<LRH>SCIENCE TEACHING

<RRH>GENERAL INSTRUCTIONAL METHODS AND STRATEGIES

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<AU>David Treagust

<AFF>Curtin University, Australia

<TF>There is a multiplicity of instructional methods and strategies used in science classes that vary from those that are primarily didactic or teacher-centered to those that are primarily student-centered or learner-centered. A major consideration in writing this chapter was to organize these methods and strategies within some coherent framework such that readers can also locate instructional methods and strategies not described and discussed in this review.

<TX>Instructional methods and strategies can be organized in terms of the amount of direct control that teachers and instructors have over their implementation. Consequently, the organizing theme for this review is the degree of teacher-centeredness compared with student-centeredness of the methods. Six general instructional methods and strategies in teaching science in schools and universities are discussed, namely, demonstrations, classroom explanations, questioning, forms of representations, group and cooperative learning, and deductive-inductive approaches such as the learning cycle. Each of these general methods has elements of both teacher-centeredness and student-centeredness, but the order of presentation in this chapter ranges from more to less

teacher-centeredness in the instruction. Strategies and teaching approaches have been omitted from this review, and it is intended that the reader can determine where omitted teaching approaches fit in the framework. Gabel (2003) has reported a similar range of effective strategies for learning science.

Four considerations over the past two decades have had a major influence on the type of instructional methods and strategies used in science classes, and these underpin the methods reviewed. The first consideration is the acknowledgment that learners construct their own individual understanding and that this can be promoted by specially designed instruction (Anderson & Helms, 2001; Duit & Treagust, 1998). Within this consideration, learners intentionally construct their own knowledge, using their existing knowledge, and thereby are able to view the world in ways that are coherent and useful to them (Sinatra & Pintrich, 2003). The second consideration is that the content of the science to be learned is acknowledged as a problematic issue. Few researchers who investigate students' learning of science comment on the problematic character of the science content itself. Rather, the accepted focus of several decades of cognitive pedagogical research has been to provide suggestions for improving the teaching and learning of particular science topics (see, for example, Fensham, 2001; Fensham, Gunstone, & White, 1994).

The third consideration that pervades the instructional methods discussed is the promise that teaching strategies and approaches aimed at enhancing student metacognition might lead to corresponding improvements in conceptual understanding of curricula (Gunstone, 1994; Hennessey, 2003). According to Baird & White (1996, p. 194), "metacognitive strategies are employed by a person in a process of purposeful enquiry and . . . comprise reflection (to determine purpose) and action (to generate information).” Consequently, there is much “promise that interventions aimed at enhancing student metacognition might lead to corresponding improvements in conceptual understanding of curricula content.” Strategies such as the use of concept maps (Novak, 1996), predict-observe-explain tasks (White & Gunstone, 1992), personal logs, reflections, portfolios, and discussion have been shown to be of value in the development of metacognitive capabilities. The fourth consideration is the realization that many teachers have utilized many of the methods described here in a form of action research as they examine, implement, and evaluate these methods (see, for example, Hodson & Bencze, 1998).

Each section starts with the key theoretical and empirical issues of learning identified in the literature that underpin each type of instructional approach. This is then followed by some examples of research to illustrate the effectiveness or otherwise of each instructional approach. This short review of general instructional methods and the usefulness of these strategies discusses existing research and is intended to help readers to re-evaluate the status of these methods and strategies in science education, to ask new questions, and to spark further improvement in some new directions in research and practice related to general instructional methods and practices.

<1>Demonstrations

<TF>For over a century, laboratory work has been used in teaching and learning school science. With the popularity of the constructivist-informed teaching approaches since the 1980s, teachers have emphasized the role of hands-on experiences in learning science (Hofstein & Lunetta, 2004). In this chapter, the focus is on demonstrations in teaching

science, which are a less expensive or a safer way of providing students with experiences of laboratory experiments. Drawing on an extensive literature review of laboratory work, White (1996) argued that this ubiquitous practice of teaching school science for more than a century did not appear to directly improve understanding of science because "imaginative practices are rare and mindless routine common in school laboratories" (p. 771). Details about the laboratory in science teaching are found in Chapter 16 and are not repeated here. Although the use of demonstrations in teaching science does not serve all of the main goals of laboratory work highlighted by Lazarowitz and Tamir (1994), such as skills, concepts, cognitive abilities, understanding the nature of science, and attitudes, it does serve to motivate students in the science classroom (White, 1996).

