MODERN DEVELOPMENTS IN SCIENCE EDUCATION

Saouma BouJaoude
Science and Math Education Center, American University of Beirut, Beirut, Lebanon

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Summary

Research has determined that science education is presently in crisis worldwide. There is evidence that science education at all educational levels is not preparing students to live and work in the science and technology rich environment of the twenty-first century. Moreover, interest in and attitude toward science is declining in many developed countries. These failings are blamed on the unacceptable quality of teaching. Against this backdrop of alarming news, what are the teaching approaches that are recommended to improve the quality of science education and what does research say about the status of science education worldwide. Consequently, the purpose of this chapter is to summarize the major trends in promising approaches to teach science, review the research in science education published between 2008 and 2011 in two prominent science education journals, namely Journal of Research in Science Teaching and International Journal of Science Education, and provide conclusions regarding the improvement of science.

1. Introduction

In a 2006 commentary on the status of science education in the United States, the Nobel prize winner Carl Wieman and his colleague Katherine Perkins (Wieman & Perkins, 2006) asserted that "*there is considerable evidence that science classes from elementary school through to university are generally failing to provide most students with a thorough understanding of science that will allow them to live and work successfully in the twenty-first century. Sadly, these classes are also frequently suppressing whatever interest students may have in the subject*" (p. 290). Similarly, a European Commission's report entitled "Science Education Now: A renewed pedagogy for the future of Europe"

(2007) affirmed that many studies have identified an alarming decline in European young people's interest in science and blamed this decline on the way science is taught in schools. Concurrently, research has shown that citizens of developing countries lack the necessary knowledge and skills in science and technology to function in the modern world (Ogawa 1998). What makes the above findings worrying is that they have emerged at a time when education, political, economic, and community leaders worldwide have agreed that science and technology are the catalysts for change in modern society and when science is needed by all citizens to make informed decisions regarding science-related scientific issues such as global warming and the green house effect.

Against this backdrop of alarming news, what are the teaching approaches that are recommended to improve the quality of science education and what does research say about the status of science education worldwide. Consequently, the purpose of this chapter is to summarize the major trends in promising approaches to teach science, review the research in science education published between 2008 and 2011 in two prominent science education journals, namely Journal of Research in Science Teaching and International Journal of Science Education, and provide conclusions regarding factors that will lead to the improvement of science learning.

2. Approaches to Teaching Science

Advances in developmental psychology and cognitive science research have revolutionized the way educators think about teaching and learning science. Presently, science educators realize that students' brains are not empty vessels waiting to be filled with knowledge transmitted by the teacher. Rather, they believe that most people learn best through personal experience and by relating new information to what they already know. They also understand that learners need to construct their own scientific knowledge by actively taking control of their learning. Specially, learners have to be able to identify and analyze problems, explore and test solutions in a variety of in-school and out-of school situations, conduct their own investigations, analyze and communicate their findings, and reflect on their learning in their attempts to rethink their explanations and retry experiments and re-evaluate problem solutions. Furthermore, students need to acquire the scientific and technological knowledge and develop the skills that will permit them to be productive and creative members of society and to develop attitudes that will help them to use their knowledge and skills responsibly when taking every day and professional decisions. They must develop skills that are particularly important for effective functioning in the ever-changing world of work in which the traditional bases of economic competition continue to change (Partnership for 21st Century Skills, 2011). This requires that students develop a strong conceptual base and essential problem solving and critical thinking skills that they can apply in a variety of situations; knowledge and skills that should be the focal points of teaching and learning science in the classrooms of the twenty first century (Resnick, 1999).

To be effective and efficient citizens of the scientific and technological world in which we presently live and in order not to be alienated, overwhelmed, and demoralized by the changing world, it is not sufficient for students to remember information in the same way it was presented in class; that is to learn by rote. Instead, they need to be able to use what they have learned in novel situations to answer new questions, solve new problems, relate what they have learned to everyday life, and facilitate learning new subject matter; that is, to learn meaningfully (Mayer, 2002). Rote learning is described as learning new information through the use of memorization. It suggests the absence of connections between new and previously learned information. Because new information is not connected to existing concepts in the learner’s mind, it is easily forgotten (Anderson & Ausubel, 1966). In contrast, meaningful learning, described by Ausubel (1968) as the establishment of non-arbitrary relations among concepts in the learner’s mind, is the fundamental process that underlies the acquisition of useful information and the construction of new knowledge (Novak, 1990). BouJaoude (1992) argued that students who are able to establish connections among concepts and other forms of knowledge are more likely to understand and remember what they learn. Also, they might be able to address misunderstandings and to solve problems through the use of the relations they construct between new knowledge and relevant existing concepts.

