TEACHING STRATEGIES FOR DEVELOPING SCIENTIFIC LITERACY AND ON STUDENTS’ ACHIEVEMENT IN BIOLOGY

SALAMA YOUSSEF 1* & CHENNAOUI MOHAMMED2

1 Hassan 1st University, Biology Department, Polydisciplinary Faculty of Khouribga, 25000, Morocco.
2 Regional Centers for the Professions of Education and Training (CRMEF), El Jadida, Morocco email: chennaoui_mohammed@yahoo.fr (M. Chennaoui)

Article Info

Abstract

All too often biology courses over-emphasize trivial and easy-to-test activities that ask students only to recall, recognize, describe, or "compare and contrast" information that has been memorized. I have observed this weakness on the exams of major universities. Alfred Whitehead noted that "So far as the mere imparting of information is concerned, no university has had any justification for existence since the popularization of printing in the fifteenth century." This is no less true today with the availability of the Internet. The introductory course should incorporate a diversity of learning outcomes, and this diversity should be reflected both in classroom activities and in student assessment protocols. The proposal will also make a case for the urgent development of an online student-centered learning environment, including possible activities that would be included in the course. A combination of multiple teaching approaches is necessary for changing students learning from surface learning to deep learning, passive learning to active learning, over-dependent learning to independent learning, and developing students in the ‘generic skills’ of a scientist and the skills for ‘lifelong’ learning including problem solving skills, communication skills, and cooperative skill.

1. Introduction

Educational activities should reflect what real people actually do, as biologically literate citizens or employees. Little of their time is spent watching lectures, rather they are involved in application of information -- decision-making, problem-solving, investigation, policy analysis, debate, critical thinking, creative thinking, and information-retrieval. These are the activities that should be occurring in the lecture hall, field, and laboratory. Fortuitously, they are also the kinds of activities that create an exhilarating learning environment.

Since 2000, study after study has made it clear that there is an alarming crisis in relation to students’ interest in science, either as a possible future career, or as an intrinsic interest that will continue after school” [1]. In the UK in the late 1960s, the publication of the Dainton report [2] which examined the flow of candidates in science and technology into higher education documented a swing from science in the school-age population as a whole. The list of countries experiencing declining interest of students in science is on the increase particularly among the developed countries [1]. One factor which has contributed to low interest in science by students is the method adopted for teaching and learning science. Fensham [1] listed four views of students which contribute directly to low interest in science: (i) Science teaching is predominantly transmissive, (ii) The content of school science has an abstractness that makes it irrelevant, (iii) Learning science is relatively difficult, for both successful and unsuccessful students, and (iv) Hence, it is not surprising that many students in considering the senior secondary years are saying: Why should I continue studying science subjects when there are more interactive, interesting and less difficult ones to study?

* Auteur correspondant ; salama.youssef@gmail.com (Y. Salama)
This unhealthy development in the disposition of students towards science has sparked the search for and development of alternative methods of science teaching and learning which can stimulate students’ interest and guarantee an educational system that offers equal opportunities for all sexes. Science education as a field of study is therefore in dire need of methods with qualities such as lesson clarity, promotion of self-activity, promotion of self-development, stimulation of interest and curiosity and relying on the psychological process of teaching and learning to recommend to science teachers. The methods should encourage science teaching and learning that is better than it is now.

Many students today are learning science in a passive way in classrooms where information is organized and presented to them by their teacher [3]. They noted that “often, the teacher pays little attention to what students already know about science. In this learning model, the information transmitted by the teacher and curriculum materials are assumed to make sense and seem reasonable to the students”. This model views science from a limited perspective. Science, seen in this way, has been influenced by the manner in which it is taught and studied. With this conception, science is thus viewed as a collection of organized body of information about the natural world. However, another view of science is the dynamic interaction of thought processes, skills and attitudes that help learners develop a richer understanding of the natural world and its impact on society. Moyer et al., [3] pointed out that “science viewed in this way, sees science as not just a body of knowledge but rather a process for producing knowledge”. This latter view of science therefore calls for a change from the transmission method of presenting science to students to allowing the students to interact with the natural world to create knowledge.

Arising from the view of science as a process for generating knowledge, major reform efforts were carried out in science education in the 1990s and culminated in the development of the National Science Education Standards (NSES) [4] in the U.S. The content standards presented in the National Standards elaborate what students should understand and able to do in natural science, and the personal and social context that should be considered in the design of science curriculum. Bybee et al., [5] stated that “these standards emphasize inquiry-oriented activities, connections between science and technology, the history and nature of science as students develop an understanding of fundamental ideas and abilities in science, and a vision of good science teaching model. The NSES, although recommended for the U.S educational system, are internationally practiced in science education. Bybee et al., [5] noted that the standards encourage all students – including members of populations defined by race, ethnicity, economic status, gender, and physical and intellectual capacity - to study science throughout their school years and to pursue career in science. The NSES emphasize that the learning of science is an active process. Learning science is something that students do, not something that is done for them. They further stated that doing science requires students to be involved in both physical and mental processes, collectively known as scientific inquiry. Scientific inquiry requires both hands-on activities and minds-on as well.