<2>Demonstrations for Motivation

<TF>Laboratory demonstrations in the teaching of science can provide colorful, surprising, or dramatic effects—such as burning a piece of magnesium ribbon before a junior class of science—which motivate students but do not necessarily help them develop an understanding of the particular concept being demonstrated. Roth, McRobbie, Lucas, and Boutonne (1997) have shown that there are good reasons why students may fail to learn from demonstrations about motion, namely because students who come to the practical classes with their own ideas about motion do not observe the phenomena they studied as expected by their teacher. Similarly, the teacher expected the instructions to be self-evident but did not realize that their students did not share his theoretical perspective. Consequently, for demonstrations to be effective, research has shown the central importance of the instructor as a mediator of student learning and an interpreter of the content of science (Watson, 2000).

<TX>Demonstrations that create interest have the potential to engender learning by combining demonstrations with teachers' classroom explanations (Ogborn, Kress, Martin, & McGillicuddy, 1996). Ogborn et al. produced an interesting and thought-provoking analysis of how science teachers can utilize demonstrations in the classroom to explain science and thereby improve the level of understanding of the science concept introduced by the demonstration. Their work is discussed more fully in the section on Explanations.

<2>Demonstrations to Increase Student Cognitive Involvement

<TF>To make demonstrations more student-centered, teachers may consider using Predict-Observe-Explain (POE) activities described by Champagne, Gunstone, and Klopfer (1985); White and Gunstone (1992); and Gunstone (1995). POE activities can be a very useful way to juxtapose demonstrations with explanations. In a POE activity, students are first asked to predict what would happen next in a demonstration. Subsequently, they have to observe the demonstrations carefully and finally to explain what they have observed. The teacher can have a follow-up group or whole-class discussion with the students to discuss their observations and explanations. One example of effective use of POEs in teaching science is Palmer's (1995) study in primary schools in which the POE technique was used by teachers to identify students' knowledge and to understand their science conceptions and their process skills development. As another example, Liew and Treagust's (1995) studied the use of POEs for the topic of heat and expansion of liquids with grade 11 physics students. Students' learning was evident in their observations and interpretations; frequently their prior beliefs, knowledge, and

expectations influenced their observations, which both positively and negatively affected their new learning.

<2>Demonstrations Enhanced by Computer Software

<TF>The use of technology in science education has been extensively discussed by Linn (2003), although her review did not directly mention demonstrations. However, three of Linn’s discussion points were science visualization, science simulations, and modeling, each of which can be relevant to demonstrations. Indeed, computer technologies allow more interactive POE activities to be used in instruction to engender student understanding. As an example of these activities, Kearney, Treagust, Yeo, and Zaknik (2002) incorporated POE tasks into a multimedia computer program that used real-life digital video clips of difficult, expensive, time-consuming, or dangerous scenarios as stimuli for these tasks. Projectile motion phenomena in physics were used in designing the POE tasks in the study. The findings indicated that multimedia-supported POE tasks had a noticeable impact on the 10th- and 11th-grade classroom environment in allowing students to control the pace of their learning, to confidently discuss their learning while manipulating and observing the demonstrations.

<TX>In another study, science teachers used POE activities from an interactive computer program BioLogica (Concord Consortium, 2001) in 10th-grade classrooms to foster a deeper understanding of genetics reasoning (Tsui & Treagust, 2003). In the computer activities, students were given tasks that involved the prediction of the observable changes when they manipulated the objects in the multimedia. The findings suggested that the multiple representations of genetics in BioLogica with embedded POE tasks might have contributed to students’ development of genetics reasoning by way of

engendering motivation and interest. Furthermore, such POE tasks embedded in computer multimedia are likely to foster classroom social interactions conducive to co-construction of knowledge. This latter concern was evident in Kozma’s (2000) study on students learning chemistry with computer multimedia; the findings suggested that the new symbol systems per se were not sufficient to aid learning and that “these new symbolic systems and their symbolic expressions may best be used within rich social contexts that prompt students to interact with each other and with multiple symbol systems to create meaning for scientific phenomena” (p. 45).

The general findings from these studies indicated that demonstrations in the form of POE tasks delivered through interactive computer multimedia can provide new learning opportunities for students in science education and have implications for authentic technology-mediated learning in science classrooms. When students became more motivated and more engaged, they were more likely to develop a better understanding of the content of science because they can play an active or intentional role in the process of learning (Bereiter & Scardamalia, 1989).

