers, particularly in the way lessons can be prepared and taught. Teachers, in my view, should seize the opportunities that are offered to advance their computing skills, to learn about available technology, and to share their own ideas and experiences.

6. Conclusion

According to Webster's Online Dictionary³¹, there are a number of definitions included for the word *dangerous*, including: "Being precarious, insecure, chancy, uncertain or unsure". This thesis has sought to show that these factors are incorporated in today's science teaching and education. Issues discussed, such as the deterioration in student interest in science, declining enrolment in science courses at all levels of education, and increasing lack of science teachers could all, in light of the definition above, be considered as being 'dangerous'. Furthermore, unless these issues are addressed, the situation will become exacerbated – a fact that researchers and scholars are well aware of, as they seek to highlight the situation and propose means of arresting this downward trajectory.

Moreover, this is a picture that can be seen around the world. In some countries these issues are more pressing than others, but science education is a global concern. And yet, in my opinion, the key to the future lies in the hands of individuals – teachers and educators. They are, of course, dependent to varying degrees upon their local school environment, curricula, and constraints such as finance and available resources. However, it is their teaching abilities and strategies, and how they interact with students, that will ultimately enable them to communicate effectively the *big ideas* of science and equip their students to be citizens of the 21st century, with all the necessary skills that this demands. And, it is in teaching science for all students, not just the few who will specifically pursue a science-related career, that a *science for citizenship* agenda will have personal, national and worldwide significance.

In summary, as quoted at the beginning of this thesis, "A wise teacher's words spur students to action and emphasize important truths" (The Holy Bible, Ecclesiastes 12:11a). It is my view that the future

³¹ <http://www.websters-online-dictionary.org/definitions/dangerous?cx=partner-pub-0939450753529744%3Av0qd01-tdlq&cof=FORID%3A9&ie=UTF-8&q=dangerous&sa=Search#922>

of science education and teaching requires such wise teachers, those of quality who will educate, inspire and empower.

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LIST OF APPENDICES

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APPENDIX I - Science performance scores for countries participating in TIMSS 2007 and their corresponding HDI values for that year

| | TIMSS 2007 Science Performance 4 th grade | UN Human Development Index (HDI) (2007) |
|----------------------------|---|--|
| TIMSS scale average | 500 | |
| Singapore | 587 | 0.836 |
| Chinese Taipei | 557 | † |
| Hong Kong-SAR | 554 | 0.855 |
| Japan | 548 | 0.880 |
| Russian Federation | 546 | 0.708 |
| Latvia | 542 | 0.777 |
| England | 542 | 0.845 |
| United States | 539 | 0.899 |
| Hungary | 536 | 0.803 |
| Italy | 535 | 0.849 |
| Kazakhstan | 533 | 0.707 |
| Germany | 528 | 0.883 |
| Australia | 527 | 0.931 |
| Slovak Republic | 526 | 0.811 |
| Austria | 526 | 0.846 |
| Sweden | 525 | 0.885 |
| Netherlands | 523 | 0.937 |
| Slovenia | 518 | 0.825 |
| Denmark | 517 | 0.864 |
| Czech Republic | 515 | 0.843 |
| Lithuania | 514 | 0.785 |
| New Zealand | 504 | 0.903 |
| Scotland | 500 | 0.845 |
| Armenia | 484 | 0.697 |
| Norway | 477 | 0.937 |
| Ukraine | 474 | 0.709 |
| Iran, Islamic Rep. of | 436 | 0.684 |
| Georgia | 418 | 0.698 |
| Columbia | 400 | 0.676 |
| El Salvador | 390 | 0.653 |
| Algeria | 354 | 0.662 |
| Kuwait | 348 | 0.767 |
| Tunisia | 318 | 0.665 |
| Morocco | 297 | 0.551 |
| Qatar | 294 | 0.800 |
| Yemen | 197 | 0.424 |

