DEEP AND SURFACE LEARNING APPROACHES IN SCIENCE: A COMPARISON

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Abstract: Previous researchers have often described students' approaches to learning as either deep or surface. What does this mean in the specific context of science learning? The purpose of this study was to compare in greater depth, the qualitative differences between what is commonly referred to as deep versus surface approaches to learning science and articulate the subtleties of these constructs. Six grade 8 students judged as typically using learning approaches ranging from deep to surface were taped during hands-on class activities during regular science classes. They were also interviewed about their understanding of some related science concepts. Analysis of the students' discourse and behaviours during class activities and their interview responses revealed several differences in their learning approaches. These differences were grouped under five emergent categories: generative thinking, nature of explanations, questioning, metacognitive activity, and approach to tasks. Implications based on these findings are discussed.

Students adopt different learning approaches as a result of both individual characteristics (e.g., ability, locus of control, motivation) and situational factors (e.g. nature of task, learning context, perceptions of institutional requirements, background knowledge). This could be a deep approach characterized by meaningful learning or a surface approach characterized by rote learning (Biggs, 1987; Entwistle & Ramsden, 1983; Marton, 1983). The learner adopting a deep approach focuses on understanding the content of the learning material, relates parts to each other, new ideas to previous knowledge, and concepts to everyday experiences. On the other hand, 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. Most of the earlier research on students' learning approaches was on reading from text (Marton & Saljo, 1976) and domains other than science.

Recent research in science education also suggests that a student's learning approach is a factor influencing his or her learning outcome. Studies by BouJaoude (1992), Cavallo and Schafer (1994), and Hegarty-Hazel and Prosser (1991a, 1991b) showed that a deep approach is associated with more coherent understanding of underlying concepts, fewer misconceptions, and more interrelated and better developed propositional knowledge. These studies focused on the relationship between students' learning approaches and their science performance and the quantitative outcome of learning. Little research has been done on how students' learning approaches and learning strategies relate to the construction of their conceptual knowledge, and how the use of these strategies figures into educational discourse, particularly in a naturalistic setting. Although some studies (e.g., Baird & White, 1982) have provided some information about qualitative differences in learning in terms of application of cognitive strategies, few studies have been made that have a sufficiently descriptive approach about individual differences in science learning. Thus, examining how students differ in the way they learn may shed light on the processes of knowledge acquisition that lead to different learning outcomes. Accordingly, the primary purpose of this study was to compare in greater depth, the qualitative differences between a deep and surface learning approach to learning science. This problem and its related findings are important because there exists no principled and detailed account of the characteristics associated with learning approaches specifically in the context of science learning.

Method

A grade 8 science class from a school in the U.S. was observed during instruction in a chemistry unit which lasted nine weeks. Six target students judged as typically adopting learning approaches ranging from deep to surface were selected for more in-depth study. They were identified by the Learning Approach Questionnaire based on a modification of Entwistle & Ramsden's (1983) instrument and their teacher's evaluation of their learning approaches in science. Other selection criteria included: good attendance, being verbally expressive and 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 as meaningful learners who used a predominantly deep learning approach, Carl and Dale as rote learners who typically used a more surface approach, and Quin and Bess as learners who used an approach that lay somewhere between a deep and surface approach. Rick and Mary were "A" students, Quin and Bess were "B" students, and Carl and Dale were "C" students. The boys were audiotaped and the girls were videotaped during hands-on activities during their regular science classes and were encouraged to think aloud and to 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 and states of matter, physical and chemical changes, acids and bases. Laboratory activities included the separation of a salt-sand mixture, plotting the temperature graphs of water and salt water, and paper chromatography using different colored pen inks. The target 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 used to obtain further information about what the students were thinking of during the laboratory activities. Data from multiple sources (field notes, transcripts of classroom discourse from the audiotapes and videotapes, audiotaped 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

From an analysis of the data, five categories emerged as meaningful perspectives that would illuminate the differences between deep and surface approaches to learning. These were (a) generative thinking, (b) nature of explanations, (c) asking questions, (d) metacognitive activity, and (e) approach to tasks.