<1>Classroom Explanations

<TF>In order to contribute to students’ ability to make sense of the world, science teachers’ descriptions and explanations of scientific phenomena are critically important activities in classroom teaching (Horwood, 1988). Accordingly, description is intended to provide pieces of information, not necessarily related, but explanation is intended to connect between and among pieces of information. Treagust and Harrison (1999) highlighted the importance of teachers’ effective explanations in the classroom and how the expert teachers “draw creative word pictures that both appeal to and inform a diverse

group like a class of students” (p. 28). As such, how to verbally explain science concepts to students and teach them how to verbalize their understanding is important. As Johnson-Laird (1983) put it, “if you do not understand something, you cannot explain it” (p. 2).

<TX>In science teachers’ classroom explanations, it is very common to employ deductive and inductive strategies in an interactive way. Usually verbal or written language is used together with gestures, and sometimes the explanations may also use some actional-operational strategies, such as physical models or demonstrations (Gilbert, Boulter, & Elmer, 2000). Researchers have identified the use of language in classroom explanations as having paramount centrality for understanding science (see, for example, Yore, Bisanz, & Hand, 2003; Sutton, 1992). Furthermore, the work of Ogborn et al. represents a marriage of frameworks from the more traditional science education and those from language and communication, particularly semiotics. Ogborn et al. considered classroom explanations of science as analogous to stories and summarized four roles of language used in meaning-making during explanation of science in the classroom: (1) creating differences—the teacher explains science by making use of the differences between herself and her students (e.g., knowledge, interest, power, familiarity of the content, etc.); (2) constructing entities—the teacher explains by using some created entities or “new chunks of meanings” (e.g., *energy*, *heat*, or *gene*) (p. 14) about which students are to think when the teacher “talk[s] [them] into existence” (p. 14); (3) transforming knowledge—the teacher explains the constructed entities by using narratives, particularly analogies and metaphors (e.g., an eye as a camera or the pituitary gland as the conductor of the hormonal system) (see Sutton, 1992); and (4) putting

meaning into matter—the teacher explains by demonstration and persuades students that things are as they are shown or by imposing meaning into the things (e.g., tissue is to be seen as cells).

The first two roles are mainly deductive strategies in which the teachers communicate to the students the concepts of science and some necessary contexts as motivators or advance organizers. The third and fourth roles engage the students in the use of inductive and deductive reasoning in an interactive way while the teacher emphasizes the explanation to engender student understanding of the particular concept.

Ogborn et al.'s work on classroom explanations is in line with recent interests of science educators in the use of language (e.g., Halliday & Martin, 1993; Lemke, 1990; Yore et al., 2004) and more discursive practices (e.g., Bell, 2000) in classroom instruction. Their work is also in keeping with another recent interest in Vygotskian perspectives among science educators such as Hodson and Hodson (1998) and Howe (1996), who argued for using a Vygotskian sociocultural perspective in the teaching and learning of science.

<1>Questioning

<TF>Discursive and sociocultural practices in the science classroom are relevant to instructional practices such as wait time (Rowe, 1974), dialogue patterns (Lemke, 1990), and checking student understanding in classroom discourse (Mortimer & Scott, 2000).

<TX>First, research has indicated that questioning during classroom teaching is often unproductive without wait time for students to think before answering. On the basis of an extensive review of the literature, Tobin, Tippins, and Gallard (1994) concluded that wait time (Rowe, 1974) appears to be an important factor in instruction when

teachers pursue higher-cognitive-level learning in their students. Appropriate wait time during questioning affects higher-cognitive-level achievement directly by providing additional time for student cognitive processing and indirectly affecting the quality of discursive teacher-student interactions.

Second, teacher and student discourse in the classroom is affected by the way that teachers use questioning. For better meaning-making, more useful questioning has to go beyond the triadic dialogue in which the teacher asks questions, calls on students to answer them, and then evaluates their answers. In analyzing such discourse, Lemke (1990) suggested dialogues other than the triadic dialogue, such as student-questioning dialogue—a pattern in which students initiate questions on the content of the lesson and the teacher answers them; the teacher-student duolog—a prolonged series of exchanges between the teacher and one student in triadic dialogue or student-questioning dialogue; teacher-student debate—a prolonged series of exchanges in which students challenge or disagree with the teacher on the content of the lesson; true dialogue—a pattern in which the teacher and the student(s) ask and answer one another's questions and respond to one another's amendments as in normal conversation; and cross-discussion—a pattern in which students speak directly to one another about the subject matter and the teacher acts as a moderator or an equal participant without special speaking rights.