| | TIMSS 2007 Science Performance 8 th grade | UN Human Development Index (HDI) (2007) |
|----------------------------|---|--|
| TIMSS scale average | 500 | |
| Singapore | 567 | 0.836 |
| Chinese Taipei | 561 | † |
| Japan | 554 | 0.880 |
| Korea, Rep. of | 553 | 0.865 |
| England | 542 | 0.845 |
| Hungary | 539 | 0.803 |
| Czech Republic | 539 | 0.843 |
| Slovenia | 538 | 0.825 |
| Hong Kong-SAR | 530 | 0.855 |
| Russian Federation | 530 | 0.708 |
| United States | 520 | 0.899 |
| Lithuania | 519 | 0.785 |
| Australia | 515 | 0.931 |
| Sweden | 511 | 0.885 |
| Scotland | 496 | 0.845 |
| Italy | 495 | 0.849 |
| Armenia | 488 | 0.697 |
| Norway | 487 | 0.937 |
| Ukraine | 485 | 0.709 |
| Jordan | 482 | 0.665 |
| Malaysia | 471 | 0.735 |
| Thailand | 471 | 0.642 |
| Serbia | 470 | 0.729 |
| Bulgaria | 470 | 0.736 |
| Israel | 468 | 0.869 |
| Bahrain | 467 | 0.806 |
| Bosnia and Herzegovina | 466 | 0.706 |
| Romania | 462 | 0.754 |
| Iran, Islamic Rep. of | 459 | 0.684 |
| Malta | 457 | 0.809 |
| Turkey | 454 | 0.672 |
| Syrian Arab Republic | 452 | 0.576 |
| Cyprus | 452 | 0.804 |
| Tunisia | 445 | 0.665 |
| Indonesia | 427 | 0.580 |
| Oman | 423 | † |
| Georgia | 421 | 0.698 |
| Kuwait | 418 | 0.767 |
| Colombia | 417 | 0.676 |
| Lebanon | 414 | † |
| Egypt | 408 | 0.611 |
| Algeria | 408 | 0.662 |
| Palestinian Nat'l Auth. | 404 | † |
| Saudi Arabia | 403 | 0.741 |
| Morocco | 402 | 0.551 |
| El Salvador | 387 | 0.653 |
| Botswana | 355 | 0.614 |
| Qatar | 319 | 0.800 |
| Ghana | 303 | 0.459 |