Generative Thinking

Generative thinking refers to the students' ability to generate an idea when they did not have an immediate ready-made solution to a problem, particularly when the problem was unfamiliar and could not be solved by using simple recall of facts or a rote algorithm. Four main levels of generative thinking emerged. In level 1, the students remained stuck, saying "I don't know" and did not proceed with thinking further. In level 2, the students gave an "evasive" response that did not directly answer the question but was related to it. In levels 3 and 4, the students attempted to think hard and give an answer which might be correct or incorrect. While the answers at the third level were short and lacking in details, answers at the fourth level were more elaborate and illustrated with examples and references to real life experiences. Levels 1, 2, and 3 would be characteristic of a surface approach to learning, while level 4 would be typical of a deep approach. When students used a deep approach, they tended to venture their ideas more spontaneously. Their responses were more sustained, interconnected, elaborate, and precise with specific referents. The students usually resorted to daily life experiences, past episodes, examples, and self-generated analogies as tools to keep their thinking going. On the other hand, students using a surface approach tended to give up thinking more easily, or gave a vague response that did not answer the question directly, or that was brief and unelaborated. Their thinking was more piecemeal and the students moved from one idea to another without a sense of directional link between the isolated ideas.

The following example on paper chromatography of pen inks illustrates the differences in generative thinking. During the post-instructional interview, the students were asked what they thought chromatography was used for, and what was the purpose and significance of calculating the retention factor, R_f, for each color spot. In class, the teacher had only introduced the R_f as simply a formula, $R_f = D_C / D_S$, the distance the colour moved (D_C) divided by the distance the solvent moved (D_S). Carl had blindly followed the instructions to calculate the R_f and said, “I didn’t think. Just did it,” and “I don’t know” repeatedly when asked about the R_f. This is an example of level 1 of generative thinking. Bess responded with “so that we could understand it a little bit more” which did not specifically answer the question (level 2). When asked what chromatography was used for, she responded with “to match something” without giving any specific referents or elaborating any further (level 3). Compare the answers given by Rick and Mary (level 4). Although their ideas of the R_f were not scientific, they were able to generate on the spot answers that seemed plausible and quite complete in themselves compared to the other students, despite not having any extra content knowledge about the $R_{f.}$ Rick thought of the R_f as being associated with the relative proportions of the component colors of the ink and gave a specific hypothetical example to illustrate his ideas. Mary came up with the idea of the R_f as an index of the purity of a substance. She also gave examples that were not simply exact reproductions of the “crime lab chemistry” class activity regarding a ransom note, but extensions of the activity such as identifying samples of food dyes, blood, and clothing dyes in forensic science.

Nature of Explanations

There were four main types of explanations, reflecting different levels of depth and sophistication. The explanations associated with a surface learning approach tended to be reformulations of the question (level 1), of a “black box” variety (level 2) which did not refer to a causal mechanism, or macroscopic (level 3) which referred only to what was visible. Black box explanations included mere observations or descriptions of what happened instead of telling why or how an event occurred, rote explanations in which the student gave textbook-like answers that sounded scientific but did not relate meaningfully to the situation, global explanations which lacked specific referents, “cyclic” explanations in which the student switched back and forth between two ideas without advancing, and anthropomorphic explanations. In contrast, a learner using a deep approach tended to give “microscopic” explanations (level 4) which described non-observable theoretical entities and cause-effect relationships. This type of explanation was like a model or mini-theory which served as a link between the macro and micro levels. Microscopic explanations also included references to personal experiences in trying to understand a phenomenon but might not articulate unseen mechanisms.