Third, to ask questions on higher-level thinking has been shown to be significant in improving the quality of classroom discourse. For example, Mortimer and Scott (2000) used the flow of discourse framework to analyze classroom talk. The framework is based on Vygotskian and neo-Vygotskian perspectives (Vygotsky, 1978; Wertsch, 1991) that classroom talk can mediate the development of meaning and understandings between teachers and students and student learning of science concepts. The importance of such analysis is that a teacher’s ability to manage classroom discourse can support students’ development of knowledge and meaning-making. Mortimer and Scott expanded upon the triadic dialogic pattern to a form of teacher intervention as he or she regulates and guides the classroom discourse. One form of a teacher’s intervention is to support student meaning-making by asking questions to check student understanding in three ways: to ask for clarification of student ideas, to check individual understanding, and to check consensus in the class about certain ideas. As the authors argued, teacher intervention in the classroom discourse is one aspect of teacher knowledge that is often overlooked in the analysis of teaching practice.

Overall, as a general instructional strategy, questioning in classroom teaching and learning plays a very important role in determining the quality of discourse and the ways in which students learn and understand science. However, the type of questions being asked is what is important to engendering improved student learning outcomes in science (Koufetta-Menicou & Scaife, 2000).

<1>Forms of Representations

<TF>Many scientific phenomena, such as those studied in cosmology, geology, chemistry, or biology, are beyond the learner’s temporal, perceptual, and experiential limits (Kozma, 2000). Consequently, our understanding of these phenomena depends on “our ability to access and interact with them indirectly” (p. 12). This is an important issue in effective instruction and is dependent on the teacher’s expertise in representing his or her scientific knowledge in ways appropriate to the content and the way that content should be presented to a particular of group of learners. Essentially this is the notion of

pedagogical content knowledge (PCK) that Shulman (1987) has argued “represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners and presented for instruction” (p. 8). A teacher’s pedagogical content knowledge includes models, analogies, equations, graphs, diagrams, pictures, and simulations that can help the learner understand an idea. These representations may be exhibited in a variety of forms/modes such as verbal, mathematical, visual, and actional-operational. Different types of representations are used to enhance conceptual understanding, and a considerable amount of research has been conducted to investigate the effect of a single representation on learning.

<TX>Gilbert, Boulter, and Elmer (2000) considered a model in science as “a representation of a phenomenon initially produced for a specific purpose” (p. 11). From the perspectives of modeling and models in science education, Gilbert et al. delineated nine different models used in science education: a mental model, an expressed model, a consensus model, a scientific model, a historical model, a curricular model, a teaching model, a hybrid model, and a model of pedagogy. Through interactions, an expressed model is placed in the public domain by individuals or groups. According to Gilbert et al., one or more of the following six modes of representations are significant in expressed models: (1) concrete models consisting of the use of materials (e.g., a wooden model of a car); (2) verbal mode consisting of the use of metaphors and analogies in speech (e.g., a textbook descriptions); (3) mathematical mode consisting of mathematical expressions (e.g., universal gas equation); (4) visual mode consisting of graphs, pictures, and diagrams; (5) symbolic model consisting of visual, verbal and mathematical modes; and

(6) gestural mode consisting of actions (e.g., hand movements). Each of these modes has direct application to teaching strategies, and several are discussed in more detail in this section.

<1>Analogies and Metaphors

<TF>Representations include analogies and their allies, particularly metaphors. According to Glynn (1991), an analogy is a process for identifying similarities between different concepts; the familiar concept is called the analog and the unfamiliar one the target. The famous seventeenth-century astronomer Johannes Kepler (cited in Polya, 1954) once wrote: “And I cherish more than anything else the Analogies, my most trustworthy masters. They know all the secrets of Nature, and they ought to be least neglected in Geometry” (p. 12). Given the historical importance of analogical reasoning in scientific discovery, insights, and explanations, analogies have been used by textbook authors and classroom teachers to explain science concepts to students. Furthermore, learning science is the reconstruction of the products of modeling (Justi & Gilbert, 2002), and analogies are at the heart of modeling.