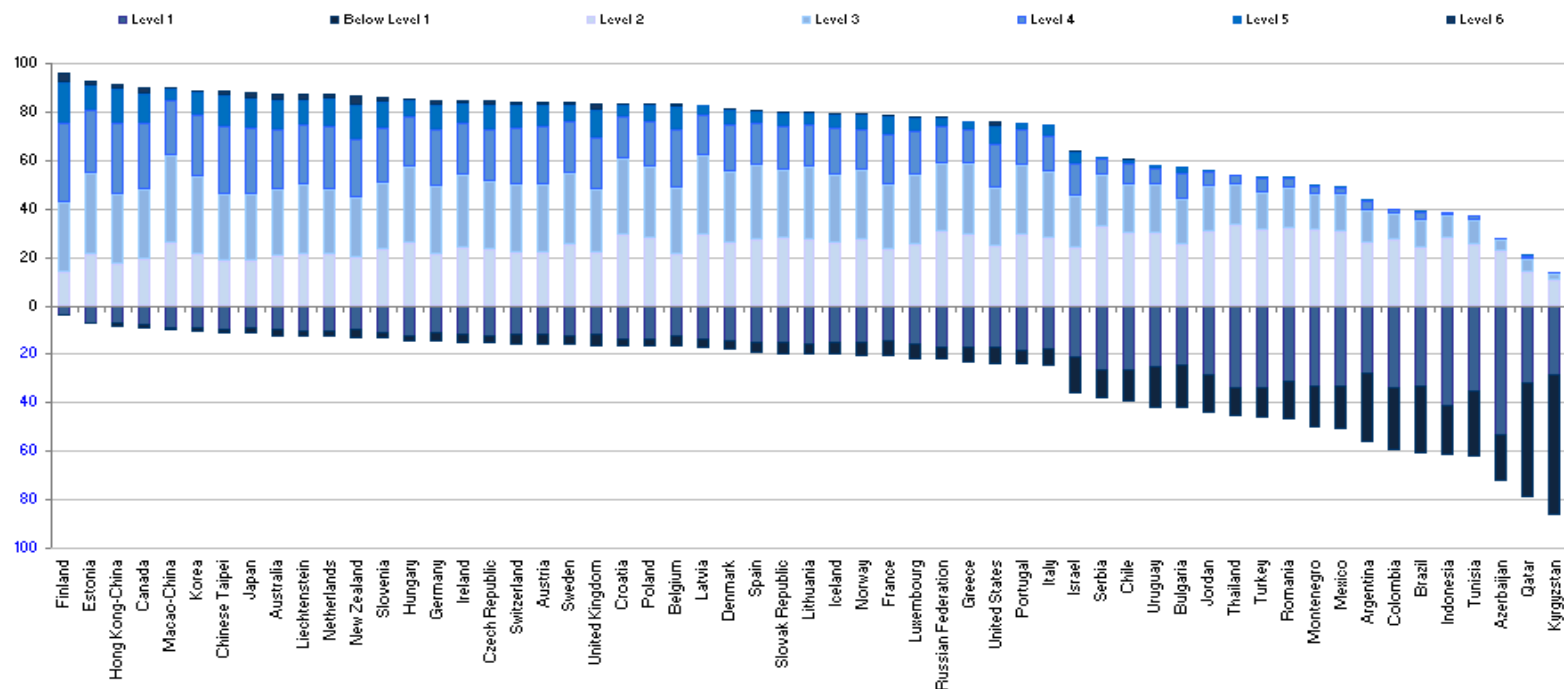
| | |
|--|--|
| | Statistically significantly above the TIMSS average |
| | Not statistically significantly different from the TIMSS average |
| | Statistically significantly below the TIMSS average |
| | Very High Human Development |
| | High Human Development |
| | Medium Human Development |
| | Low Human Development |

† Results not available

Source: TIMSS http://timss.bc.edu/timss2007/PDF/T07_S_IR_Chapter1.pdf; UN Development Index: <http://hdr.undp.org/en/statistics/>

APPENDIX II

Percentage of students at each proficiency level on the science scale








Countries are ranked in descending order of percentage of 15-year-olds at Levels 2, 3, 4, 5 and 6.

(Source: OECD PISA database 2006, Table 2.1a/ Figure 2.11a <http://www.oecd.org/dataoecd/30/17/39703267.pdf>)

APPENDIX III - Comparison of countries' science performance in PISA 2006 & PISA 2009