There are a variety of ways by which students can accomplish meaningful learning. In the following the author describes a number of strategies that can be used for meaningful learning including concept mapping, analogies, summaries and answering questions, inquiry strategies, and conceptual change strategies, strategies to address environmental issues, and using ICT in teaching and learning.

2.1. Concept Maps

One of the teaching/learning strategies that have been shown to enhance learners’ science achievement and meaningful understanding is concept mapping. Concept mapping has been used in science education in a variety of ways. Concept maps, for example, can play a significant role in curriculum development, learning, and teaching in many disciplines (Novak, 1998). They are useful in science curriculum planning for separating significant from trivial content (Starr & Krajcik, 1990). Furthermore, concept maps have been used as assessment tools because they measure dimensions different from those revealed by traditionally used assessment instruments (Markham, Mintzes, & Jones, 1994). Finally, concept maps have been used in instruction in a variety of contexts. Each context reflects an alternative theory of knowledge acquisition. On the one hand, the rationalist theory of learning suggests that subject matter has an inherent structure that should be conveyed to learners. In this context, a concept map should be evaluated by relating it to an ideal map, teacher-constructed map, or an expert concept map. Alternatively, the constructivist theory of learning underscores the uniqueness of each individual’s concept map representation with respect to organization of concepts and their construction (Beyerebach & Smith, 1990) leading to a different approach to assessing these maps and a more student-centered instructional approach which allows students to actively construct their own knowledge with teacher guidance. Still, both theories concur that meaningful learning occurs when concepts are organized in an individual’s cognitive structure.

2.2. Analogies, Summaries and Answering Questions

Generative learning is another approach to involve students in meaningful learning. When using generative learning strategies students are expected to actively generate the links between the new information and prior knowledge. A generative learning strategy is any strategy that involves students actively and meaningfully in the learning process.

Three generative learning strategies are instructional analogies, summarization, and asking questions. Instructional analogies are instances where a less familiar domain is made understandable by referring to similarity relations with a more meaningful domain. They provide a bridge between what is known and what is less known (Dagher, 1995). Analogies help in achieving conceptual change and problem solving, constructing explanations, and building arguments (Gentner, & Holyoak, 1997), and in concept learning (Cosgrove, 1995). Summaries are brief statement representing the condensation of information representing the basic and central ideas of a discourse (Friend, 2002). Students' generation of summarizing sentences increases the generative processing in memory. The summary writer must ensure that the summary is true to the original meaning and decide what to include, what to eliminate, and how to reorganize information. Finally, educators think that engaging students in answering thought-provoking questions or in generating them will help them gain the knowledge and skills necessary for managing their own learning (Chin, Brown, & Bruce, 2002; Chin & Chia, 2004)

2.3. Inquiry Strategies

Science has a unique nature and specific teaching strategies might be needed to help students to understand the content, methods, and nature of science. Contemporary conceptions of the nature of science suggest that scientific knowledge is empirically based, tentative, and value laden. Moreover, scientific knowledge is inferential, creative, and socially and culturally embedded. The fact that science is by nature empirical, tentative, value laden and socially embedded necessitates emphasizing meaningful learning, because, when students learn science by rote they develop unrealistic and unacceptable notions of the nature of science as a collection of disconnected facts. There are different strategies by which teachers can provide the context within which students can learn science meaningfully while concurrently understanding the nature of science. According to the Wisconsin State Department of Public Instruction (2003) these strategies include: Establishing context, seeking to establish personal relevance, making emotional connections, relating learning to the real world, establishing patterns, thinking of the big picture, allowing for processing time, and promoting in-depth interdisciplinary inquiry.

Science educators have developed many student-centered strategies to enhance meaningful learning and help students understand the nature of science. One of the characteristics of these strategies is that they are both hands-on and minds-on, a characteristic that allows students to manipulate objects and experience events while at the same time engaging their minds in thing about science and reflecting on their experiences. Two of these strategies, general inquiry and problem-based learning are described in the following.