<TX>Teachers’ use of analogies, in one or several forms of representation, has been an important line of research into teaching and learning of abstract science concepts, and reasoning and problem solving, and for conceptual change (Dagher, 1995). Analogies and metaphors have been used in science education as instructional strategies to engender interest, motivation, and understanding (Harrison & Treagust, 1994; Martins & Ogborn, 1997; Venville &Treagust, 1996). Since the time before computers were used in the classroom, science teachers have been using a range of different representational techniques to present information to students, such as verbal and written language,

graphics and pictures, practical demonstrations, abstract mathematical models, and semi-abstract simulations (van Someren, Boshuizen, de Jong, & Reimann, 1998).

Research has shown that analogical teaching approaches can enhance student learning. For example, the findings of the study by Treagust, Harrison, Venville, and Dagher's (1996) indicated that a teacher's use of a cart with wheels moving obliquely over different surfaces as an analogy for refraction of light in a 10th-grade physics class successfully engendered conceptual change in student learning about the refraction of light. Martins and Ogborn explored how primary school teachers used metaphors to think about scientific ideas of DNA and genetics. The results of the study indicated that these primary school teachers creatively and imaginatively assimilated and constructed metaphorical models, drawings, and analogies to understand the scientific ideas of DNA and genetics. Metaphors and analogies thus connected their everyday knowledge to scientific ideas. In another example, a cross-age study involved secondary school, undergraduate, and postgraduate students' use of analogy and anthropomorphism along with their alternative conceptions of mental models of chemical bonding (Coll & Treagust, 2002). Findings indicated that learners made use of analogy and anthropomorphism to aid their explanations of chemical bonding. Coll and Treagust suggested that teachers need not only to encourage learners to use analogy but also to carefully examine curriculum and to postpone instruction of complex models to a later stage in the students' program of study. However, when analogies were used for chemistry problem-solving in a college preparatory chemistry course, Friedel, Gabel, & Samuel (1990) showed that the use of analogies was not an appropriate teaching strategy when the teachers did not determine whether the analog was meaningful to the students or when the instructional time was too short.

In brief, despite the fact that analogies appear to be useful as strategies in teaching and learning of abstract concepts, they are “double-edged swords” (Glynn, 1991, p. 227) which, when not used cautiously, may lead to miscomprehension and misdirection. Two further problems with analogies presented in textbooks and used by classroom teachers are when teachers use analogies as mechanical clichés, that is, when they are used without thought about their meanings, and when inconsistencies between the analog and the target result in students being unable to map the shared attributes and delineate the limitations of analogies. To address these problems, Treagust, Harrison, and Venville (1998) developed a teaching model called FAR—referring to Focus, Action, and Reflection—whereby teachers overtly direct students’ attention to the similarities and dissimilarities of the analog and target concept. This teaching model was developed in cooperation with science teachers based on an earlier analysis of exemplary analogies in textbooks (Glynn, 1991).

<1>From Multiple Analogies to Multiple Representations

<TF>In view of the problems in using analogies as part of instruction, Glynn (1991) suggested using several analogies (for a single concept), which can allow students to examine the concept from more than one perspective. Each perspective (analogy) brings particular features of the concept into a clearer focus; thus students will have a more comprehensive understanding of that concept and its relationship to other concepts.

<TX>Along this line of thinking, Harrison and Treagust (2000) reported a year-long study of the role of multiple models in student learning about atoms, molecules, and

chemical bonds in an 11th-grade chemistry class. The outcomes suggested that students who socially negotiated the shared and unshared attributes of common analogical models for atoms, molecules, and chemical bonds used these models more consistently in their explanation. As well, students who were encouraged to use multiple particle models displayed more scientific understandings of particles and more interactions than did students who concentrated on a single model. Harrison and Treagust proposed, among other pedagogical recommendations, that multiple models should be introduced at an early stage and consistently developed and invoked during learning discussions. In view of the weakness in the ways models were represented in this study, the authors suggested that further research be done to find out what influence the representational form of analogical models has on the effectiveness of model-based learning.