| | PISA 2006 Science performance | | PISA 2009 ³² Science performance | | Point difference in PISA 2009 (compared with PISA 2006 performance) | + - |
|--------------------|-------------------------------------|--|---|--|---|--------|
| OECD average | 500 | | 501 | | | |
| Finland | 563 | | 554 | | 9 | - |
| Hong Kong-China | 542 | | 549 | | 7 | + |
| Canada | 534 | | 529 | | 5 | - |
| Chinese Taipei | 532 | | 520 | | 12 | - |
| Estonia | 531 | | 528 | | 3 | - |
| Japan | 531 | | 539 | | 8 | + |
| New Zealand | 530 | | 532 | | 2 | + |
| Australia | 527 | | 527 | | 0 | |
| Netherlands | 525 | | 522 | | 3 | - |
| Liechtenstein | 522 | | 520 | | 2 | - |
| Korea | 522 | | 538 | | 16 | + |
| Slovenia | 519 | | 512 | | 7 | - |
| Germany | 516 | | 520 | | 4 | + |
| United Kingdom | 515 | | 514 | | 1 | - |
| Czech Republic | 513 | | 500 | | 13 | - |
| Switzerland | 512 | | 517 | | 5 | + |
| Macao-China | 511 | | 511 | | 0 | |
| Austria | 511 | | 494 | | 17 | - |
| Belgium | 510 | | 507 | | 3 | - |
| Ireland | 508 | | 508 | | 0 | |
| Hungary | 504 | | 503 | | 1 | - |
| Sweden | 503 | | 495 | | 8 | - |
| Poland | 498 | | 508 | | 10 | + |
| Denmark | 496 | | 499 | | 3 | + |
| France | 495 | | 498 | | 3 | + |
| Croatia | 493 | | 486 | | 7 | - |
| Iceland | 491 | | 496 | | 5 | + |
| Latvia | 490 | | 494 | | 4 | + |
| United States | 489 | | 502 | | 13 | + |
| Slovak Republic | 488 | | 490 | | 2 | + |
| Spain | 488 | | 488 | | 0 | |
| Lithuania | 488 | | 491 | | 3 | + |
| Norway | 487 | | 500 | | 13 | + |
| Luxembourg | 486 | | 484 | | 2 | - |
| Russian Federation | 479 | | 478 | | 1 | - |
| Italy | 475 | | 489 | | 14 | + |
| Portugal | 474 | | 493 | | 19 | + |
| Greece | 473 | | 470 | | 3 | - |
| Israel | 454 | | 455 | | 1 | + |
| Chile | 438 | | 447 | | 9 | + |
| Serbia | 436 | | 443 | | 7 | + |
| Bulgaria | 434 | | 439 | | 5 | + |
| Uruguay | 428 | | 427 | | 1 | - |
| Turkey | 424 | | 454 | | 30 | + |
| Jordan | 422 | | 415 | | 7 | - |
| Thailand | 421 | | 425 | | 4 | + |
| Romania | 418 | | 428 | | 10 | + |
| Montenegro | 412 | | 401 | | 11 | - |
| Mexico | 410 | | 416 | | 6 | + |
| Indonesia | 393 | | 383 | | 10 | - |
| Argentina | 391 | | 401 | | 10 | + |
| Brazil | 390 | | 405 | | 15 | + |
| Colombia | 388 | | 402 | | 14 | + |
| Tunisia | 386 | | 401 | | 15 | + |
| Azerbaijan | 382 | | 373 | | 9 | - |
| Qatar | 349 | | 379 | | 30 | + |
| Kyrgyzstan | 322 | | 330 | | 8 | + |

³² Shanghai-China, Singapore, Dubai (UAE), Trinidad & Tobago, Kazakhstan, Albania, Panama and Peru also took part in the PISA 2009 survey

| | |
|---|---|
|  | Statistically significantly above the OECD average |
|  | Not statistically significantly different from the OECD average |
|  | Statistically significantly below the OECD average |
|  | Increase in science performance in PISA 2009 |
|  | Decrease in science performance in PISA 2009 |








Source: OECD PISA 2006 database <http://dx.doi.org/10.1787/141844475532>;
 OECD PISA 2009 Database <http://www.oecd.org/dataoecd/54/12/46643496.pdf>

APPENDIX IV - Science performance of countries' in PISA 2006 & 2009, and their corresponding HDI values for those years

