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THE CHANGING FACE OF SCIENCE EDUCATION: PREPARING SCIENTIFICALLY LITERATE CITIZENS OF TOMORROW

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ABSTRACT

Science has social implications. Educating students in science involves more than the acquisition of 'facts' or the development of investigative skills. If students are to become independent and responsible citizens, they need to be capable of understanding scientific issues and their impact on society. An argument will be put forward in favour of a science education that considers the social implications of scientific activity on both a local and global scale. Teachers need to change traditional teaching methods to more innovative activities that are more child-centred and take into consideration the social and ethical aspects of the scientific enterprise.

Keywords: Science education, social aspect pedagogy, citizenship

1. INTRODUCTION

The 21st century has brought with it new scientific advancements that keep pushing the boundaries of science and scientific knowledge. Two such scientific activities that have been current issues in the news on a global scale are cloning and genetically modified organisms (GMOs). In cloning we find that advances have moved on from DNA cloning which involves the transfer of a DNA fragment from one organism to a self-replicating genetic element, to reproductive cloning where an animal that has the same nuclear DNA as another currently or previously existing animal is generated, to therapeutic cloning also called "embryo cloning," that involves the production of human embryos for use in research. The goal of this latter process is not to create

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cloned human beings, but rather to harvest stem cells that can be used to study human development and to treat disease. There have been requests by scientists to governments to allow research in this area. The main area of research is within therapeutic cloning where scientists want to study the possibility of using stem cells to clone human organs which can then be used for transplants. This would do away with the problem of finding a matching organ and increase the percentage success for transplants as the probability of rejection would be much less. Similarly, advances in biotechnology have led to the production of genetically modified organisms produced by a special set of technologies that alter the genetic makeup of living organisms as animals, plants, or bacteria. Genetically modified products include medicines and vaccines, foods and food ingredients, feeds, and fibers. Such advancements have helped farmers improve the quality of their crop and increase their produce. There have been however, concerns in that it is as yet unknown if such organisms are harmful to human health. The effect of cross pollination between genetically modified organisms and natural organisms is as yet unknown as is their impact on the ecosystem. GMOs also bring with them dominance in the market by industrialized countries, introducing monopolies that make developing countries uncompetitive, thus contributing to increasing global inequalities of wealth that already exist.

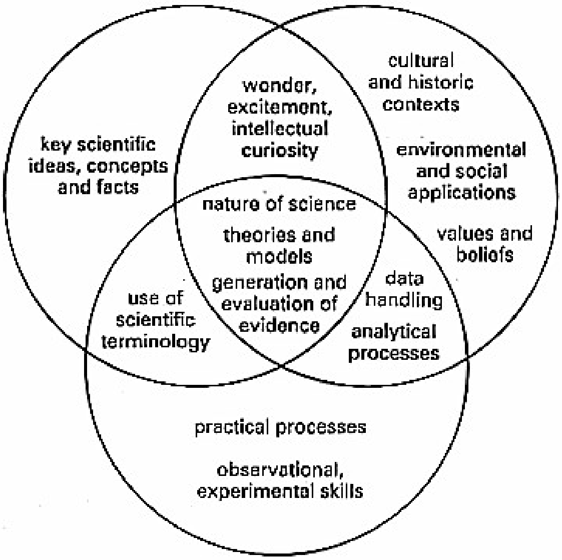
Science today is much more part of the layman's life than it was a few decades ago. The greater penetration of media, particularly T.V. and that of the internet, have all been instrumental in bringing scientific advancement into the sitting room of each and every household. In fact, cloning and genetically modified organisms made the news headlines a number of times in international media. Issues and debates about scientific research thus are no more only a concern of scientists and those directly involved in it. It has now become the responsibility of each and every citizen across the globe. Gone are the days when ordinary people were kept ignorant of scientific research and development. Citizens today have access to knowledge created across the world. This knowledge brings with it a responsibility for each and every individual. Citizens today should feel empowered and consequently should hold opinions about issues, sometimes also taking action if necessary in different ways to influence activities and initiatives being taken locally and globally. They can do this through exercising their rights like voting, participating in protests and by adopting particular lifestyles. However, in order to be able to do this, citizens need to be educated in science that would enable them to understand scientific and technological issues.