Knowledge, which is long lasting and available for use later, is created through the transmission of experience. The expansion of education, creation of new fields of discipline and development of different instructional approaches, calls for detailed assessment of instructional strategies before they are selected to use in science classroom. Also with the increasing emphasis on lesson clarity, promotion of self-activity, stimulation of interest and curiosity, teaching methods associated with subject matter disciplines, instructional variety, retention rates and life-long learning, there is good reason to explore other instructional approaches for teaching science different from the one predominantly used (lecture) for very long time. This exploration is to determine if the methods have varying effects on students’ achievement when compared with the lifelong objectives of teaching science. This indeed formed the rationale for the current study of determining the effects of concept mapping, cooperative learning, learning cycle and lecture instructional strategies on students’ achievement and retention of biological knowledge when used for instruction.

Four Theories of Learning

1.1. Transmission Method (Traditional Method)

The transmission view of teaching and learning sees teachers as passing over their knowledge to their pupils [5-9]. This view is strongly linked to expository teaching; teachers standing at the front telling their pupils about scientific ideas. The transmission view implies that the pupil’s role in the learning process is largely passive, and that a pupil’s mind is a tabula rasa- a blank state onto which knowledge can be written. The lecture or traditional teaching method has the following advantages:

a) It is easy to create interest in a topic or subject by the teacher.

b) Students easily acquire knowledge, new information, and explanation of events or things.

c) It helps students to clarify and gain better understanding of a subject, topic, matter or event.
d) Students and teachers cover more content materials within a short period of time.

The major limitation of this method is that there is relatively little student activity and involvement [10-12]. Thus, the students are said to be passive. The limitation experienced with the transmission approach led to the development of other views of science teaching and learning.

1.2. Discovery Method

Discovering learning involves presenting pupils with information in a form which requires them to discern relationships within the information and to structure and make sense of the information and relationship. This form of self-directed learning could promote higher forms of thinking with the aid of meta-cognitive strategies [13]. Discovery learning sees pupils as having a much more active role in their learning. Proponents of this approach argue that the enhanced learning by learners is due to their active participation in learning process.

The use of discovery approach for teaching and learning has been associated with science education for over one hundred years now [5, 14]. Ajaja [15] noted that the school science curricula like Biological Science Curriculum Study (BSCS) [16], Chemical Education Material Study (CEMS) [17] and Chemical Bond Approach (CBA) [18] which adopted the discovery approach to teaching emphasized the presentation of science to pupils as a way in which they could conduct their own inquiries into the nature of things. Discovery learning in science places a strong emphasis on practical work organized in such a way that pupils make observations, look for patterns, and come up with possible explanation for those patterns.

The discovery method, unlike the lecture method, has the following advantages:

1) It helps the pupil understand the material better by showing him that the concepts involved are so reasonable that he can discover them himself or herself.
2) It helps a learner to remember concepts, principles and laws better since what is discovered is by far less likely to be forgotten.
3) It helps the individual to learn on his own so that he or she may become increasingly independent of the teacher.
4) It keeps the teacher in touch with his or her class so that he or she knows whether the pupils understand or follow the work.

After a long use of discovery approach for teaching and learning of science, it became apparent that there were limitations with the approach. Bennett [6] reported that questions were asked about the appropriateness of asking pupils to “discover” things for themselves when both teachers and pupils knew that the answers were already there in the form of currently accepted scientific theories. There was also a question over the nature of the understanding pupils developed when left to their own devices and to what extent pupils “discover” the scientifically accepted explanations of the phenomena they experience. These identified limitations and criticisms levied against discovery learning, paved the way for a shift in research efforts from discovery learning to constructivism.

1.3. Developmental views of learning

Research work in the field of psychology of education has examined how children’s abilities to obtain, process and use information develop as they grow and mature. Bennett [6] noted that the single most influential theory of cognitive development in the twentieth century emerged from the work of Jean Piaget. His theory describes four stages of intellectual development through which children pass:

- Sensori-motor stage (0-2 years) Children learn through their senses and physical experiences.
- Pre-operational stage (2-7 years) Children reason directly from what they perceive and may not be logical.
- Concrete operational stage (7-11 years) Thinking characterized by logic and does not require real objectives at hand.
- Formal operational stage; (11 years and above) Children become capable of abstract thought.

2. Which strategy best suits biology teaching?

Two key processes in learning are central to Piaget’s theory. Piaget viewed learning as an active process in which the learner compares and contrasts modes of thinking about new experiences with those of prior experiences. Moyer et al., [3] noted that often the child realizes that the explanation used for an earlier experience does not fit with a new experience. This is resolved by the learner having to modify his/her way of thinking to come to a conclusion that seems personally reasonable Piaget called this, process of thought adjustment equilibration [19]. This adaptation occurs through the two active thought processes, assimilation and accommodation.

2.1. Constructivism

Cognitive psychologists and science educators influenced by the early work of [20-24] are of the view that useful knowledge is not passed along intact from one person to another, nor is it discovered in the external world. The synthesis of the ideas generated from these theorists gave rise to the constructivist perspective. The constructivist insists that knowledge
is produced by the learner [3, 6, 21, 25]. Underlying the constructivist perspective is the notion that all people normally try to make sense of their world. Through their own constructive processes, individuals impose order and predictability on phenomena and events of the world. Bybee et al., [5] stressed that the constructivists contend that we cannot directly teach a student the principles of science.

