Learning Science Using a Deep Approach: Case Studies of two Students

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Abstract
What kinds of strategies are associated with a deep approach to learning science? How do these strategies interact to facilitate learning? This paper attempts to answer these questions by identifying some of these learning strategies and discussing how they might interact. Two groups of Grade 8 students were taped as they participated in hands-on science activities during a nine-week chemistry unit. To find out more about their understanding of the related science concepts, the students were also interviewed both before and after instruction of this unit. The focus in this paper is on case studies of two students who showed a deep approach to learning. Analysis of transcripts produced several categories which were used to classify the different strategies used by the students. Examples illustrating the use of these strategies are provided.

Introduction
In a particular learning context, students may have a predominant learning orientation; a deep approach characterized by meaningful learning, or a surface approach characterized by rote learning (Biggs, 1987; Entwistle & Ramsden, 1983). The learner who adopts a deep approach focuses on understanding the content of the learning material, and relates new ideas to previous knowledge and to everyday experiences. In contrast, the learner who uses a surface approach tends to memorize discrete facts and views a particular task in isolation from other tasks and from real life as a whole. Research in science education suggests that a student's learning approach influences his or her learning outcome. The study by Cavallo and Schafer (1994) on grade 10 students' understanding of genetics topics showed that the more meaningful the students' learning orientation, the more meaningful the understanding they tended to attain (as measured by the inter-relatedness and complexity of their knowledge exhibited). Studies by Hegarty-Hazel and Prosser (1991a, 1991b) showed that for both student learning in electricity and photosynthesis, deeper and more meaningful strategies were associated with better developed propositional knowledge, and more surface strategies with less developed propositional knowledge. BouJaoude (1992) also found in a study of high school students, that the relatively meaningful learners performed significantly better than the rote learners on a misunderstandings post-test in chemistry, and developed more coherent understanding of the underlying concepts.

The above-mentioned studies explored the relationship between students' learning approaches and their learning outcomes. However, little research has been done to investigate how students' learning approaches and thinking processes relate to the development of their conceptual knowledge, and how these figure into educational discourse, particularly in a naturalistic setting. If a deep learning approach is a factor in promoting more meaningful understanding and better developed propositional knowledge, what are the kinds of learning strategies used that are characteristic of a deep learning approach? More information about the strategies that enhance deep level learning in science will provide a better understanding of how cognitive processes interact in the knowledge acquisition process. This information will also extend our understanding of what is meant by a deep approach in the specific context of learning science beyond earlier conceptualizations which were more general in nature. Thus, it is of interest to study the strategies that such students use, especially at a "fine grain" level involving analysis of their thinking processes. Accordingly, a primary purpose of this study was to identify the kinds of learning strategies that students use as they construct meanings and develop their conceptual knowledge. This paper presents part of the results of a larger study; *it focuses on case studies of two students who showed a predominantly deep approach to learning.*

Method

A year 8 science class from a school in the US was observed during instruction in a chemistry unit which lasted nine weeks. Six target students representing learners using a deep or surface approach were selected for in-depth study. They were identified using the Learning Approach Questionnaire based on a modification of Entwistle & Ramsden's (1983) instrument, as well as the teacher's evaluation of their learning approaches. The 31-item Likert questionnaire measured students' tendency to learn meaningfully using a deep approach or by rote using a surface approach. The Cronbach alpha reliability coefficients of internal consistency for the meaning orientation and reproducing orientation scales were .86 and .65 respectively. Test-retest reliabilities over a 9-day period were .86 and .80 respectively for these two scales. Other selection criteria included: good attendance, being verbally expressive, being on-task, at least average success in science, and ability to work well with each other.

The students worked in two groups of three during their class activities. The boys' group consisted of Rick, Quin, and Carl while the girls' group comprised Mary, Bess, and Dale. Rick and Mary were identified independently by both the Learning Approach Questionnaire and the teacher, as meaningful learners who used a predominantly deep learning approach, Carl and Dale as rote learners who typically used a more surface approach, while Quin and Bess used an approach that lay somewhere between a deep and surface approach. The boys were audiotaped and the girls were videotaped during their regular science hands-on activities in class, and were encouraged to think aloud and verbalize their thoughts. Field notes which focused on classroom discourse and science activities were taken. The topics covered in this chemistry unit included the nature of matter (elements, mixtures, compounds, atoms and molecules), states of matter and changes of state, physical and chemical changes, acids and bases. Laboratory activities included the separation of a salt-sand mixture, qualitative analysis of unknown mixtures (comprising combinations of salt, sugar, baking soda, flour, and cornstarch), plotting the temperature graphs of water and salt water, paper chromatography using different colored pen inks, and determining whether given substances were acids or bases using cabbage juice and blueberry juice as indicators. The students were also interviewed individually both before and after instruction of the chemistry unit to find out more about their understanding of the science concepts in this unit. During the post-instructional interviews, stimulated recall was also used to obtain further information about what the students were thinking of during the laboratory activities. This provided information about silent thoughts which were not always verbalized and captured on tape. Data from multiple sources (field notes, transcripts of taped classroom discourse and interviews with the students, and students' written work) were analyzed in relation to each other; this served to triangulate the data and to help enhance the credibility of the findings and assertions made (Lincoln & Guba, 1985).