2. THEORETICAL BACKGROUND

So what does it mean to do science for citizenship? Science education across the world has gone beyond the mere transmission and acquision of knowledge. Students also experience the scientific method through laboratory work and investigations. Laboratory work is today an established part of students' education in science. However, process and content do not encompass all that science education should provide. Many proponents in science (Driver *et al.*, 1996; Durant *et al.*, 1989; Miller, 1983; Wynne, 1990) agree that the public understanding of science involves at least three aspects:

- *An understanding of some science content.* This refers to scientific facts, laws and theories that make up scientific knowledge;
- *An understanding of the scientific approach to enquiry.* This does not only involve an understanding of science investigations and the process it involves but also of the role of theoretical and conceptual ideas in interpreting outcomes of investigations;
- *An understanding of science as a social enterprise.* This includes the human and institutional aspect within which science develops (Driver *et al.*, 1996).

FIGURE 1: ELEMENTS OF SCIENCE



Source: (Ratcliffe, 1998, p.8)

Mary Ratcliffe (1998) provides a wider framework for the contribution of these three aspects. She portrays the three main components of science: scientific concepts (content); practical processes, observational, experimental skills (process); and values and beliefs, cultural and historical contexts, social and environmental issues (attitudes) as overlapping. The intersection of the three components provides students with a view of the nature of science. Science education has so far focused on the transmission of content and the process of doing science. Alas, the third aspect of values and beliefs has been somewhat neglected. It is only recently that science educators have turned their attention to the social and ethical implications of science as a response to the hype produced in the media by research activities such as those in the area of cloning and GMOs.

However, before moving on to look at ways through which science can contribute to citizenship, one needs to revisit the meaning of citizenship on a local and global level. Isin and Wood (1999) state that citizenship can be described both as a set of cultural, symbolic and economic practices as well as a bundle of rights and duties. They argue that it is important to recognize both aspects and that many rights often arise from practices which later earn the status of laws. Schmitt-Enger (2004) defines active citizenship as the capacity of citizens to self-organise in a multiplicity of forms for the mobilization of resources and the exercise of powers for the protection of rights to achieve the end of caring and developing common good. Science today forms an integral part of our everyday life. The economy of a country often depends on it. Our quality of life depends on it. As active citizens, individuals have both powers and responsibilities. They thus have the responsibility to decide about scientific issues, to exert pressure on governments to change policies that they do not agree with, to introduce laws that protect life, and human health and lifestyles. Citizens today are empowered with the option of taking action about issues and consequently they need to possess particular skills and attitudes. This can only be achieved if students are given a science education that enables them to understand social issues related to scientific activity and research. It is only through scientific literacy with an emphasis on social issues that one can have active citizens.

How science is related to citizenship or how do citizens use science? Jenkins (1997) identifies a number of features in an individual that is an ordinary citizen's, approach to science: These features include:

- *Interest in science that is differentiated by science, social group and gender*: Different groups show different inclinations in interest. For example, women tend to be more interested in issues related to medicine than to physical sciences.
- *Interest that is linked to decision-making and action:* Individuals may only be interested in particular aspects of science because they happen to be related to some decision or action they want to take. For example, they would be interested in telecommunications because they want to decide what type of communication system e.g. Satellite dish, cable or other if they need to choose what to install in their homes.
- *Understanding that is just adequate for its purpose*: Individuals tend to be happy with a level of understanding that serves its purpose, without questioning its validity, this often leading to holding misconceptions about scientific issues.
- *Knowledge that is considered at a same level as other types of knowledge:* Social, and psychological aspects are on the same level as scientific knowledge.