Inquiry is a teaching strategy that aims to teach students about conducting investigations and using and assessing evidence in order to answer questions or solve problems. Scientific inquiry, specifically, refers to the varied ways by which students emulate scientists by studying the natural world and proposing explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world. Inquiry teaching aims to develop students' higher order and critical thinking skills and in-depth and meaningful understanding of content. Inquiry appears as a major component of standards and curricula around the world (e.g. National Research Council [NRC], 1996; National Audit Office [NAO], 2006) and has been advocated as the teaching strategy of choice by the European Commission (2007).

When teaching by inquiry, teachers assume the role of a facilitator of the inquiry process; they plan the different aspects of the lessons and guide students in the investigations. Moreover, they insure that students plan and implement their investigations carefully; taking their time to identify multiple sources of data and to think through alternative sources of evidence and alternative solutions. Finally, teachers encourage students to reflect on the various aspects of the investigation to consolidate gains and use what they have learned in novel situations. According to Ayoubi and BouJaoude (2005) good science teaching has been linked to teaching by inquiry because this teaching strategy involves a) putting emphasis on both process and content, thus allowing students to develop profound understandings of science content as well as how scientists work; b) relating content to students' experiences and prior knowledge; c) encouraging students to be curious about the world around them, d) providing opportunities for integration across different content areas; e) developing students' communicating skills through sharing of thoughts and collaborative work; and f) preparing students to be citizen who take informed decisions about science related issues.

The extent of teacher guidance during inquiry depends on the learners' cognitive level and the level of sophistication in conducting investigations. Herron (1971) developed a scale that provides teachers with guidelines for using and assessing inquiry in the classroom (Figure 1). Level 0 is usually used with students who are new to inquiry. Thus they are given the problem, the procedure to follow as well as the solution or expected answer. Level 1 is used with students who are a little more advanced, thus they get the problems and procedure and are required to reach the solution themselves. In level 2, the students are only given the problem and are required to develop the procedure and reach the solution. In level 3, students come up with their own problem, develop their own procedure, and reach their own solution. This is open inquiry that may be very useful if students are working on a Science Fair project.

Level	**Problem**	**Procedure**	**Solution**
0	X	X	X
1	X	X	
2	X		
3			
Note: An "x" indicates that students are provided with the information or steps necessary to complete the designated component.			

Figure 1. Herron scale: evaluating the level of inquiry

While inquiry in science was the focus of the science education standards in the 20th century, the reformulation of these standards in the 21st century emphasizes the inter-relationships of science, technology, engineering and math in what is now known as STEM education which focuses on scientific inquiry and engineering design (National Research Council [NRC], 2011a). For example, the document entitled “A Framework for K-12 science education: Practices, crosscutting concepts, and core ideas” suggests that in the United States all students should have “some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology.” (NRC, 2011a, p. ES 1).

A variety of specific teaching strategies have been advocated to involve students in inquiry leaning. These include problem-based learning, Predict, Observe Explain (POE), the learning cycle, and the 5-E learning cycle. Problem-Based Learning (PBL) is a form of experiential learning that involves students in posing real-world problems, preferably from the students’ environment, and using resources, under the guidance of the teacher, to resolve the problems while at the same time developing content knowledge and problem solving skills associated with the problem. The POE’s three steps allow students to predict what might happen if an event were to take place, observe what actually happens, then amend their explanations if what they had predicted contradicts what they observed or add to their original explanations to account for the observations. The learning cycle involves three steps and requires students to explore, explain, then apply, while the 5-E model – which is an extension of the learning cycle – involves **e**ngaging students in an activity, allowing them to **e**xplore the problem identified in the activity, **e**xplain the results of their exploration, **e**xtend their knowledge, and finally **e**valuate their work.

2.4. Conceptual Change Strategies

As indicated above science educators realize that students’ brains are not empty vessels waiting to be filled with knowledge transmitted by the teacher. Rather students come to the classroom with preconceived notions and understandings that they have developed from their experiences. These preconceived notions are sometimes at variance with accepted scientific knowledge and are called alternative conceptions (or misconceptions). The existence of misconceptions has been documented in hundreds of research studies worldwide. The existence of alternative conceptions necessitates the use of conceptual change strategies that address them directly because they have been resistant to change by ordinary teaching methods.

