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Teaching Biology to Prospective Elementary School Teachers So as to Promote Transition from Receiver to Giver of Information

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Introduction

Advanced knowledge acquisition differs in important ways from introductory learning. Advanced knowledge acquisition refers to learning a content area beyond the introductory stage but before extensive experience and practice (Spiro, Coulson, Feltovich, and Anderson, 1988; Spiro & Nix, 1990; Jacobson & Spiro, 1995). At this stage, knowledge must be reasonably correct and active rather than inert. The goals of learning shift from *knowledge reproduction* to *knowledge use*. The theory was initially developed to describe the instructional needs of advanced medical students. It applies equally well to advanced undergraduates who are nearing completion of their professional program. In both cases, students need to attain a deeper understanding of content material, a sense of mastery over it, an ability to reason with it, and the fluency to apply it flexibly in diverse contents.

Prospective elementary school teachers (Liberal Studies majors) in their senior year of college are advanced learners. Assuming that they gain admittance to a credential program, they are just one year away from being certified as practicing teachers. These students have spent their lives assimilating information, often quite passively, yet they are about to be thrust into a situation where they are expected to be the expert, the giver of information, the organizer of ideas, the interpreter of events, the guide to understanding. As a group they seem to be located near the passive end of the passive - active learning continuum and to be less prepared than most students to assume the mantle of authority.

In spite of the fact that these college seniors have spent 18-25 years engaged in formal learning, they have rarely had any formal instruction in *how to learn*. They have also rarely been encouraged to examine or reflect on what they are doing or how they are doing it. Promoting development of these skills can help learners progress along the transition from receiver to giver of information, from passive to active user of information. Prompting active learning habits and cognitive flexibility in these students is particularly challenging and requires multiple instructional strategies as described below. The biology course we describe aims to help students develop confidence in their knowledge, become skilled at applying knowledge in diverse ways, and become fluent in constructing their own representations of ideas. In short, the course aims to promote cognitive flexibility, independent learning, and personal responsibility for learning in students who initially tend to resist and be confused by such efforts.

Strategies for Stimulating Cognitive Flexibility

Our focus is helping to create a new cadre of teachers. Below we describe the primary instructional strategies by which we aim to achieve our goals.

1. Stimulate curiosity and elicit prior knowledge.

Prospective elementary students are often fearful of and hostile toward science. We attempt to draw them in, make science interesting to them, and arouse their curiosity by using everyday phenomena to illustrate ideas and serve as bases for discussion. Students perform carefully selected experiments and are encouraged to reason about outcomes, especially those that fail to match their expectations. In this way, students gradually assume ownership of ideas being discussed, while at the same time the instructor becomes informed about both prevalent misunderstandings and useful prior knowledge upon which new learning can build.

2. Prompt students to build runnable mental models through prediction & interpretation.

Making a prediction requires running a mental simulation of an experiment or building a mental model (situation model) of some phenomenon (Kintsch, 1984; Scardemalia, Bereiter, McLean, Swallow, & Woodruff, 1989; Brown, Collins and Duguid, 1989). If the outcome is contrary to prediction, there is need for reworking the mental model, making revisions and running it again. Predicting outcomes induces learners to connect ideas together into functional schema. Students also become more committed to the experiment and more interested in its outcome. Performing the experiment and observing results then becomes, in part, an exercise in debugging their mental model. When outcomes differ from predictions, students tend to assume they did something wrong (they maintain their mental model and attribute unexpected results to failure to conduct the experiment correctly). To overcome this phenomenon, comparison of results with predictions and interpretation of outcomes involves a) informal discussions among peers, b) input from instructor, c) examination of outcomes obtained by each group, and d) class discussions. The multiple data sources and associated discussions provide impetus and support for students to revise their mental models.

3. Promote conceptual change.

Conceptual change and learning increases as the quality of cognitive engagement increases (Hannafin & Hooper, 1993). Cognitive engagement refers to "...the intentional and purposeful processing of lesson content" (Hannafin, 1989). Engagement requires strategies that promote manipulation of information rather than memorization. Engagement can be induced through cognitive dissonance, posing argumentative questions, requiring the development of a supportable position, and asking learners to generate predictions. Three key strategies for promoting conceptual change are described below.