- *Scientific knowledge that is considered alongside its social and institutional connections:* Citizens value scientific knowledge according to its source. So knowledge being issued by particular institutions will be held to be more valid than that of other institutions that do not hold as high a status.
- *Attitudes to considering risks associated with scientific and technological issues:* Citizens tend to carry out risk assessments on the basis of other aspects such as social, psychological and contextual factors than just on scientific basis.
- *Informed citizens make more discriminating judgments about science and technology related issues:* The more informed citizens are about scientific issues, the more they are able to understand the consequences and make better judgment. However, this does not automatically mean that they would necessarily make more rational decisions.

3. CURRICULAR IMPLICATIONS AND PEDAGOGY

It is on these aspects that an argument is put forward for the need to include the social aspect of science as part of students' science education to ensure better citizens in the future. The social aspect of science needs to become part and parcel of students' science education rather than just an added on activity every now and again. If one wants to have citizens that possess the necessary basic scientific knowledge; the skills needed to evaluate, analyse and be critical of the scientific knowledge presented; and to have attitudes towards science and sustainable development (moral, social, economic and ethical) in order to be able to make informed and independent choices with respect to scientifically related issues, it cannot be left to chance. Science educators have to design science curricula that incorporate social issues as an integral part of teaching schemes. This brings with it new demands and challenges to science education that would make it 'more value laden than content laden' (Gatt, in press).

Having put forward the argument for including the social, moral and ethical aspect of science, the question that automatically stems is – How do we teach it? One definitely cannot use the transmission view (Sutton, 1992). In such an approach, the learner is considered passive, simply receiving information that is stored without necessarily understanding the implications to everyday life and society. If one wants students to develop skills, attitudes and values, teaching needs to be more student-centred rather than teacher-centred as in the case of the transmission view. It is essential that the learner is an active participant in the learning process. This puts forward an argument in favour of adopting the constructivist approach to teaching.

What is constructivism and what are its implications to teaching. A lot has been written about it and many have proposed different types of constructivist approaches. Basic to the theory of constructivism advocated by these numerous educators and researchers is the belief of the necessity for every human being to put together thoughts, interpretations and explanations which are personal to him or herself in making sense of his/her experiences and situations. How do students make sense of experiences? Windschitl & Andre (1998) argue that students construct their knowledge from individual and/or interpersonal experience and from reasoning about these experiences' (p.147).The learning process involves an interaction between the learner and the material to be learnt. Duit and Glynn (1996) 'view constructive learning of science as a dynamic process of building, organising, and elaborating knowledge of the natural world' (p.3). Constructivist learning is always an interpretative process involving individual's constructions of meaning relating to specific occurrences and phenomena. These constructions are built through their relation to prior knowledge (Watts, 1994, p.32).

The origins of constructivism can be traced back to Giambattista Vico in 1710 who argued that one knows a thing only when one can explain it. Since constructivism has become a popular theory of learning in science education, various 'strains' of constructivism have been put forward in literature. These range from cognitive constructivism (Cobb, 1994), sociocultural constructivism (Cobb, 1994), piagetian constructivism (Stofflet & Stoddard, 1994) also referred to as psychological constructivism by Matthews (1994), critical constructivism (Watts & Jofili, 1998), contextual constructivism (Cobern, 1993), trivial constructivism (Von Glasersfeld, 1993), social constructivism (Von Glasersfeld, 1993) or sociological constructivism (Matthews, 1994), pragmatic constructivism (Bettencourt, 1993) to radical constructivism (Von Glasersfeld, 1995) among others. Constructivism has also been attributed to form part of a number of academics' theories, ranging from Jean Piaget (Bliss, 1993) and his theory of cognitive development, George

Kelly (Bannister and Fransella, 1986) and his personal construct theory, Vygotsky (1978) and the idea of scaffolding to radical constructivism by Ernst Von Glasersfeld (1993).

The constructivist philosophy, whatever the approach, holds that individuals construct for themselves a unique picture of the world, and that in constructing this picture they must understand the concepts which, in the case of science, the scientific community accepts as being true. The question for science teachers thus becomes how to provide for individual's private knowledge construction but at the same time ensure that this private knowledge relates to the publicly accepted knowledge constructed by scientists. Science teachers must become flexible in their planning to enable them to change direction in response to students needs (Hand & Vance, 1995). Hence the argument is being put forward in favour of adopting a constructivist approach when teaching science for citizenship.