2.2. Three Instructional Strategies

The notion that learning is influenced by prior experiences and must be constructed by the learner led to the development of what has become the dominant view of learning in science education today [5, 6, 15, 26, 27]. The impact and influence of this view of learning gave rise to the development of new strategies of teaching science such as concept mapping, cooperative learning and learning cycle where the emphasis is on the active participation of learners in the learning process. All three instructional strategies share complimentary objectives of engaging students in the learning process and promoting higher thought processes and more authentic behaviors required for scientific and technological development. Wise and Okey[28] stated that effective science classroom appears to be one in which students are active, kept aware of instructional objectives and receive feedback on their progress towards the stated objectives. In classroom where elements of constructivism are incorporated in teaching and learning, students get opportunities to physically interact with instructional materials and engage in varied kinds of activities. This position suggests that for effective learning to take place, students must be actively involved in the learning process. The three instructional strategies which employed the principles of constructivism are discussed below [28, 29].

2.3. Concept Mapping

A concept map is a two-dimensional representation of the relationship between key ideas. At first glance, a concept map looks like a flow chart in which key terms are placed in boxes connected by directional arrows. When based on educational psychology theories of how we organize information, concept maps are hierarchical, with broader, more general items at the top and more specific topics arranged in a cascade below them. According to Novak[29], a standard concept map construction methods include the following series of steps:

i. define the topic;
ii. list the most important concepts;
iii. arrange concepts hierarchically;
iv. add links to form a preliminary concept map;
v. add linking phrases;
vi. add cross links; and
vii. review map.

The principle of a concept map is that it provides a visual means of showing connections and relationships between a hierarchy of ideas ranging from the very concrete to the abstract [6, 30]. Patrick [15] noted that concept maps help in understanding ideas by showing the connections with other ideas. The benefits of concept mapping are mainly to the individual making the map. The process of simplifying concepts and arranging them on a page forces the learner to think about what is most important. It helps to clarify one’s thought and understanding and makes learning more meaningful. A concept map can be a heuristic device that is a process in which the learner can make discoveries and uncover meanings through trial and error. It helps in the development of critical thinking skills which is a conscious effort to think about thinking.

Patrick [15] stated that the development of concept mapping as an instructional tool can be traced to the early work of Ausubel and others in the 1970s. Continuing, Patrick noted that since its introduction, concept mapping has become a very useful tool in teaching and learning and particularly in science education. Literature on concept mapping indicates that it has been used for instruction, assessment and learning [26, 31-34].

Some studies on the effects of concept mapping when used as an instructional tool for teaching and learning, indicated its relevance in improving the cognitive and affective aspects of learning. A study conducted by Patrick [15] determined the effects of concept mapping as a study skill on student’s achievement in Biology. The major findings of this study indicated a significant and consistent improvement in Biology achievement as the period of experience with the use of the method increased. Also, students who used concept mapping as a study skill retained biological knowledge longer than those who used other methods. All the students interviewed in the concept mapping classroom agreed that concept maps helped them not only in the determination of the relationships among the concepts but also shaped their understanding of the concepts and increased their critical thinking. The findings of Hall, Hall et al., [35], and Kinchin[36, 37] were similar to these research findings. Kinchin[36] found a significant impact of concept mapping on achievement when used for instructing secondary school biology students. Kinchin[37] in a study comparing the effect of the use of concept mapping as a study skill on students achievement, found a positive effect on students who used concept maps to revise and summarize the materials given.

Apart from studies which solely determined the effects of concept mapping on students' achievement,
mapping has been used along with other instructional strategies and their combined effects on students’ achievement determined. Whereas some studies showed significant improvement on students’ achievement when concept mapping was combined with other instructional strategies, others found no significant differences. For example, Okebukola[38] investigated whether concept mapping alone as an instructional strategy in Biology would enhance meaningful learning when compared with concept mapping in cooperative learning groups. The study found a significantly higher achievement scores in Biology among students in the concept mapping group than those in class, taught with concept mapping and cooperative learning group. Jegede et al.[39], comparing the effectiveness of concept maps as teaching strategy in Nigeria, and Ezeudu[40], examining the effect of concept mapping on students’ chemistry achievement in Enugu and Nsukka educational zones, found that students taught with concept mapping significantly performed better on achievement tests than those in the control group. These findings indicate that concept mapping facilitates meaningful learning and understanding of concepts in science.  