Results

Case studies of Mary and Rick, who used a predominantly deep approach, will be used as exemplars to illustrate the learning strategies used. These strategies could be broadly classified as elaboration and integration strategies, and comprehension-monitoring strategies. In this paper, *the focus will be on the elaboration and integration strategies.* While any student may use these strategies, a learner using a predominantly deep approach would be disposed to use such strategies consistently more often than one using a predominantly surface approach.

The Case Study Students

Mary was an intrinsically motivated, gifted "A" student, with an inquiring mind. She demonstrated self-initiated engagement in most tasks both behaviorally and cognitively, paid attention to details when carrying out tasks, had a keen sense of observation, and frequently asked questions. Her thoughts were constantly in flux as she sought to construct and reconstruct her ideas. This was particularly evident during the interviews as she frequently paused to think, change, and self-correct her answers while giving her reasons for doing so. When confronted with a problem, she often tried to project what would happen, generate an explanation for her observations, and construct a theory for it. As she said, "to theorize and try to hypothesize what would happen is really the most interesting part for me on the lab."

Rick was an "A" student, enthusiastic, and with an alert mind. Unlike Mary who regarded herself as a group leader and initiated most of the tasks, Rick and his group partners divided the tasks equally among themselves. Consequently, he did not play a dominant role in his group. While doing his experiments, he often thought of alternative ways of doing things. Rick also had a keen sense of observation. He enjoyed discussing scientific ideas with his mother who worked in a science research laboratory at the university. He was very capable of abstract thinking and had a vivid imagination. One striking characteristic of Rick was that he was often able to generate an impromptu explanation for his observations of natural phenomena. He rarely said "I don't know" to a question and would instead attempt to think hard and venture an explanation.

Elaboration and Integration Strategies

Elaboration and integration strategies refer to those that students used when they tried to relate new and existing knowledge or build internal associations among different aspects of the new knowledge in their efforts to understand. They demand constructive generative processing and because of their role in facilitating the integration of new and prior knowledge, they tend to be the most potent in promoting meaningful learning. Strategies associated with a deep approach to learning include the following: (1) visualizing and generating mental images, (2) creating analogies to explain scientific phenomena, (3) hypothesizing, constructing thought experiments, and predicting possible outcomes, (4) giving explanations and constructing theories, (5) invoking personal experience and prior knowledge, and applying them to new situations, and (6) asking questions. These strategies are not mutually exclusive, and were often used in combination by the students. Samples of discourse that exemplify each of these categories are provided. In the discourse segments, the following transcript convention [...] indicates a pause.

Visualizing and Generating Mental Images

Rick stood out as having a particularly rich imagination. He often made use of mental imagery to explain physical phenomena. Being very capable of abstract thinking, he had a ready explanation for how things happened in the physical world at the microscopic and molecular level. Although not all his ideas were canonical, they attempted to explain mechanisms which he thought could account for observed phenomena. What was remarkable about him was that unlike most other students whose answers merely had a "textbook" quality to them, his ideas often went beyond the standard scientific explanations normally given in textbooks or discussed in class.

Example. When attempting to explain why he thought the air molecules in a flask remain spread out and referring to the molecules as "atoms", Rick elaborated, "*I kind of think of it as air pillows. They are invisible. I pretend that they are invisible and they would hold the atoms. That's what makes them float around*". He also compared the air molecules to magnetic poles, reasoning that the air molecules were spread out because the "like poles" on the molecules did not attract each other. In addition to his "air pillows" and "magnetic poles" explanations. Rick also expanded on his ideas by further conceptualising that the air molecules would be spinning and "[an atom] will never be close enough to another atom while it's spinning to attract each other." In explaining how the smell of freshly baked cookies gets from the kitchen to an adjacent room, Rick again used his ideas of "air pillows."