The debate regards constructivist teaching concerns the extent to which it is possible for any teacher to intervene in the thinking of a learner. This highlights the purpose and value of an intervention and how this can be achieved, and how effective it may be (Watts & Jofili, 1994). Learners organise and manage experiences so that their actions maximise desirable results and minimise undesirable ones. A constructivist teacher works at the interface between learner and the curriculum, to merge agendas and bring the two together in a way that is meaningful for the learner without diminishing the curriculum. It must be noted, however, that construction does not give students the licence to claim that their meaning is as good as that of the scientist (Fensham, Gunstone & White, 1994). It is important to keep in mind that some meanings are better than others, especially those constructed and agreed on by the community of scientists. Likewise, one can use the same argument in the case of looking at the implications of scientific research to society and the environment.

Constructivism has been widely adopted when developing teaching schemes aiming at improving students' understanding in science and specifically in targeting students' wrong ideas, known as alternative frameworks. Examples of the main approaches included conceptual change (Posner *et* al, 1982; Strike & Posner, 1985), Driver and Oldham's (1986) constructivist approach adopted in the Children Learning in Science (CLISP) project, concept mapping (Hammer *et al.*, 1998) and mental models, (Gilbert, 1998). Common features which emerge are the use of cognitive conflict, metacognition and the application of scaffolding in promoting students' active participation in learning.

Duit and Glynn (1996) suggest that a constructivist model of science instruction demands that teachers need to encourage students to think metacognitively (thinking about their own thinking) by activating students' existing mental models. This can be achieved by supporting the process of constructing mental models, helping students to transform conceptual models into physical ones and to think out loud. Teachers need to encourage students to represent a problem in a variety of ways and have students assume the role of teachers, employ reading, writing, discussion and debate. They also need to begin lessons with simple concepts and problems to foster motivation and question students 'who, what, when and where', encouraging students to pose their own science problems. These are approaches that fit in well when considering social implications. This argument is discussed in more detail further on.

These aspects emphasise the need for learning to be stimulating. One can achieve this through the use of challenge or cognitive conflict, reflection or what is known as metacognition, and the ability to build patterns (Adey, 1997). It is important to provide children with opportunities where they can work out their ideas in their own language (Baxter, 1998) and to look at the implications of such issues.

The whole learning process is based on a number of basic implications about constructivist learning. Driver and Oldham (1986) list these assumptions to include:

- Learning outcomes depend on both the learning environment and the learner's prior knowledge. Teachers cannot assume that students do not possess any ideas about concepts and issues before formal instruction. On the contrary, children do hold ideas and these interfere with the learning that takes place;
- Learning involves the construction of meaning. Students need to make sense of what they are doing in order to learn;

- Construction of meaning is a continuous process. Learning takes place all the time and teachers should allow time for learning and construction of knowledge to take place;
- Meanings, once constructed, are evaluated and can be accepted or rejected. Students evaluate experiences they encounter in terms of their previous experiences. From this they decide whether they accept this new knowledge or not; and
- There are patterns in the types of meanings students construct due to shared experiences and language used for communication.

Going back to the issue of teaching skills, attitudes and values and in considering the constructivist approach to teaching, one asks what would be the type of learning activities that teachers could adopt. What is central to any activity that targets the teaching of these aspects of science must be based on one particular central issue, that the students must have ownership of the activity and issue being considered. It is only through ownership that students can empathise and understand the various implications of scientific issues. So what types of activities can teachers organise to highlight the social aspect of science? A holistic approach needs to be taken that allows students to research, learn, share opinions and consider ways in which they can take action. Here are some approaches that teachers can adopt.

- **Discussion:** A simple discussion of an issue where children give their views about the implications of science. This is however, at a lower level of active engagement. However simple this approach, teachers need to learn how to ask questions that provoke discussion. They also need to be able to create an atmosphere where students feel that their opinions are valued and provide a valid contribution to the discussion. Teachers have to be careful to remain impartial, act as chairs and steer discussion on the issue without taking over or imposing their positions about the issue.