The activity on plotting the temperature graphs when water and salt water were heated will be used as illustrations. Unlike the other four students (Carl, Quin, Bess, and Dale) who could not think of any reason for why salt raised the boiling point of water, Rick said:

> Salt in it… makes the water thicker…. It [salt] kind of fills up a lot of empty spaces between the [water] molecules. And so the heat couldn’t pass through it as fast as it did through the plain water. So it had to add more heat to break through the salt particles and heat up the water.

It is possible that his observation that salt “makes the water thicker” could have triggered him to think of the salt molecules filling up the empty spaces between the water molecules. Although Rick’s explanations were not completely normative, they were like a model or mini-theory that attempted to explain the mechanism of how things worked in the physical world. Rick referred to unobservable theoretical entities such as particles and molecules, and attempted to link these at the micro level with his observation at the macro level, describing a cause-effect relationship. His "microscopic" explanation would be an example of level 4. Mary also predicted that salt would raise the boiling point of water. She thought about how she had used salt on the driveway to melt snow in winter, and reasoned that the temperature of “salt water would rise a little bit higher than regular water." Referring to the chemicals in salt and antifreeze, she thought that it had "something to do with the chloride in it that makes the thing heat hotter …. like anti-freeze for your car has some kind of chloride in it." Mary also thought of "boiling baby bottles," saying "salt water sterilizes things …. it’ll make the water hotter so that it will kill more bacteria and stuff that are on the baby bottles. I learned that from a friend who I baby-sit for." She often related the phenomenon being considered to her experiences in daily life and attempted to make connections between them. Her explanation would also be an example of level 4.

When asked why she thought the temperature remained constant when water boiled, Dale described her graph instead, merely stating her observation. Upon further probing she replied, “because it can’t get any hotter.” Her answer was more a reformulation of the question in different words (level 1). Bess’ attempts to explain the effects of salt on the boiling of water resulted in a cyclic explanation. When she was asked how salt water affected the temperature curve, she said “it gets hotter faster.” Then in response to why that might be so, she replied “because it has got salt in it.” When she was then again asked how salt might affect it, she returned to her former idea that “it just makes it get hotter.” Such a “cyclic explanation” is of the “black box” variety (level 2) because it does not offer a mechanism nor explain how the observed effect might occur.

Questioning

Questions associated with a surface approach referred to more basic, factual (requiring only recall of information), or procedural information. Factual questions were often closed questions with a single, unambiguous answer. They typically related to information in the textbook, or some simple observation about an event. Examples would be “What color is that? Blue?” Procedural questions were those which sought clarification about a given procedure or asked how a task was to be carried out, particularly where step-by-step instructions were given. Examples would be “could we pour this out now?”. Questions associated with a deep approach to learning tended to be “wonderment” questions which reflected the students’ curiosity, puzzlement, skepticism, or speculation. They 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. Unlike basic factual and procedural questions which were typically either ignored or simply responded to with a simple short answer, wonderment questions served to direct further inquiry, tended to elicit responses that were of a more conceptual nature, and had a greater potential contribution for an advancement in conceptual understanding.

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 had been given (e.g., “how are we going to recover the salt from the solution?”).

Metacognitive Activity

This refers to the students’ use of comprehension-monitoring and evaluative strategies that indicate they were reflecting on the learning process and their strategy of thinking. The students who used a deep approach to learning displayed more cognitive self-appraisal and regulatory control of the learning process. When students used a deep approach, they (a) constantly self-evaluated their ideas by making statements that expressed their understanding (e.g., “I’ve figured out what I wanted to say!”), that recognized a comprehension failure (e.g., “no, I don’t get it”), and that expressed value judgments (e.g., “I know I’m just rambling on”, “oh no, I didn’t draw that right, I’m getting confused”), (b) made self-questioning statements when they encountered something confusing (e.g., “oh no, what am I going to do?”), (c) detected their errors and spontaneously self-corrected them, (d) noted and attended to anomalous data and counter-intuitive events, (e) considered a range of possible answers and attempted to understand alternative ideas, and (f) considered limitations in their own or others’ ideas and critiqued them.