Markwo and Lonning [42] investigated the use of students’ constructed maps and the effects the maps had on students’ conceptual understanding of Chemistry experiment that they performed. They found that learning was enhanced and the construction of the pre and post instruction concept maps did help students understand the concepts in the experiments they performed. Novak [43] and Ezeudu [40] provided two opposing views on how concept mapping affect students’ of different sexes. Ezeudu [40], who studied the interaction effect between concept mapping and gender on achievement in Chemistry, found that the male students significantly out-performed the females in the achievement test administered. Novak [43] found that there was no significant difference in achievement between males and females taught with concept mapping. This is consistent with the finding of Patrick [15] as earlier reported. The major limitation of concept mapping is that it taps high cognitive ability and a very good mastery of the subject area. Low ability teachers and learners may not be able to draw and use concept maps for teaching and learning. Bennett [6] identified two major limitations of the use of concept mapping in instruction. First, concept mapping is not easy to construct, and respondents require training and practice in producing maps. Second, there are difficulties with the interpretation of concept maps in particular with devising appropriate ways of scoring to enable valid comparisons to be made. Thus limitations are found to frustrate low achievers in mastering the techniques required for the use.

2.4. Cooperative Learning
Cooperative learning is an instructional strategy which organizes students in small groups so that they can work together to maximize their own and each other’s learning. Specifically, the cooperative learning approach to instruction is where students are arranged in pairs or small groups to help each other learn assigned material [26, 34]. Interaction among students in cooperative learning groups is intense and prolonged [13]. In cooperative learning groups, unlike self-directed inquiry, students gradually take responsibility for each other’s learning. Borich[13] and Trowbridge et al.[26] identified four basic elements in cooperative learning models. Small groups must be structured for positive interdependence; there should be face-to-face interactions, individual accountability, and the use of interpersonal and small group skills.

Cooperative learning has been found to be useful in several areas such as helping learners acquire the basic cooperative attitudes and values they need to think independently inside and outside the classroom [13, 31]; promoting the communication of pre – social behavior; encouraging higher order thought processes; and fostering concept understanding and achievement [13, 26, 31, 34]. Cooperative learning brings together in adult-like settings which, when carefully planned and executed can provide appropriate models of social behavior [44]. Steven and Slavin[44] noted that if all other benefits of cooperative learning were not enough, the fact that it has been linked to increase in the academic achievement of learners at all ability levels is another reason for its use. Cooperative learning is known to actively engage students in the learning process and seeks to improve the critical thinking, reasoning, and problem solving skills of the learner [45-47].

A review of studies on the effects of cooperative learning on students’ achievement indicated that cooperative learning gains are not limited to a particular ability level or sex but to all who engage in it [45, 48-51]. Stevens and Slavin [44] linked cooperative learning to increase in academic achievement of learners at all ability levels. While studies by Glassman [52] and Johnson et al.[31] found cooperative learning to emphasize the status and respect for all group members, regardless of gender. Very importantly, the study by Crosby and Owens [49] found that different cooperative learning strategies can be employed to help low ability
students who had difficulties making success in the traditional classroom to improve achievement. A more recent study by Ajaja and Eravwwoke\cite{48} reaffirmed the ability of cooperative learning when used as an instructional strategy to bring about significant improvement in students' achievement in school science subjects. The findings of the study indicated that students in cooperative learning group outscored those in the lecture group in an achievement test and a non – significant difference in achievement scores between male and female students in the cooperative learning group.

The major disadvantages of cooperative learning include:

i. not all members of a group will participate in solving the problems they are confronted with;
ii. some very active members of a group may overshadow less active ones;
iii. the method is time consuming; and
iv. low ability students who solely depend on the teacher for all information may not be able to make any contributions during cooperative learning.

3. Learning Cycle

The learning cycle is a generic term used to describe any model of scientific inquiry that encourages students to develop their own understanding of a scientific concept, explore and deepen that understanding and then apply the concept to new situations \cite{53}. The learning cycle is an established planning method in science education and is consistent with contemporary theories about how individuals learn \cite{22}. It is useful in creating opportunities to learn science. There are different models of the learning cycle; popular among these models are the three-phase model, four-phase model and the five-phase model.

Moyer et al.,\cite{3} stated that the learning cycle model of learning and teaching evolved for the past 40 years. The emergence of this model was influenced by the work of Jean Piaget and its application by Atkin and Karplus\cite{54}, who applied cognitive development theory and discovery learning to instructional strategies in elementary science. Karplus and Myron Atkin with the support of the National Science Foundation developed a three phase learning cycle that served as the central teaching/learning strategy in the newly introduced science curriculum improvement study (SCIS) program\cite{54}.

The first three phase model of the learning cycle consisted of: Exploration, Invention and Discovery and were first used in the SCIS program \cite{3, 34}. Continuing, they noted that these terms were modified to Exploration, Concept Introduction and Concept Application by Karplus. Moyer et al.,\cite{3} reported the observation of Barman and Kofar\cite{55} and Hackett and Moyer \cite{56} that the cycle evolved through modification to include additional phases such as engage, explain, elaborate, extend and apply and are used to frame single guided discovery lesson as well as extend experiences such as chapters and units. They noted that a fifth phase, evaluate, was incorporated into an elementary science program developed by the Biological Science Curriculum Study \cite{57}. These series of modifications gave birth to the model called 5E learning cycle the model used for this study.

Studies by Nuhoğlu and Yalçın\cite{58} and Ajaja\cite{30} showed that learning cycle enhanced the retention of science knowledge. Nuhoğlu and Yalçın\cite{58} specifically emphasized that learning cycle make knowledge long lasting and that students become more capable of applying their knowledge in other areas outside the original context. There appears to be scarcity of literature on the effect of learning cycle on retention when separated from achievement as a whole.