Recently, new perspectives on computer-based multiple representations used in instruction (Ainsworth, 1999) have provided a more robust framework for interpreting analogical models and their relatives such as metaphors, which have been in use for centuries as vehicles for reasoning. According to Ainsworth’s (1999) conceptual analysis of existing computer-based multirepresentational learning environments (Ainsworth, Bibby, & Wood, 1997; Hennessy et al., 1995), there are three major functions that multiple external representations (MERs) serve in learning situations—to complement, to constrain, and to construct. The first function of MERs in Ainsworth’s (1999) functional taxonomy is to use representations that provide complementary information or support complementary cognitive processes so that learners can reap the benefits of the combined advantages, such as using both diagrams and verbal-textual representations. The second function is to use a familiar representation to constrain the interpretation (or misinterpretation) of a less familiar representation so as to help learners develop a better understanding of the domain. The third function of MERs is to encourage learners to construct a deeper understanding of a phenomenon through abstraction of, extension from, and relations between the representations. Ainsworth's functional taxonomy of MERs has been based largely on research in mathematics (see, for example, Ainsworth et al., 1997; Larkin & Simon, 1987) and physics (see, for example, Hennessy et al., 1995). The notion of multiple representations has also been used to improve learning in other domains such as chemistry (see, for example, Kozma, 2000) and medicine (see, for example, Boshuizen & van de Wiel, 1998).

In school learning, multiple representations provide new opportunities to engender student motivation, interest, and understanding. In a recent study on the motivational aspects of learning genetics (Tsui & Treagust, 2004), a science teacher used an interactive computer program called BioLogica alongside other teaching strategies and resources to teach genetics in a 10th-grade biology class. Findings showed that MERs in the computer program intrinsically motivated the 10th-grade students in their learning of genetics, which is a linguistically and conceptually difficult topic in biology. The salient features of the MERs of the computer program identified in this study included instant feedback, flexibility, and visualization. Students' motivation was interpreted as curiosity, control, fantasy, and challenge, which were similar to Malone and Lepper's (1987) taxonomy of intrinsic motivations. The finding of this study also indicated that most students improved their genetics reasoning after instruction, indicating that computer-based MERs hold promise in providing new opportunities for learning abstract concepts in science.

<1>Levels of Representation

<TF>One major difficulty for learning science at school is that scientific knowledge can be represented at a number of levels, some of which are not observable to the learners. Scientists must be able to represent knowledge in order to conduct research, and teachers must do so in order to teach students. Perhaps this is most important in the field of chemistry, which is difficult to learn because many concepts are abstract and are unfamiliar to students, whose personally constructed representations are often in conflict with scientifically accepted explanations (Treagust & Chittleborough, 2001). Learning of chemistry is a matter of learning about its representation at different levels, which can describe (descriptive and functional), represent (representational), and explain (molecular) chemical phenomena (Johnstone 1993).

<TX>Teachers do need to be cognizant of the three levels of representation and their meaning as follows: symbolic—comprising a large variety of pictorial representations, algebraic and computational forms; microsocopic—comprising the particulate level, which can be used to describe the movement of electrons, molecules, particles, or atoms; and macroscopic—comprising references to students' everyday experiences. According to Johnstone (1991), most teachers used the triangle of multilevel thought in their teaching without being aware of the demands being made on the students. In Johnstone's triangle of multilevel thought, knowledge of chemistry can generally be organized as three ideas of structure, bonding, and energy. Johnstone argued against teachers using all three levels in their teaching. To make learning easier, teachers should teach chemistry only at the macro level or at most at two levels. Johnstone also extended this triangle of multilevel thought to the teaching of physics and biology. In physics there

are also three similar levels of representations: the macro (visible moving bodies), the invisible (e.g., forces, reactions, electrons), and the symbolic (mathematics, formulas). The pedagogical implications of Johnstone's notion of multilevel thought are that teachers cannot simultaneously present the three levels of representations in teaching difficult science concepts. Otherwise, students would become overloaded with information and be unable to see the connections between the levels.

In biology, too, there are three levels: the macro (plants or animals), the micro (cells), and the biochemical (DNA, etc.). Marbach-Ad and Stavy (2000) articulated Johnstone's triangle of multilevel thought to explain why genetics in biology is so difficult to teach and learn because it is difficult to understand meiosis (micro level) and the connection between meiosis and Mendelian genetics (macro level).

<1>Group Learning and Cooperative Learning

<TF>As reviewed by Lazarowitz and Hertz-Lazarowitz (1998), the use of group learning in science education has been rather recent, but the learning outcomes are very promising. For science teachers, Stahl's (1996) handbook provides a comprehensive selection of highly effective and widely used cooperative learning strategies that science teachers can use in the primary and secondary science classrooms.