> Well, I think *the atoms from the smell get attached to the atoms in the air.... they are kind of like on the air pillows, they are being carried around.* And while they are being carried around, there is like a circulation going in your room.... (drawing) See, there's like an air pillow right here. And there's an atom sitting right there.... And *the particle from the smell* that you pick up, ... they are little, they [...] *fly around, and eventually they attach to some. There's probably more than one, they attach to different places. And then this air pillow is being carried around in the air and it travels from places to places.*

For Rick, his idea of "air pillows" and rich mental imagery helped him form a coherent picture of how the invisible molecules moved in the air.

<u>Creating Analogies to Explain Scientific Phenomena</u>

Both Rick and Mary often used self-generated analogies to explain phenomena.

<u>Example .</u> When attempting to explain why a football does not feel so hard in the evening when it is cool, Rick offered an analogy. The following excerpt illustrates this.

R: Well, I think during the day when they just pumped it up, because the sun is shining and it's so hot around, the football gets warm and all the air molecules inside get warmed up too. And which is why they are more spread [...] and they keep the football hard. Because they are more spread and they kind of push out, push the walls out. So it doesn't come in.... I think they just take up more space.... And they keep the walls of the football from coming in. And then in the evening when it cools down, the molecules inside the football also get cooler and so they come together, they compact more and then the football is softer.... I think when it gets hotter, they move more [...] like faster. They go in different directions. And when it's colder, they just come closer together, they compact more, and they don't move that much.

I: Why do you think the molecules would move more when it's hotter?

R: Well [...] hmm.... *The way I think about it is maybe the same as people. When it's warm outside, you want to go out and do more things that involve movement, like maybe play soccer, basketball. And when it gets cold, you feel a little bit lazy.*

<u>Hypothesizing, Constructing Thought Experiments, and Predicting Possible Outcomes</u>

Before carrying out their laboratory experiments, Rick and Mary often projected ahead, predicting the possible outcomes of their action.

<u>Example.</u> Before doing the activity on plotting the temperature graph for ice as it was heated to boiling point in the absence and presence of salt, Mary predicted that plain water would boil at 100° C, and that the temperature would stay constant "because if water boils at 100° C, it doesn't have any higher that it has to go to boil." With salt in the ice water, Mary predicted that the boiling point would be higher than 100° C because "it [salt water] conducts more heat due to the salt" but that "it wouldn't go above 105° C because by then the water would have all evaporated." She stood out in her group as one who seemed to be constantly thinking ahead; she also used patterns and trends in temperature differences that she noticed to extrapolate and predict future data. The following segment illustrates this.

B: 1, 4, 5, 7 [°C] (reading the temperatures recorded for the first 2 min from her data sheet)
D: 30 s (announcing time at 30 s intervals)
M: 9 [...] *I'm hypothesizing that the first initial leap in temperature was like the first burst, and then it would gradually go up by 2 [°C] every 30 s.*
D: 30 s
M: 11. See it's pretty evident that it is going to keep going up by 2, although *as the hot-plate gets hotter, it might go faster.* Feel the heat radiating off this [hot-plate].

When the temperature reached 29° C, Mary remarked, "100° C is 212° F. And 212° F is boiling point. *So once it reaches 10° C, it should be boiling.*" She also anticipated bubbles forming at the bottom of the beaker. At 87° C, she said," this is the third time in a row it had 7° C as a consecutive number [the temperature difference was 7° C for the last three times]." When the temperature reached 95° C, Mary said, "Ah! 95. We've got 5 more degrees to go." Finally, when the temperature reached 100° C, Mary commented, "*It's boiling now, so it will slow down.*"

Giving Explanations and Constructing Theories .

Rick and Mary gave relatively more elaborate explanations of phenomena. While carrying out an activity, it was quite natural for them to spontaneously theorize about how and why things happened the way they did. Their explanations described non-observable theoretical entities and cause-effect relationships, and were like models or mini-theories which served as a link between the macro and micro levels. To generate such explanations, they often used mental imagery, analogies, real-life experiences, or hypothetical examples to articulate their ideas.

Example. In the laboratory activity on separating a salt-sand mixture, when Mary was heating the salt solution after she had filtered off the sand, she remarked to Bess, "See, look! There's salt gathering around the edges [of the pan]. If more salt goes around the edges, we could have a possible theory." In the post-instructional interview, Mary explained what she was thinking of then.