3a) Belief competition.

Some demonstration tasks and activities are designed to disconfirm common alternative conceptions. The goal is to produce cognitive disequilibrium and challenge students in such a way that they replace their non-scientific ideas with scientific ones. For example, a prevalent alternative conception is that, when water boils, the bubbles are composed of hydrogen and oxygen. One disconfirming activity is to collect and condense the water vapor, obtaining nearly the same volume of water as was lost during boiling. This can contribute to but is often not sufficient to achieve the desired belief substitution - multiple activities are required.

3b) Knowledge elaboration.

Other demonstration tasks and activities are designed to extend scientifically acceptable ideas held by students. For example, raisins are added to carrots and celery in a diffusion lab. The veggies become crisp in fresh water and limp in saturated salt water, while raisins absorb water in both situations. In order to explain these contrasting observations, students must add a level of sophistication to their mental models of diffusion.

3c) Ill-structured cases.

At each class session, several students give reports about biology topics in the news. This activity serves several purposes. First, students are able to apply what they are learning in the classroom to the comprehension of newspaper and magazine articles and television shows. Second, they become aware that the media provide a steady stream of biology information for lifelong learning. Third, they are often able to use the news stories to enlarge their understanding of topics being studied in class. Fourth, these specific, student-chosen cases enlarge our appreciation of the various contexts in which biology ideas are found. Fifth, they help students build connections between concepts and specific instantiations of those concepts (cases), thereby integrating both into overlapping and interconnected schema. Sixth, as each student stands before the class and presents material that they alone have interpreted, synthesized and organized, they move along the continuum from receiver to giver of information.

4. Promote students' active learning.

As von Glasersfeld (1993) noted, hands-on activities do not in themselves promote meaningful knowledge construction. Such activities must be combined with significant opportunities for interpretation, knowledge-building, reflection, and revision. We use a computer-based tool, SemNet®, to help students acquire the skills of meaningful knowledge construction (Fisher, 1991). With SemNet, students create semantic networks of their evolving biology knowledge (Figure 1. SemNet®). A semantic network is a model of how we organize denotative factual information in long term memory (Quillian, 1967, 1968). Students' net-building activities both promote and reflect their internal knowledge constructions. The emphasis is on building a robust and well-organized set of connections among important ideas.

5. Provide scaffolding and support for student knowledge construction.

SemNet prompts students to connect their ideas together while mirroring and reinforcing those connections (Figure 1.). SemNet serves as an extender of short term memory, allowing students to review, reflect upon and revise their thinking. In addition, when students work in small groups to construct a semantic network, the collaboration stimulates dialogue and meaning negotiation. When students' review other students' nets, they gain insights into alternative ways of thinking about and representing the same idea.