| | PISA 2006 Science performance | UN Human Development Index (HDI) (2006) | | PISA 2009 ³³ Science performance | UN Human Development Index (HDI) (2009) |
|--------------------|-------------------------------------|---|--|---|--|
| Finland | 563 | 0.868 | | 554 | 0.869 |
| Hong Kong-China | 542 | 0.849 | | 549 | 0.857 |
| Canada | 534 | 0.883 | | 529 | 0.886 |
| Chinese Taipei | 532 | † | | 520 | † |
| Estonia | 531 | 0.811 | | 528 | 0.807 |
| Japan | 531 | 0.877 | | 539 | 0.881 |
| New Zealand | 530 | 0.898 | | 532 | 0.904 |
| Australia | 527 | 0.928 | | 527 | 0.935 |
| Netherlands | 525 | 0.882 | | 522 | 0.888 |
| Liechtenstein | 522 | 0.882 | | 520 | 0.889 |
| Korea | 522 | 0.858 | | 538 | 0.872 |
| Slovenia | 519 | 0.819 | | 512 | 0.826 |
| Germany | 516 | 0.881 | | 520 | 0.883 |
| United Kingdom | 515 | 0.842 | | 514 | 0.847 |
| Czech Republic | 513 | 0.841 | | 500 | 0.841 |
| Switzerland | 512 | 0.873 | | 517 | 0.872 |
| Macao-China | 511 | † | | 511 | † |
| Austria | 511 | 0.845 | | 494 | 0.849 |
| Belgium | 510 | 0.861 | | 507 | 0.865 |
| Ireland | 508 | 0.891 | | 508 | 0.894 |
| Hungary | 504 | 0.802 | | 503 | 0.803 |
| Sweden | 503 | 0.885 | | 495 | 0.884 |
| Poland | 498 | 0.779 | | 508 | 0.791 |
| Denmark | 496 | 0.861 | | 499 | 0.864 |
| France | 495 | 0.860 | | 498 | 0.869 |
| Croatia | 493 | 0.757 | | 486 | 0.765 |
| Iceland | 491 | 0.883 | | 496 | 0.869 |
| Latvia | 490 | 0.771 | | 494 | 0.769 |
| United States | 489 | 0.897 | | 502 | 0.899 |
| Slovak Republic | 488 | 0.803 | | 490 | 0.815 |
| Spain | 488 | 0.857 | | 488 | 0.861 |
| Lithuania | 488 | 0.780 | | 491 | 0.782 |
| Norway | 487 | 0.934 | | 500 | 0.937 |
| Luxembourg | 486 | 0.853 | | 484 | 0.850 |
| Russian Federation | 479 | 0.700 | | 478 | 0.714 |
| Italy | 475 | 0.844 | | 489 | 0.851 |
| Portugal | 474 | 0.778 | | 493 | 0.791 |
| Greece | 473 | 0.846 | | 470 | 0.853 |
| Israel | 454 | 0.864 | | 455 | 0.871 |
| Chile | 438 | 0.764 | | 447 | 0.779 |
| Serbia | 436 | 0.724 | | 443 | 0.733 |
| Bulgaria | 434 | 0.729 | | 439 | 0.741 |
| Uruguay | 428 | 0.740 | | 427 | 0.760 |
| Turkey | 424 | 0.665 | | 454 | 0.674 |
| Jordan | 422 | 0.658 | | 415 | 0.677 |
| Thailand | 421 | 0.637 | | 425 | 0.648 |
| Romania | 418 | 0.743 | | 428 | 0.764 |
| Montenegro | 412 | 0.760 | | 401 | 0.768 |
| Mexico | 410 | 0.735 | | 416 | 0.745 |
| Indonesia | 393 | 0.568 | | 383 | 0.593 |
| Argentina | 391 | 0.757 | | 401 | 0.772 |
| Brazil | 390 | 0.681 | | 405 | 0.693 |
| Colombia | 388 | 0.667 | | 402 | 0.685 |
| Tunisia | 386 | 0.658 | | 401 | 0.677 |
| Azerbaijan | 382 | 0.677 | | 373 | 0.710 |
| Qatar | 349 | 0.800 | | 379 | 0.798 |
| Kyrgyzstan | 322 | 0.577 | | 330 | 0.594 |

³³ Shanghai-China, Singapore, Dubai (UAE), Trinidad & Tobago, Kazakhstan, Albania, Panama and Peru also took part in PISA 2009 survey

Note: UNHDI values given for England and Scotland are those of the UK

| | |
|---|---|
|  | Statistically significantly above the OECD average |
|  | Not statistically significantly different from the OECD average |
|  | Statistically significantly below the OECD average |
|  | Very High Human Development |
|  | High Human Development |
|  | Medium Human Development |
|  | Low Human Development |

† Results not available

Source: UN Development Index: <http://hdr.undp.org/en/statistics/>; OECD PISA 2006 database

<http://dx.doi.org/10.1787/141844475532>; OECD PISA 2009 Database <http://www.oecd.org/dataoecd/54/12/46643496.pdf>;