> [Drawing] These are water [molecules]. When you pour the salt into them, the molecules combine, they stick together.... When you heat the water, the molecules separate. The heat acts as a reactant to separate the molecules.... So that the salt, the sodium chloride molecules gather round at the edges to separate from the water molecules. And the water molecules are left in the middle.... I'll just label this *salt water theory*.... When we were boiling the water and the salt was gathering around the edges, the water in the pan was hot. And the water that I added was cold. So it made kind of like a spark explosion reaction. Like the molecules didn't agree.... And it made the little sizzling thing. And I think that it increased the process of the salt separating because it made the molecules spin faster.... I was thinking that maybe if the cold water is not agreeing with the hot water, that would speed up the process of the salt separating faster.

It was typical of Mary not to simply let her observations slip by without trying to self-explain what caused them to happen. In this case, she theorized about how heating the salt solution could have helped to separate the salt from the water, and how adding cold water might have catalyzed the separation process.

Invoking Personal Experiences and Prior Knowledge, and Applying to New Situations

Whenever they encountered a new problem situation, both students attempted to relate this to other familiar past experiences.

Example. The problem of how to separate a salt-sand mixture proved particularly challenging for Mary's group and they first tried using a sifter, a magnet, and creating static electricity, all without success. Then Bess asked some questions which stimulated Mary to think of ideas that led her to a "breakthrough", a moment of insight, when she finally solved the problem by adding water to the salt-sand mixture, filtering the sand, and then heating the salt solution with an alcohol burner to evaporate the water and recover the salt.

B: Sand [...] sand is on a beach, right?
M: Beaches are warm.
B: And you know what else? Salt water comes onto beaches. How does the salt stay there, or what?
M: OK, *we are going to go back to the fire theory*!

In the post-instructional interview, Mary explained what she was thinking of then.

> I was trying to think about like the ocean and stuff.... And I was thinking about when I went to my grandma's house one summer [...] she has a beach-house on Myrtle beach.... there's kind of like a cliff thing on the left of the house. And there's always like a thin film of salt that's on the rocks. And *I was trying to think of how that salt had gotten there, extracted from the water. And [...] uh, finally it dawned on me, I was like woh! [...] you know, the ocean's moving you know. It's warm, the sun's on it. You know, maybe that's how it got there. And then it just clicked at me. I was like wow! That's how you do it. So I poured the [salt] water in the thing [aluminium pan] and I heated it up.*

Mary had made a connection between the salt, sand, and heating in the current activity and the beach sand, salt on the rocks, and hot sun when she was by the ocean.

Asking Questions

Questions associated with a deep approach to learning tended to be "wonderment" questions beyond those of a factual or procedural level which sought basic information. They reflected the students' curiosity, puzzlement, skepticism, or speculation and focused on explanations and causes, predictions, or on resolving discrepancies in knowledge. They were pitched at a conceptually higher level, required an application or extension of taught ideas, and apparently sprung from a deep interest of the students or arose from an effort to make sense of the world. They were asked when students tried to relate new and existing knowledge, integrate complex and divergent information from multiple sources, or build internal associations among different aspects of the new knowledge in their efforts to understand. Students who used a deeper approach to learning tended to ask wonderment questions more spontaneously perhaps because asking such questions is, to a large extent, related to the inclination to self-generate explanations and construct theories.

Wonderment questions included (a) comprehension questions which typically sought an explanation of something not understood (e.g., "why do some pen ink run faster than others?"), (b) prediction questions which were of the "what would happen if ..." variety involving some speculation or hypothesis-verification (e.g., "if you put more than one color, would it separate into just more colors?"), (c) anomaly detection questions in which the student expressed skepticism or detected some discrepant information and sought to address this anomalous data (e.g., "so it's staying at 100^{o} C?"), (d) application questions in which the student wondered of what use was the information that he or she was dealing with (e.g., "what is the R_f used for?"), and (e) planning or strategy questions where the student was temporarily stuck and wondered how best to proceed next when no prior procedure has been given (e.g., "how are we going to remove the salt from the solution?").