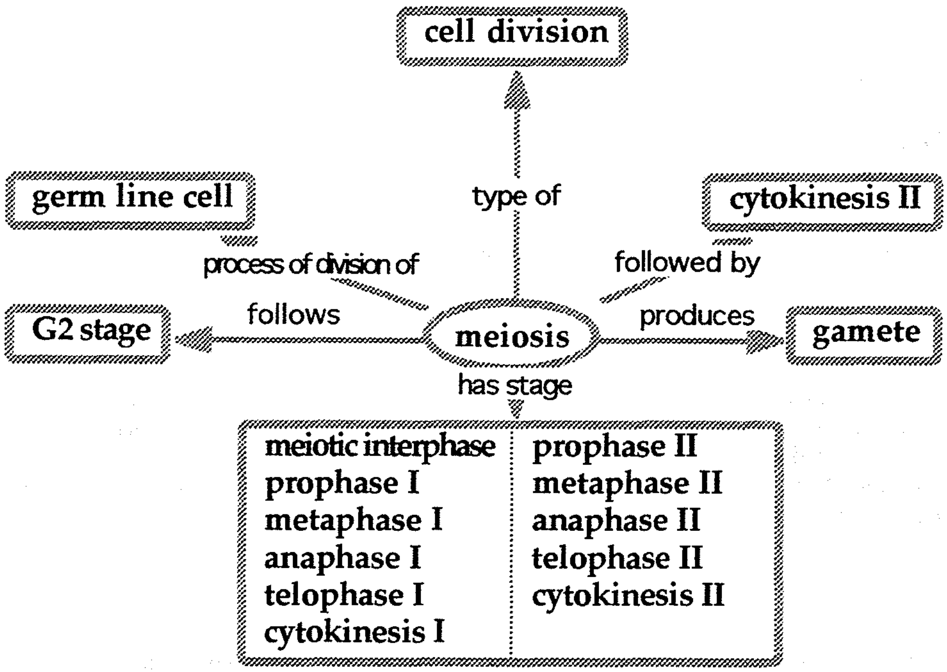

Figure 1. Graphic display of a concept (meiosis) in SemNet®.

6) Diagnose & remediate underdeveloped cognitive skills.

With SemNet we can see how students are thinking at a level of detail heretofore impossible. Some of the most frequent errors we observe are quite surprising, such as the inability to distinguish and correctly use simple relation rays like *'has part / is a part of'*. Since such relations are used again and again, it must be difficult to learn biology when these relation meanings are misunderstood. Fortunately once identified, this problem seems to be readily remediated on a relation by relation basis. Less surprising and also less easily corrected errors include the inability to identify discriminating features of an idea, failure to organize knowledge systematically and hierarchically, and a tendency toward paucity of description and interconnection of ideas.

7. Prompt students to identify central ideas.

Students are expected to identify the main ideas and give robust descriptions of them in their semantic networks. The Knowledge Core and list of Concepts by Embeddedness display options in SemNet summarize what students have actually done and allows them to quickly see if they have succeeded in developing what they perceive to be the key ideas. Deep understanding of ideas involves having a large and well integrated set of connections with relevant images and related concepts. Understanding something means knowing the relationship to higher more inclusive ideas (Resnick, 1983).

8. Prompt students to integrate ideas.

We have developed strategies for prompting students to create functional knowledge organizations rather than inert knowledge structures. For example, in describing the circulatory system, students describe the flow of blood through the four chambers of the heart and the major vessels and organs of the body using the relation: *'receives blood from / passes blood to* .' It is possible, then, to follow the course of a single platelet or red blood cell on its passage around the body by double-clicking through the net. Creating such a pathway leads to a fairly deep understanding of a system.

9. Avoid oversimplification and over-regulation.

Biology is inherently a messy and complex field of study. An instructor walks a fine line in making that complexity apparent while not letting it become overwhelming. Our use of multiple familiar phenomena to illustrate each main idea, our analyses of ideas in multiple ways, our willingness to accept multiple correct representations of ideas, and our deliberate selection of labs that often give unexpected results are some of the means we use to avoid oversimplification and over-regulation.

10. Prompt students to construct multiple representations.

SemNet mirrors students ideas and reflects their knowledge back to them in multiple ways including: graphic representations of each concept; temporal flows; lists of concepts, relations, and instances by various criteria; knowledge core; and hierarchies. These multiple representations of a single knowledge structure enhance students' appreciation of the robustness of their knowledge. As peers review one another's nets they see additional and often strikingly different representations of the same ideas.

11. Evaluation.

Learners periodically review their peers' work and seem to gain important insights from doing so. Evaluation, involving the comparison, critique or assessment of a body of work, is the said to be the highest of the cognitive skills (Bloom, 1953). As learners engage in evaluation they acquire a new sense of maturity and a new perspective on their efforts

Conclusion

Prospective elementary school teachers have spent years engaged in formal learning, often assimilating information passively. As they approach passage into the teaching profession, more active knowledge organization is needed. We describe a variety of strategies to promote and support this transition. Ideally, we should be building comprehension and reasoning skills from the beginning of a child's education and not relying on simplistic, non-productive exposure to and memorization of content in the early years (e.g., Driver & Erickson, 1983; von Glasersfeld, 1993; Tobin, 1993). If this had been the case, efforts such as ours would not be needed.

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