<TX>To encourage students to construct meaningful knowledge networks, science teachers need to provide opportunities to engage the students in motivating and interactive activities and cooperative learning activities (Treagust & Chittleborough, 2001). A review of the literature on cooperative learning indicates that most of the studies are on biology learning, and the major learning outcomes focused generally on the cognitive domain rather than on the affective domain (Lazarowitz & Hertz-Lazarowitz,

1998). Accordingly, five cooperative methods of instructions have been used in science education:<NL>

(1) Learning together (Johnson & Johnson, 1975) involves students in heterogeneous groups of four or five working together to achieve some common goal in such a way as to develop both personal and group skill.

(2) The jigsaw method (Aronson, Stephan, Blaney, & Snapp, 1978). In this method, the class is divided into jigsaw groups of five (students a to e), with each student assigned a special part of a group task, and an expert group with members from those with the same part. The expert group members, after mastering their skills, return to the jigsaw group to tutor their teammates to achieve the goal.

(3 and 4) Student Teams and Achievement Division (STAD) (Slavin, 1978) and Teams Games Tournaments (TGT) (De Vries & Slavin, 1978). These are the same in involving five common components: class presentation, by the teacher followed by discussion, teams working on teacher-prepared worksheets, quizzes (STAD), or game/tournament (TGT);

(5) Peer Tutoring in Small Investigative Group (PTSIG) (Lazarowitz & Karsenty, 1990). PTSIG involves four basic features of investigation, interaction, interpretation, and intrinsic motivations combined into six stages of the model.

<TX>According to Lazarowitz and Hertz-Lazarowitz's (1998) review, previous research has shown positive results of cooperative learning in different subject areas across different academic levels in the cognitive, affective, and social domains of learning. At the primary school level, the positive learning outcomes included increased students' academic achievement, helping behavior, and peer support. At the high school

level, both junior and senior students improved their learning, as demonstrated by higher cognitive achievement, more positive attitudes, greater self-esteem, more engagement on tasks, and increased motivation and enjoyment. Fraser (1998) also reported that cooperative learning promoted a positive learning environment. Similar positive learning outcomes were reported at the college level when the studies included cognitive preferences, concept learning, and gender differences.

Although cooperative learning appears to be a promising strategy for the cognitive, social, and affective development of student learning at school, teachers and researchers have to develop relevant, rich, and challenging curricula. There are several challenges of using group and cooperative strategies in supporting student learning. First, such strategies should be able to address student learning along multiple dimensions of the cognitive, affective, and social domains of learning. Second, science teachers using group and cooperative methods to address classroom learning issues have to be cognizant of any sociocultural peer effects due to ability, gender, and cultural differences (see, for example, Forman & Cazden, 1985). Third, cooperative learning involves interaction with peers in communities of learners and with computer data bases in a distributed fashion (see, for example, Brown et al., 1993; Windschitl, 1998). These challenges should be incorporated into the teacher education programs to allow pre-service teachers and in-service teachers to develop their knowledge of group and cooperative learning strategies used in their teaching.

<1>Inductive and Deductive Reasoning—The Learning Cycle Approach

<TF>The traditional textbook approach to science learning provides information and challenges students to think deductively by reasoning from cause to effect. However, this

reasoning contrasts with the way that many scientists, such as geneticists, inductively reason and learn in their research work from effect to cause. Indeed, this approach is consistent with most science teaching approaches using laboratory experiments that implicitly assume that students learn by inductive reasoning. However, as previously stated, whether laboratory work will necessarily improve student learning is a contentious issue (White, 1996), and the challenge of inductive reasoning could be what makes laboratory tasks difficult for students.

<TX>The learning cycle approach has survived into the present time as an important instructional strategy (see, for example, the review by Abraham, 1998). According to Lawson, Abraham, and Renner (1989), the learning cycle originated from the work of Robert Karplus in the Science Curriculum Improvement Study (SCIS) program for U.S. elementary and junior high schools in the late 1950s and 1960s, and in Chester Lawson’s work in biology education in U.S. high schools and universities during the same period. It was from Lawson’s project that the famous Biological Science Curriculum Study (BSCS) project had developed during the post-Sputnik reforms in science education.