Discussion and Conclusions

Most of the earlier research on students' learning approaches focused on reading from text (Marton & Saljo, 1976) and domains other than science. The results of this study have provided more detailed information about the learning strategies associated with a deep approach in the specific context of learning science. This goes beyond earlier descriptions which were more general, broadly defined, less domain-specific, and more pertinent to reading of texts. The present description of the students' learning strategies also takes into account those strategies that are used when students are engaged in hands-on investigations which are an integral part of learning in science. Both students who used a predominantly deep learning approach often generated mental images, created analogies to help them relate two independent events, hypothesized, constructed thought experiments and predicted possible outcomes, gave self-explanations and constructed theories, invoked personal experience and prior knowledge and applied them to new situations. Some of the learning strategies identified in this study (e.g., creating analogies, self-evaluating) overlap with those in Weinstein and Mayer's (1986) discussion of learning strategies which referred to learning in general domains rather than a specific subject, and with an emphasis on learning from prose or text. However, the strategy of self-generating explanations and constructing theories seems to be more perculiar to learning in science.

How do these strategies interact to faciliate learning in science? A possible model is proposed. When learners use a deep approach, they are constantly monitoring the status of their understanding through self-evaluation and self-questioning. Detection of a comprehension failure or puzzlement leads the students to try and understand this puzzlement. They do this by asking pertinent questions to acquire the missing pieces of knowledge or resolve conflicts in their understanding. This initiates a process of hypothesizing, predicting, and thought experimenting where they envision the consequence of a proposed solution. By asking questions, the students also engage in self explanations to answer their own questions. These explanations are generated via the use of mental imagery, analogies, and reference to past experiences and prior knowledge. By explaining the phenomena observed, the students attempt to bridge the gaps in their understanding by linking related pieces of knowledge. During this stage, the students try out their ideas, imagine consequences, ask "what if?" questions, and generally play mentally with various entities and mechanisms to see if they might fit. Proposed explanations may be tested by prediction and testing done to see if these consequences occur. Confirmation of the prediction is taken as support for the explanation.

One final point pertinent to the findings relates to the issue of whether using a deep approach is productive for all learning situations. It is generally acknowledged in the literature that using deep processing strategies is desirable for learning and would facilitate conceptual change (e.g., Chinn & Brewer, 1993; Pintrich, Marx, & Boyle, 1993). However, using a deep approach can also lead a student to form idiosyncratic ideas which are scientifically incorrect. For example, during the separation of the salt-sand activity, Mary constructed her "salt water theory" to explain how she thought heat would facilitate the separation of salt from the water molecules. And Rick generated ideas of "air pillows" to explain molecular movement in air. One could argue that a deep approach might be counterproductive to learning, especially if it leads to erroneous ideas that may be resistant to change and thus, difficult to eradicate. However, an alternative way to look at this would be that even though this active theorizing could potentially lead to non-scientific ideas, other deep processing strategies could also help the student to detect conflicts between the evolving ideas and what is correct. On the whole, this may have a compensatory effect and lead to improved learning in the long run. One implication of this study's findings for classroom instruction is that teachers can devise instructional scaffolding to encourage their students to use these strategies. This would hopefully lead to the behaviors that are associated with a deep learning approach.

References

Biggs, J. (1987). *Student approaches to learning and studying*. Melbourne: Australian Council for Educational Research.

BouJaoude, S.B. (1992). The relationship between students' learning strategies and the change in their misunderstandings during a high school chemistry course. *Journal of Research in Science Teaching, 29*(7), 689-699.

Cavallo, A.M.N. & Schafer, L.E. (1994). Relationships between students' meaningful learning orientation and their understanding of genetics topics. *Journal of Research in Science Teaching, 31*(4), 393-418.

Chinn, C.A. & Brewer, W.F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science education. *Review of Educational Research, 63*(1), 1-49.

Entwistle, N.J. & Ramsden, P. (1983). *Understanding Student Learning*. London: Croom Helm.

Hegarty-Hazel, E. & Prosser, M. (1991a). Relationship between students' conceptual knowledge and study strategies--part 1: Student learning in physics. *International Journal of Science Education, 13*(3), 303-312.

Hegarty-Hazel, E. & Prosser, M. (1991b). Relationship between students' conceptual knowledge and study strategies--part 2: student learning in biology. *International Journal of Science Education, 13*(4), 421-429.

Lincoln, Y.S. & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage.

Marton, F. & Saljo, R. (1976). On qualitative differences in learning. I - Outcome and process. *British Journal of Educational Psychology, 46*, 4-11.

Pintrich, P.R., Marx, R.W. & Boyle, R.A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-200.

Weinstein, C.F. & Mayer, R.F. (1986). The teaching of learning strategies. In M.C. Wittrock (Ed.), *Handbook of research on teaching* (pp. 315-327). New York: Macmillan.