For example, Mary, as a learner who often used a deep approach would typically try to recall her past experiences and think of all things she knew that were associated with the problem at hand and ask herself questions of the type “have I come across this before?” and “what do I know about this?” And while executing a task, she would constantly reflect to assess the extent to which her implemented ideas were working, revise or modify them when necessary, and use alternative strategies if needed. She periodically checked if what she was thinking or saying made sense, and was alert to discrepancies in her thinking. In contrast, when the students used a surface approach, they rarely reflected on their own performance and seldom critically evaluated the new information, compared it with their prior knowledge, or reflected on the efficacy of the procedures used to process the information. They hardly made self-evaluation statements or asked themselves questions such as “why am I doing what am I doing?”, “what does this mean?”, “why does this happen?”, and “does this seem correct?”. In this mode of learning, the students did not use an active, interrogative approach. Instead, they followed the given procedures blindly and relied more on memorized facts.

Approach to Tasks

One characteristic of a deep learning approach was that the student was more persistent in following up on an idea with some sustained interest before moving to another one, while one using a more surface approach might give up an idea as soon as it did not work. When using a deep approach, the student would also attempt to generate ideas on his or her own whereas one using a surface approach would be more reliant on external resources such as other peers or the teacher for ideas. The student using a deep approach engaged in “on-line theorizing” where he or she spontaneously generated explanations for cause-effect relationships and mini-theories to account for observations of phenomena while carrying out tasks and also tended to think ahead and predict outcomes when performing an activity. He or she was also more capable of attending to multiple foci, and could focus on several aspects of a phenomenon at the same time, while a surface approach learner had a more limited or single focus. When a student used a deep approach, he or she did not ignore information that was incomprehensible but rather ruminated over this puzzlement instead of letting it slip by. Such a student also showed a more sophisticated level of observation and was better able to discriminate finely between differences in not only what was visible and obvious, but also inferred patterns and trends. In contrast, a learner using a surface approach noticed mainly gross, macroscopic features. Finally, a deep approach learner was also more likely to engage in talk at the conceptual, analytical, and metaconceptual levels, beyond the procedural and observational levels that the surface approach learner typically engaged in.

The problem-solving activity where the students had to devise a method for separating salt from sand will be used as an illustration. Mary first suggested using a sifter. Unlike Mary who attempted to generate her own ideas and dwell more on them, Bess kept visiting other groups to see what they were doing and tried to get ideas from them, giving up one idea as soon as it did not work. Together with Mary and Dale, she tried using a magnet, creating static electricity by using a plastic filter funnel and a plastic spoon, heating the salt-sand mixture dry, and then finally adding water to the mixture followed by draining off the sand residue and evaporating the water from the salt solution over an alcohol flame. Mary displayed not only a “hands-on” orientation, but also a “minds-on” approach to the tasks. For instance, when the salt solution was boiling, Bess seemed to have only a single focus and was fixated on the presence of salt in the solution, making comments such as “I still see a lot of salt,” and “it’s like crystallizing.” Mary, on the other hand, was better able to notice nuances in her observations, and focused on multiple aspects of the phenomena such as the sizzling effect of adding cold water to the hot, dry mixture, the salt dissolving in the hot water, the salt settling down to the bottom of the pan when more water evaporated, and the salt grains spluttering and sticking to the edges of the pan.

One major difference between Mary and her partners was her engagement in on-line theorizing where she spontaneously generated explanations for cause-effect relationships to account for her observations of phenomena. In this capacity, she was able to go beyond the kind of thinking displayed by Bess and Dale. For example, when she noticed the water sizzling and the salt gathering around the edges of the pan, she theorized about how heating the salt solution could have helped to separate the salt from the water, and how adding cold water catalyzed this separation process when it sizzled.

> [Drawing on paper] 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.

Although her mini-theories may seem naive, they reveal how a deep approach learner might react to ordinary, commonplace situations and perhaps see the extraordinary in the ordinary.