4. Successful learning

The problem of successful learning is at the heart of many contemporary studies that are concerned with the development of abilities \cite{59}, observing the dimensions of learning \cite{60}, developing seven intelligences \cite{61}, and teaching with the five dimensions of learning. According to Marzano et al.,\cite{62}five types of thinking, called the five dimensions of learning, are essential for successful learning. That is what is essential for differentiating the learning process from its results and seeing the close connection between them.

Learning as a process means students’ making conscious efforts to achieve their personal educational needs, interests and goals in accordance with social conditions for effective adaptation and integration in social life, and in accordance with the current state of science and culture. It involves "processes of acquiring knowledge and skills through practice, teaching or information. Learning by doing is recommended nowadays and is defined as "the process of acquiring understanding, knowledge, skills and attitudes through practical and applied activities."

It is the process of becoming competent. Learning as a result is represented with the expected results, obtained by the student, which can be the basis and means for further learning. "Knowledge changes knowledge.” Knowledge should be used with the meaning of decision making, problem solving, goals, experimental testing, investigation and analysis of the system. Effective learning is assessed by its results in relation to the objectives.

Education in the modern world is not limited to a certain period of human life but is a lifelong process.
It is "the beating heart of society," a bridge between past, present and future and its meaning becomes deeper and deeper with time. People need to return to learning so as to cope with new situations arising in their personal and working life. This need is very obvious and is becoming increasingly stronger. The only means to achieve this that everyone learns how to learn. For this purpose, it is necessary to stick to the four pillars: learning to live together, learning for knowledge, learning for acting, and learning to be" [63].

For the life in the twenty-first century, new personal characteristics are needed - memory, physical abilities, aesthetic feelings, communication skills, and charisma of the leader. Knowledge is dynamic and constantly changing from one state into another, which is what has to be acquired, restored and used in life.

Today's world of expanding information technology and collaborative scientific research demands that students be able to communicate across disciplines and cultures. As instructors, we need to help our students learn how to apply the scientific process, and weave it into a useable fabric with other disciplinary approaches.

5. What should we do in the future?
We have been introduced to a number of theories of learning and ways in which we can teach science to encourage the development of deep learning strategies in our students. Contemporary teaching approaches in the sciences currently focus on student-centred activities, and how we can encourage students to develop lifelong learning skills. This is especially important in science with the current ‘information explosion’.

The purpose of teaching is not to import content knowledge only, but to encourage the development of generic skills of a student (e.g. scientific writing, communication, computing, problem solving and experimental design, data handling skills and lifelong learning skills). Teachers need to reconsider what they will teach and must also understand how students learn. Encouraging a student-centred learning approach.

6. Combination of multiple teaching strategies
For teaching our course, I do not believe there is a single teaching method suitable. The methods will depend on the characteristics and content of the course. We should combine multiple methods of teaching together, using them appropriately according to the actual situation. At present, we should retain the traditional teaching form – the lecture. Probably the most useful teaching and learning strategies that could be introduced into the lecture would be the use of case study scenarios and concept mapping. Activities such as teamwork, including poster preparation and presentation, are better introduced into the practical classes.

6.1. Applications of team work
It is well known that having students work in small peer groups, is one of the better ways to teach science [47, 64] and this includes teaching science via case studies! The use of peer group learning scenarios helps to overcome any initial student reticence, fosters the development of good communication skills, and promotes positive social interactions within the peer group Cooperative learning may occur in or out of class. In-class exercises may involve answering or generating questions, explaining observations, working through derivations, solving problems, summarizing lecture material, troubleshooting, and brainstorming. Out-of-class activities include carrying out experiments or research studies, completing problem sets or design projects, writing reports, and preparing class presentations [65].

6.2. Discussions in large classes
Large group discussions can be an excellent learning tool, but how can we use them in a classroom? Most science teachers do not have the experience to run these types of classes. Preparation and control are the key ingredients. Teachers should use appropriate questions, body language, blackboard planning, and summarization to make it all work. This is method to give students a question during his lecture, and allow them to discuss amongst themselves for 10 minutes and then he lets students give their answers whilst he writes those he thinks are correct or relevant on to an overhead. He gives positive feedback and praise to the students and then finally gives a conclusion about the question.

6.3. Poster
Poster work is another useful team activity for students. It is usually an out-of-class activity for a small peer group. Such activities help students to develop a deeper understanding of what they are learning, through cooperation with one another. In addition it helps them develop design skills and presentation skills. There are other forms of teamwork like the peer group activity, e.g. by using interesting games to motivate students and generate active participation in learning and helping them to understand and consolidate what they have learned.

6.4. Use of concept mapping
Concept mapping is an activity with numerous uses in the biology classroom. Its value in planning, teaching, revision, and assessment, and the attitudes of students and teachers towards its use, are
discussed. Comments made are illustrated with excerpts from interviews with teachers and students who were involved in classroom concept mapping exercises. The use of expert maps for scoring is described, and some of the pitfalls are considered. Finally, the value of concept mapping as an aid to reflective practice is discussed.