One of the first models of conceptual change was developed by Posner, Strike, Hewson, & Gertzog (1982). This model posits that there are four conditions for conceptual change to succeed: there should be dissatisfaction with existing concepts and new concepts should be intelligible, plausible and fruitful. This model was however criticized because it is overly rational and because it neglects motivational factors such as students’ goals, values, self efficacy beliefs, and control beliefs (Treagust & Duit, 2008). Others have criticized this model because of its lack of emphasis on context as a mediator of conceptual change (Treagust & Duit, 2008). Another popular model of conceptual change was developed by Driver and Scanlon (1989). This model includes five steps: 1) Orientation, during which students are introduced to the task, 2) elicitation of students' ideas, 3) restructuring of ideas during which students are involved in a variety of activities to restructure their ideas, including the exposure to cognitive conflict among other activities, 4) application of the new ideas in new situations, and 5) review change of ideas by comparing the initial ideas to the new ones.

It is worth noting that cognitive conflict (or the use of discrepant events) has played an important role in conceptual change models with research. However, the use of cognitive conflict has also been criticized because it does not always lead to successful and permanent conceptual change (Treagust & Duit, 2008). In conclusion, Treagust and Duit (2008) assert that multi-dimensional conceptual change perspectives that consider both cognitive and affective outcomes of learning as conceptual change seem to be more effective than ones that do not consider these factors even though there have not been meta-analytical studies that confirm this conclusion.

2.5. Strategies to Address Environmental Issues

Students living in the 21st century will eventually have to participate in decision-making regarding science-related issues that are environmental or controversial socio-scientific in nature. Preparation for such participation can be accomplished by adopting a science-technology-society-environment approach (STSE).

The aims of including STSE issues in the teaching of science are helping students to learn and understand science content and at the same time make informed decisions about scientifically-based environmental issues. STSE can be incorporated in the science curriculum by using a variety of strategies that include the study of products and systems, issues awareness, moral development, issues investigation and action learning. While action learning is the ultimate aim of using STSE approaches, students need to develop the skills to investigate issues in preparation for decision making and action learning.

These skills include identifying and clarifying the basic question to be answered, gathering data about the issue under study, evaluating the data, proposing tentative solutions, and determining the acceptability of the solution in the context where it is being considered.

Two strategies that can be used to investigate issues are the Futures Wheel (BouJaoude, 2000) and the Issues Analysis Technique. The futures wheel is a teaching technique that encourages students to think creatively in exploring the implications of a particular issue or event.

There are no right answers when completing a futures wheel and no decision-making occurs. Rather, it is used to analyze issues in preparation for decision-making. When developing a Futures Wheel students look at an event, experience or decision and ask "What might happen if...?" and construct a graphic representation of the direct and indirect effects of the issue or event that is being analyzed. Similarly, the issues analysis technique involves students in analyzing issues by identifying the Problem, the issue, the players who have a role in the issue, the positions of the players concerning the issue, the beliefs held by the players, and the values on which the beliefs are based. Based on this analysis, various strategies to resolve the issue are identified.

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Biographical Sketch

Saouma BouJaoude graduated from the University of Cincinnati, Cincinnati, Ohio, USA in 1988 with a doctorate in Curriculum and Instruction with emphasis on science education. From 1988 to 1993 he was assistant professor of science education at the Department of Science Teaching, Syracuse University, Syracuse, New York, USA. In 1993 he joined the American University of Beirut (AUB). He served as Director of the Science and Math Education Center (SMEC) (1994-2003), Chair of the Department of Education (2003-2003-2009), and is presently director of SMEC and the Center of Teaching and Learning. Dr. BouJaoude has published numerous research articles in international journals such as the Journal of Research in Science Teaching, Science Education, International Journal of Science Education, Journal of Science Teacher Education, the Science Teacher, and School Science Review, among others. In addition, he has written chapters in edited books in English and Arabic and has been an active presenter at local, regional and international education and science education conferences. Dr. BouJaoude is member of several international science education research associations and has served as the International Coordinator and a member of the Executive Board of National Association for Research in Science Teaching. Presently he serves on the editorial boards a number of science education journals and is a reviewer for others. In 2009 he was appointed as a member of the Executive Committee of Supreme Education Council of the State Qatar.