- **Poster production:** Children can be asked to draw posters to send messages about issues that they have discussed. Posters are usually designed to send out messages to specific groups. Teachers can help students conceive the implications of science by asking them to draw up posters about an issue but which target a different group, that is, different audiences. When one changes the audience for which a piece of work is designed, it promotes an understanding of different perspectives of an issue to different interest groups related to the issue being considered.

- **Language activities:** Most of the activities in schools involve practice in written work. Teachers can utilise these sessions to consider a particular social issue and ask students to write about it, or make an oral presentation about it. Each time it is important to specify the audience for whom the letter/report/presentation is. This makes the children pay attention to what they have to say and in what way, leading to active reading, writing – knowledge construction. In fostering understanding different perspectives, students can be asked to take up various roles, such as the government's position, the activists' view, the local authority etc. It is a way of helping students realise how the same issue impinges on different interest groups in different ways, how different groups have different agendas and how these influence the way people interpret and take standpoints with respect to scientific issues.

- **Research Projects:** The teacher can introduce a social issue that is of current concern. A newspaper cutting, news report or some other form of contribution in the media can be used to spark off the discussion. However, in this case, students will be asked to look up some scientific information about the issue. It is important to try and elicit differing ideas and opinions so that cognitive conflict would be present. Cognitive conflict is one way of promoting meaningful learning. Getting students to disagree will motivate them to look up information and to formulate arguments in favour of their belief. It is a strong learning tool that makes learning a lasting experience.

- **Role playing:** Role playing is one way of getting students to understand how people in different positions view things differently due to having different agendas. An issue can be tackled, for example the decision to allow research in a particular type of cloning and students are asked to represent different groups, for example, the government, the Health Minister, the research institute proposing the study, the anti-abortion group, the normal citizens etc. Each group would have to look at the issue from the particular group's point of view and come up with a standpoint, an argument in favour or against. This would require that they carry out background scientific research, that they understand the implications of allowing the particular research to take place.

There are a number of common features on which all of these types of activities are based. In fact some of such examples have been already written about by Lock and Ratcliffe (1998). The one single significant common factor is that children are actively involved in the learning process. When one deals with values and attitudes it is difficult to transfer these by simply 'telling'. One needs to place children in a position where they can understand the implications and how different groups have different agendas that may not include the welfare of the population or the world. This is achieved through getting students to disagree by holding different points of view, thus promoting cognitive conflict. If children disagree about an issue, they will then want to know about it in order to make an argument in favour of their standpoint and against that of the other or to show whether an assertion made is correct or not. The issue becomes a personal thing and this is very effective in promoting learning.

All the activities listed involve some form of use of language. This being spoken during discussion, written in producing reports, posters, reading material or listening to another groups' perspective, language forms an integral part of the learning process. In the same way as one understands a problem in the process of formulating a question about it, so will language, similarly, facilitate the understanding of the intricate issues involved when one considers the environmental and ethical issues related to science and scientific research. It is thus essential that examples chosen should be relevant and related to the students' experiences.

Finally, one must also consider the value of metacognition. Teachers too often assume that students are capable to reflect on the things that they come across at school and to see the intention behind such educational activities. However, this is often not the case. Metacognition is essential to learning as it provides learners with conscious control over their own learning processes. Teachers, therefore, need to find time to ask students to reflect on what they have been doing, why they have been doing it and the value of it. They should encourage students to trace how their level of knowledge, opinion, and attitude has changed as a result of the learning activity. Students do not go through such a process unconsciously and teachers need to promote it until it becomes an internalised process.

Obviously, the methods suggested are not exclusive. Whatever the type of activity, what is most important is to get the children involved. However, there is a changing view of what doing science in schools is to involve. There is a strong argument in favour of introducing the social aspect of science as an integral part of the science curriculum. There are also implications for changes in the way that science is to be taught. Many times, science involves the understanding of concepts that are detached from their implications to everyday life and society. Laboratory work is used mainly for the illustration and understanding of these concepts and to train students in the process of doing science. The new approach to science being advocated is that of a more holistic view of science where case studies about relevant current scientific issues are considered such that students have the opportunity to realise the implications of science on everyday life, society and the environment. This requires that teachers change their view of the meaning of doing science and to adopt different teaching methodologies than those that have been used so far.