Visual construction tools
There are various visual construction devices or 'graphic organizers' available for use in the classroom. Such tools help students to visualise how major ideas are related to their own prior knowledge, subordinate ideas, and associated ideas from other topic areas.

With specific reference to science education, the range of graphic organizers has been reviewed by Hamer et al. [66]. Each of these devices has its own strengths and weaknesses, but it is concept mapping, as developed by Novak [67], about which the research literature has been so consistently positive. This technique is explicitly grounded in David Ausubel's assimilation theory of learning, of which the central idea is that of meaningful learning (described in Novak, [68]). In this the student required to make a conscious effort to identify the key concepts in new knowledge and relate them to concepts in his/her existing knowledge structure.

Concept mapping is a highly flexible tool that can be adapted for use by almost any group of learners. The standard presentation (described in this article) can be modified to include: colour-coding of different concept types; grouping of concept types, or using variously shaped concept boxes, to guide students with special needs to an appropriate answer (e.g. Adamczyk et al. [69]); creating three-dimensional map structures as mobiles or cones to facilitate discussions or the creation of concept mapping games (e.g. Kinchin, [70]).

An example of a traditional concept map format is given in Figure 1. The concepts are written in boxes and linked by labelled arrows. The most inclusive concepts appear towards the top of the map, with more subordinate concepts towards the bottom. Where possible, these are anchored with specific examples. Whilst each concept can only appear in one place on the map, it may be linked to any number of others. The map in Figure 1 has been drawn in a way that emphasises the hierarchical nature of the ideas described.

One of the questions that students and teachers often ask is 'how many concept boxes should be included?'. There is no right answer to this, but mappers should be discouraged from using so many that it becomes unmanageable or unclear, as maps are only really useful if they portray a clear representation of the author's thoughts. I have found that maps with more than about 20 concept boxes become rather unwieldy, and might be better if they were 'pruned' or drawn as two separate maps.

In general, the research literature demonstrates reluctance to highlight any problems associated with concept mapping.

Hodson [71] notes that some students may wish to conceal some aspects of their understanding and so their maps would not provide 'total insight' to the student's perspective. In addition, it is clear from observations of changes in students' maps (even over a short period of time), that such structures are in a continual state of flux in an active learner. Therefore, a map that is to be used as the basis for further instruction has a 'limited shelf life', after which it is simply an historical record. The active use of concept maps could be applied to any of four stages of the teaching/learning process: Planning and preparation; Formative learning; Revision/summarizing; Assessment.

- **Planning and preparation**
  It has been shown that the planning of instructional sequences can be helped by the process of concept mapping to provide a coherent structure to teaching materials and making essential links explicit (e.g. Martin [72]). This may be particularly helpful in cases where 'non-specialists' (i.e. chemists or physicists) are teaching biology, as they may appreciate the support offered by a biologist colleague's map. Martin gave the following advantages to be gained by this approach to lesson preparation:
  - Increased meaning of the material for the teacher.
  - Ownership of the material by the teachers.
  - Increased concept integration.
  - Decreased likelihood of omitting key material.
  - Increased capacity to meet student needs through recognizing students perceptions of the material.
  - Increased likelihood that teachers will see multiple ways of constructing meaning.

Following from this, Martin viewed concept mapping to be a viable agent for curriculum change. This would put teachers in the position of being 'active innovators' rather than the 'passive receivers of innovation' that has been the implicit assumption of so many recent educational reforms.

- **Formative learning**
  Previous studies have suggested that the use of concept mapping in classes can help students to gain a more unified understanding of a topic, organise their knowledge for more effective problem solving, and
understand how they learn (i.e. become more metacognitively aware). It has been suggested that the promotion of meaningful learning resulting from concept mapping can act to reduce subject-based anxiety and overcome differential gender-related performance with respect to learning and achievement in science. Concept mapping can also be used as a cognitive approach to compensate when a learner exhibits a one-sided learning strategy (Huai [73]). For 'holists', who have a 'global approach', concept mapping can help the learner to focus on critical details, whereas, 'serialists' can be stimulated to take a wider perspective.

Students who gain most from concept mapping may be those identified by Silverman [74] as 'visual-spatial learners', who excel when provided with visual representations. Such students reject rote memorisation and have a need to see of the isolated ideas typically presented in lessons. This suggests that for teachers to optimise the benefits of concept mapping for their students, they first need to be familiar with their students’ current learning strategies.

In describing the value of concept mapping, Schmid and Telaro[75] have commented that: 'Biology is so difficult to learn because it consists of a myriad of unfamiliar concepts involving complex relations. The schools' favored approach to teaching unfamiliar material is rote learning. Rote learning predictably fails in the face of multilevel, complex interactions involved in biology. Concept mapping ... stresses meaningful learning, and appears to be ideally suited to address biological content.'

7. Are the learning outcomes relevant?
Learning outcomes are descriptions of what students should be able to know and do following a particular course or program. Learning outcomes are useful in that they identify a set of goals for instructors to use in their teaching. These learning outcomes provide an essential set of building blocks for the assessment of students’ performance. Most universities and professional organizations recommend that instructors identify a set of objectives for each course and assess the extent to students meet these objectives.