Originally known as *exploration-invention-discovery* (Karplus & Their, 1967), the inquiry-based learning cycle approach consists of three phases. First, the *exploration* phase provides students with the experience of the concept to be developed, such as the use of laboratory experiments, which involves deductive thought. Then, in the *conceptual invention* phase, the students and/or teacher develop the concept from the data through classroom discussion, which involves inductive thinking. Finally, in the conceptual expansion phase, the student is given the opportunity to explore the usefulness and application of the concept.

The three phases in its latest version, according to Abraham (1998), are simply “inform-verify-practice” or (I →V→P). The three phases in sequence are *identification* of a concept, *demonstration* of the concept, and *application* of the concept. The common justification of using the learning-cycle approach is based on the Piagetian notions of learning new concepts through assimilation and disequilibration in the first phase, accommodation in the second phase, and conceptual expansion in the third phase. “The three distinct phases with a definite sequence and structure are necessary for the development of conceptual understanding” (Tobin et al., 1994). Through this three-phase sequencing of hands-on laboratory experiences to engender knowledge construction, the learning-cycle approach can address the concern that laboratory work is unable to improve conceptual understanding.

Two well-documented case studies using the learning-cycle approach are the studies of Renner, Abraham, and Birnie (1985) and Abraham and Renner (1986). Renner et al.’s study—conducted in three 12th-grade physics classes in a U.S. secondary school using all or some of the phases of the learning-cycle approach—highlighted the necessity of all the three phases and the importance of their sequence in concept development of physics. The content of the student investigation in Renner et al.’s study included linear motion, heat measurement in solids, static electricity, and current and magnetism. In the second case-study example, Abraham and Renner (1986) investigated different learning cycles in six classes in senior secondary school chemistry and indicated that the normal learning cycle sequence, gathering data→ invention→ expansion, is the optimum sequence for achievement of content knowledge of chemical concepts associated with heat laws. Since the 1980s, many studies on the learning-cycle approach have been conducted in different domains and at different school and university levels (e.g., Jackman, 1990; Lavoie, 1999; Lawson, 2001; Libby, 1995; Marek, 2000; Odum & Kelly, 2001). Research on the learning-cycle approach has confirmed that this is an effective instructional strategy with many advantages over more traditional approaches in terms of student attitudes, motivation, process learning, and concept learning. Science teachers should make use of instructional materials with key characteristics of the learning-cycle approach (Abraham, 1998).

There are two trends in instructional strategies using the learning-cycle approach that are worth a more detailed discussion here. First, there has been an increase in the use of ICT in teaching with the learning-cycle approach (e.g., Dwyer & Lopez, 2001; Gibson, 2001; Marek, 2000). Dwyer and Lopez’s study involved Australian students using the simulation software Exploring the Nardoo in all phases of the learning cycle. In this study upper elementary and middle school science students were observed, along with their teacher, using simulations as they engaged in learning-cycle lessons revolving around river ecosystems. Students were asked to address complex water management issues affecting the fictional Nardoo River and improve the environment. The simulation is intended to develope students’ investigation and problem-solving skills. Findings indicated that with specific guidance in simulations, students performed better and that simulations could be used again to apply newly learned concepts in different contexts in the expansion phase of the learning cycle. Second, the learning cycle continues to be used in instructional practices at the university level (Ana G. Mendez Educational Foundation, 1987; Farrell, Moog, & Spencer, 1999; Jackman, 1990).

The most important conclusion based on research is that the inquiry-based, laboratory-based learning-cycle approach has provided students with not only hands-on experiences to learn the concepts but also the opportunity for knowledge construction from their personal experience and for application to new situations (Abraham, 1998). Nevertheless, the learning-cycle approach has its limitations, particularly when it is applied to the ICT-rich learning environment. Based largely on Piagetian psychology, the learning-cycle approach focuses on individual learning more than group learning and more on personal construction than social construction of knowledge. Although discursive practices are expected in the second phase or exploration phase, the focus is more on personal construction of knowledge developed from the data or observations in the experiments.

<1>Summary

<TF>As is apparent from this brief review, there is a wide variety of instructional methods and strategies used in the teaching and learning of science that range from those that are more teacher-centered to those that are more student-centered. Each of the six methods and strategies has a growing body of theory to support each instructional approach, and enough research has been conducted with each of these different methods and strategies to have some confidence in their effectiveness in enhancing the learning, and opportunities for learning, of students from elementary school to university. None of the approaches by themselves should be seen as a panacea that will improve science

learningl but each method or strategy can be part of a successful science teacher's instructional repertoire.

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