4. IMPLICATIONS TO PRACTICE

These new approaches require different teaching capabilities than those for which teachers have been trained during their pre-service training. This demands that teachers be provided with training to equip them with the new sills required to deliver a different curriculum. Teachers need support at different levels: technical; planning; pedagogical and management level. At the technical level, teachers need to become familiar with ICT and have good working knowledge of basic programmes. A good percentage of primary teachers in Malta are over 40 years old and experience technophobia. Likewise, one may also find secondary level teachers who are not that conversant with new technologies. Proficiency in ICT is crucial as students would be required to carry out most of their research on the internet. In today’s knowledge society, it is impossible for teachers to know all the content knowledge that is required for teaching, particularly if one is considering new technological advancements that are being added every day. Teachers therefore need to possess the technical capability to use ICT in their teaching so that they can help their students in searching and finding information about issues being discussed.

Activities targeting social issues in science are different from the traditional teaching approach. Teachers thus require new competencies to be able to prepare such activities. Since there is a tendency for these activities to be open-ended, and often there tends to be more than one possible solution, teachers may feel insecure as to how to plan and prepare their lessons. One way of overcoming this insecurity is through good planning and preparation. Rather than preparing the one correct possible method leading to one solution, teachers need to learn how to plan in terms of resources that enable students to look up relevant information. Teaches therefore need to know how to deal with the possibility of different outcomes and how to plan processes rather than products. Such skills are not easily acquired as they always bring with them a degree of uncertainty as how lessons would proceed. There therefore needs to be in-service training for teachers so that they realise the different demands in planning and to develop the necessary competencies for carrying them.

Good planning is only possible if teachers have good pedagogical background knowledge. Recent years has seen great research providing contributions and insight about the teaching and learning process, and particularly with respect to how this applies to the learning of science. New modern approaches, mainly within a constructivist framework are being advocated by many researchers. Teaching about the social aspect of science falls within these new trends. Consequently teachers are required to possess new pedagogical skills that they may not possess. It is therefore necessary to help teachers develop, either through in-service training or in-school support, these new and up to date skills such that they will be capable to respond to these new demands in the teaching of science. In addition, there also needs to be a cultural change as to how teachers view learning and how teaching in schools is to be. This cultural change is crucial as it is only when teachers are convinced of the efficacy of the approaches they adopt that they manage to deliver the curriculum effectively.

These new teaching approaches have produced a shift towards student-centred activities. Such activities demand that teachers have different management skills than those usually required in the traditional teacher-centred approach. Having students working on projects where different groups of pupils may be at different stages in their work and carrying out a variety of activities running concurrently requires different management ability than the traditionally teacher-led lesson did. It would not be of any use if there is good pedagogical planning and delivery but bad management. Teachers can only provide quality experiences if they possess all of these capabilities combined. The role of the teacher has evolved in a much more complex issue than that conceived a few years ago. As the world becomes more digitized, complex and intertwined, the same can be said to what should be taking place in schools. It is ultimately the schools' responsibility to prepare students for a productive and independent life in the world and they consequently have to mirror the present expectations and demands rather than yesterday's reality. This means that teachers carry a great responsibility in ensuring that tomorrow's citizens would be capable of being truly active citizens that ensure a better future for humankind.

5. CONCLUSION

There is no doubt that we are living in a fast changing world. The science education provided to students should mirror this. Rather than aiming to cover all the content generated, which would be an impossible feat, the capability of independent learning and understanding of scientific issues and their implications to everyday life become more important. This calls for a radical change in the way that we view science education. It is essential that this change is brought about, and quick, as otherwise we would end up with a future where citizens would not be capable of handling the scientific capabilities that we ourselves have developed. Such great power in ignorant hands would be dangerous to the future of our world. It is thus essential to act now if we want future generations to enjoy a better quality of life than we have today.

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