- Rigorously examine the learning needs of your students as future technicians, scientists, and citizens, and compose a list of learning outcomes that reflects those needs.

Students will become good decision-makers only if they have practiced weighing information and making decisions. They do not greatly benefit from simply being asked to recall information.

For example, a learning outcome claiming that students will be able to "describe" biogeochemical cycling is of less ultimate benefit to the students as future citizens than is an outcome claiming students also will be able to interpret data, forecast pollution impacts, and evaluate arguments regarding pollution risks.

A learning outcome claiming that students will be able to "discuss" or "understand" the
evidence for evolution is of less use than an outcome claiming that the students also will be able to critique arguments pertaining to evolutionary evidence and rank novel evidence or investigative designs in order of inferential power.

A course outcome claiming that the students will be able to "explain" or "describe" acid-base homeostasis incorporates a less diverse skill repertoire than an outcome claiming that the students also will be able to solve problems in acid-base physiology by applying the Henderson equation to case history information.

An outcome claiming students will be able to describe an ecological footprint is of less value than an outcome claiming that the students also will be able to evaluate the environmental impact of their personal reproductive decisions in view of the birth/death surplus in North America.

- Try ranking the course outcomes in order of importance rather than in order of subject matter. Try listing them in categories such as occupational, personal, civic, national, and global. Try classifying learning outcome utility targets as one-year, ten-year, and life-long.
- Don't underestimate the needs of non-majors. Many, after leaving college, will become involved in civic debates, in non-governmental organizations, and in politics. They can benefit from skills in information-retrieval, they can benefit from an ability to read a meta-analysis, and from a proficiency in asking incisive research questions.
- Learning outcome targets should be sufficiently flexible to maximize the individual potential of each student. A rigid curriculum may fail to cultivate unique talents, backgrounds, and interests of individual students.
- You may be surprised at how your lists of learning outcomes differ from a traditional syllabus. When you have a prioritized list of outcomes, apportion class time accordingly.
- And needless to say, test questions must actually measure these higher-level learning outcomes.
- Design classroom activities utilizing case problems that develop skills in self-directed learning, information retrieval, analytical behavior, creative and critical thinking. For example, if the students are to study cellular respiration, begin that section of the course with a captivating case of a person (or pet or wild animal) with signs of a possible metabolic pathology (e.g., phosphofructokinase deficiency) telling the students that eventually they will have to suggest a cause and possible treatment of the disorder. After some instruction in cellular respiration, have the students work in small groups to brainstorm solutions to this case. They will acquire a thorough grasp of the biology, and in addition will develop skills of disciplined analysis, reflective thinking, and problem-solving. In determining what further information they require, the students will learn to ask sagacious questions, a key skill for scientists and citizens alike.
- Involve the entire class in critically assessing a real community project, proposed project, or policy, over a period of a semester or two. This might involve the biological implications of a land-use proposal, utility upgrade, utility corridor, communicable disease control plan, community health program, climate action plan, fishery, forestry, park or wildlife management plan, drug-abuse treatment program, or whatever is available. Student groups may be assigned to investigate various aspects of the project and perhaps collect field data, and once per week the project could be discussed in class. The expectation that students will make evidence-based recommendations guarantees an authentic learning experience and creates an appetite for learning on a need-to-know basis.
- Design writing assignments that are authentic, such as constructing a web page or writing a position paper that must be sent to a politician, government department, or other organization.
- Design laboratory activities involving meaningful open-ended investigative projects that develop individual student potential and that contribute to the pre-employment resume of the student.
- Construct exams that present realistic case problems requiring students to engage in reflective thinking, problem-solving, and decision-making. This can, if necessary, be accomplished with imaginative multiple-choice questions.
- Consider the use of open-book exams, emulating the workplace, or allow students to bring to the exam a 4 x 6 inch file card that can be filled with information. This forces you to design test questions that emphasize creative thinking, analysis, interpretation,
and application of core concepts to novel data.

8. Are the teaching methods effective?

Short-term effectiveness is measured by exam results, but biology education should also confer lifelong benefits. Research shows that student achievement can be enhanced by use of (a) case examples meaningful to the learner, (b) active learning rather than passive listening (experience is always the greatest teacher), (c) concrete application of core concepts in many contexts, (d) practice and repetition, (e) feedback, and (f) emotional content.

- Teach principles of biology using case examples and assignments that are meaningful to students, e.g., human pathologies, local pollution, local industry, natural disasters, cancer, genetically modified foods, sports medicine, drug abuse, fad diets, sexually-transmitted diseases, overpopulation, climate and environmental issues, evolution political controversies, alternative medicine and health fraud, bioterrorism, influenza pandemics, or whatever is current. If there are biological concepts that cannot be presented in the context of interesting case examples, the instructor must seriously question whether or not those concepts are worth presenting.

- Emphasize generic process skills such as information-retrieval, investigation, analysis, and self-directed learning, which have many opportunities for repetition, and which have wide application beyond school. These skills are likely to be remembered and are likely to serve students well in future.