APPENDIX V - Countries participating in TIMSS 2007 and PISA 2006

| | Both TIMSS 2007 and PISA 2006 | TIMSS 2007 only | PISA 2006 only |
|-----------------|--|---|---|
| OECD countries | Australia Austria Czech Republic Denmark Germany Hungary Italy Japan Korea, Republic of Netherlands New Zealand Norway Slovak Republic Sweden Turkey United Kingdom (as a single entity in PISA, as England and Scotland in TIMSS) United States | † | Belgium Canada Finland France Greece Iceland Ireland Luxembourg Mexico Poland Portugal Spain Switzerland |
| Other countries | Bulgaria Chinese Taipei Colombia Hong Kong-China Indonesia Israel Jordan Latvia Lithuania Qatar Romania Russian Federation Serbia, Republic of Slovenia Thailand Tunisia | Algeria Armenia Bahrain Bosnia and Herzegovina Botswana Cyprus Egypt El Salvador Georgia Ghana Iran Kazakhstan Kuwait Lebanon Malaysia Malta Mongolia ¹ Morocco Oman Palestinian Nat'l Authority Saudi Arabia Singapore Syrian Arab Republic Ukraine Yemen | Argentina Azerbaijan Brazil Chile Croatia Estonia Kyrgyz Republic Liechtenstein Macao-China Montenegro, Republic of Uruguay |

† Not applicable.

¹ Mongolia participated in TIMSS 2007 but, because the quality of its data was not well documented, it was not included in the main data displays of the international reports.

NOTE: The countries that participated in TIMSS 2007 shown in this table differ from the countries shown in the international TIMSS reports (Mullis et al. 2008; Martin et al. 2008). Eight other educational jurisdictions, or "benchmarking" entities, participated: the states of Massachusetts and Minnesota; the Canadian provinces of Alberta, British Columbia, Ontario, and Quebec; Dubai, United Arab Emirates; and the Basque country of Spain.

Source: US Department of Education, http://nces.ed.gov/timss/pdf/Comparing_TIMSS_NAEP_%20PISA.pdf

APPENDIX VI - Graduating compulsory school teachers 2010
– by department

Brautskráðir í grunnskólakennarafræði 2010 – eftir kjörsviðum

| | |
|-----------------------------------|----|
| kennsla yngstu barna í grunnskóla | 53 |
| samfélagsgreinar | 25 |
| íslenska | 21 |
| stærðfræði | 14 |
| textílmennt | 11 |
| Tónlist, leiklist og dans | 11 |
| erlend mál - enska | 11 |
| almenn kennsla í grunnskóla | 10 |
| náttúrufræði | 10 |
| erlend mál - danska | 10 |
| matur, menning, heilsa | 9 |
| myndmennt | 8 |
| upplýsingatækni og miðlun | 8 |
| hönnun og smíði | 7 |
| íslenskt táknmál | 1 |
| ekki tilgreint | 1 |

Anna Kristín Sigurðardóttir, mars 2011

Source: Anna Kristín Sigurðardóttir, 2011, Slide 3

APPENDIX VII – Fourteen big ideas in science

Fourteen big ideas in science

Ideas *of* science

1. All material in the Universe is made of very small particles.
2. Objects can affect other objects at a distance.
3. Changing the movement of an object requires a net force to be acting on it.
4. The total amount of energy in the Universe is always the same but energy can be transformed when things change or are made to happen.
5. The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate.
6. The solar system is a very small part of one of millions of galaxies in the Universe.
7. Organisms are organised on a cellular basis.
8. Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.
9. Genetic information is passed down from one generation of organisms to another.
10. The diversity of organisms, living and extinct, is the result of evolution.

Ideas *about* science

11. Science assumes that for every effect there is one or more causes.
12. Scientific explanations, theories and models are those that best fit the facts known at a particular time.
13. The knowledge produced by science is used in some technologies to create products to serve human ends.
14. Applications of science often have ethical, social, economic and political implications.

Source: Harlen, 2010, p.*Preface*