- Focus teaching on fluency with core concepts, stripped of trivial details. Less is more. Students can fill in details themselves when reading, studying, and problem-solving if they have a strong grasp of key concepts and can apply them in a variety of contexts. Avoid trivia-cluttering of key concepts to the point where the students are overwhelmed by details.

- Employ learning activities that have emotional content, such as student group-work that demands some interpersonal skills and conflict-resolution skills. Incorporation of bio-ethical issues into case problems can facilitate this.

- Develop extramural assignments that require students to interact with other people and that create emotional content and social application. For example, ask students to investigate via interviews the health history of a volunteer such as a senior citizen. A written report by the student can include an interpretive pathophysiology. Similar assignments might include critical biological analysis of a local industry, business, or utility. Students might focus on some aspect of community drinking water protection, sewage treatment, power plant impacts, milling, fishery, forestry, forest health issues, woodlot management, horticultural pathology, farm habitat protection, alternative medicine practice, etc. The opportunities are endless.

- Lecture for a maximum of 20 minutes, then employ practice -- active learning in the classroom -- small group work on an assigned problem requiring discussion and choices to be debated among the students in each group. This requires students to critique the understanding of others in the group and to explain concepts to each other (peer-tutoring), creating a stimulus-rich learning field. Liberate class time for these activities by preparing manuals and hand-outs for students, thus minimizing note-taking.

- Use dialogue and diagnostic questioning when assisting an individual student. Answer a question with a question. If a student asks "Please explain PCR to me," first ask the student "What do you think PCR means?" "What is DNA?" You may well be shocked by the answers, but you will have revealed the learning pathways required to aid the student. When teaching an individual, don't give a mini-lecture, rather employ dialogue and diagnostic questioning until you are satisfied that the student has improved.

- Allow students to learn from feedback -- provide sample tests with model answers for self-practice, provide writing assignment exemplars, and allow extra credit for revision of work critiqued by the instructor.

- Arrange intervention for students who perform poorly. They should be referred to a learning assistance center for diagnostic testing. The Whimsey Analytical Skills Inventory is a powerful predictor of success in biology.

9. Problems, challenges and possible solutions

Educational activities should reflect what real people actually do, as biologically literate citizens or employees. Little of their time is spent watching lectures, rather they are involved in application of information -- decision-making, problem-solving, investigation, policy analysis, debate, critical
thinking, creative thinking, and information-retrieval. These are the activities that should be occurring in the lecture hall, field, and laboratory. Fortuitously, they are also the kinds of activities that create an exhilarating learning environment.

All too often biology courses over-emphasize trivial and easy-to-test activities that ask students only to recall, recognize, describe, or "compare and contrast" information that has been memorized. This is no less true today with the availability of the Internet. The introductory course should incorporate a diversity of learning outcomes, and this diversity should be reflected both in classroom activities and in student assessment protocols.

Problem-based learning (PBL) is an exciting way to learn biology and is readily incorporated into large classes in a lecture hall environment. PBL engages students in solving authentic biological case problems, stimulating discussion among students and reinforcing learning. A problem-based learning environment emulates the workplace and develops self-directed learners. This is preferable to a mimetic learning environment in which students only watch, memorize, and repeat what they have been told.

Effective problem-solving requires an orderly approach. Problem-solving skills do not magically appear in students as a result of instructors simply throwing problems at them. Our students use the following heuristic: "How to make a DENT in a problem: Define, Explore, Narrow, Test."

- **Define the Problem Carefully**
  What exactly are you trying to determine? Does the problem have several components? If several, state them separately. Does everyone in the group agree with the way the problem has been framed? Ask group members to "think out loud," as that slows down their reasoning and enables people to check for errors of understanding.

- **Explore Possible Solutions**
  Brainstorm ideas that may contribute to a solution. Justify your ideas to group members. Clarify for them the biology involved. Have them paraphrase your ideas. Listen carefully to the ideas of other group members and give positive feedback. Make a list of learning issues. What do we know? What don't we know? Is this problem analogous to any past problem? What core biological concepts may apply to this problem? Assign research tasks within the group.

- **Narrow Your Choices**
  After developing a list of hypotheses, sort them, weed them, and rank them. List the type of data required to test each hypothesis. Give priority to the simplest, least costly tests. It is easier to get information on the diet of a subject than it is to do sophisticated biochemical tests.

- **Test Your Solution**
  Seek from your instructor the data that you need to test your ideas. If all your possible solutions are eliminated, begin the cycle again: define, explore, narrow, test. When you encounter data that confirm one of your hypotheses you may be asked to write a biological explanation of your solution and justify it using the available evidence.

**CONCLUSION**

Preparing students for their future requires active classrooms and labs and successful learning, shaping of their personalities that are difficult to change later. Their integration into society later greatly depends on their personal qualities and skills that are largely the product of well-organized and well-completed education, including a warm atmosphere of mutual understanding and experience during their studies.

Trying to implement this idea we have been faced with several problems: How should the world educational process be organized in this rapid development so that students can learn successfully throughout their lives? What are the psychological, pedagogical and social factors that influence successful learning? How successful learning should be assessed? These questions build the foundation of a successful society of tomorrow. These challenges have motivated us to try and find some solutions that further stimulate other research.

**References**