Discussion, Implications, and Conclusions

In this study, the differences between a deep and a surface approach to learning science were compared. In summary, when students used a deep approach, they generated their ideas more spontaneously and their responses were more precise and elaborate. They also gave microscopic theory-like explanations which described non-observable entities and cause-effect relationships. Explanations associated with a surface learning approach tended to be reformulations of the question, of a “black box” variety which did not refer to a mechanism, or macroscopic descriptions which referred only to what was visible. Questions associated with a deep approach focused on explanations and causes, predictions, or resolving discrepancies in knowledge, and had a greater potential to lead to an advancement in conceptual understanding. Questions associated with a surface approach referred to more basic factual or procedural information. When students used a deep approach, they displayed more cognitive appraisal and regulatory control of the learning process through ongoing reflective thinking. In their approach to tasks, they tended to think ahead and predict outcomes, showed a more sophisticated level of observation, and were more likely to engage in talk at a higher cognitive level beyond the procedural and observational levels that learners using a surface approach typically engaged in.

The identification of finer differences between these approaches goes beyond earlier descriptions which were more general, broadly defined, less domain-specific, and more pertinent to reading of texts. Moreover, it takes into account those learning strategies that are used when students are engaged in hands-on investigations which are an integral part of learning in science. In this capacity, it has expanded on the previous framework for reading text to include hands-on activities and problem solving. The importance of this study also lies in the creation of a terminology that makes it possible to describe and discuss in an explicit and specific way, the differences between a deep and surface learning approach. One finding that emerged from this study was the recognition of a variety of types of explanation (reformulations of the question, black box, macroscopic, and microscopic) that students typically give, depending on their learning approach. This should be of value to teachers in helping them to recognize the type and quality of explanations that their students give in relation to their learning approaches, as well as the attributes of effective and not so effective explanations. A taxonomy of question types which classifies students’ questions according to different conceptual levels was developed. Such a classification could be useful in helping teachers to plan their activities so as to foster student questioning at a higher cognitive level that is characteristic of a deep approach.

In looking closely at individual students, it was evident that even among the students who used a deep approach, they showed a tendency to be deep in different ways. For example, Rick tended to think of specific hypothetical examples while Mary was more inclined to draw on personal past experience. What this suggests is that students may be more prone to deeper thinking in some dimensions and contexts than in others. By being aware of the multidimensionality of this, teachers could help students deepen their thinking starting from contexts and dimensions where they already show some depth. The use of deep strategies was not always spontaneous but was sometimes manifested only upon further probing or prompting during the interviews and when the students were specifically asked to explain a phenomenon (Chin and Brown, in press). Thus, if left to their own devices, many students may not use deep processing strategies as often as teachers would like them to or be able to develop deep processing strategies on their own. This suggests that it is necessary for the teacher to foster constructive learning activity through some kind of instructional intervention rather than leaving things to chance. Activities which involve questioning, predicting, explaining, and theorizing can be used to bolster a discussion. But rather than hope that these would just occur spontaneously in students, the teacher can provide a structure to scaffold student discourse by explicitly requiring the students to do these. While some students may not naturally engage in deep processing strategies on their own, instructional scaffolding strategies and task prompts (Davis, 1996) which provide conceptual guidance and encourage reflection could serve a cueing purpose to enhance students' cognitive and metacognitive capabilities that might lead to the behaviors associated with a deep learning approach.

References

Baird, J. R. & White, R. T. (1982). A case study of learning styles in biology. *European Journal of Science Education*, *4*(3), 325-337.

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.

Chin, C. & Brown, D. E. (in press). Learning in science: A comparison of deep and surface approaches. *Journal of Research in Science Teaching.*

Davis, E. (1996, April). *Metacognitive scaffolding to foster scientific explanations.* Paper presented at the meeting of the American Educational Research Association, New York. (ERIC Documentation Reproduction Service No. ED 394 853).

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. (1983). Beyond individual differences. *Educational Psychology, 3,* 289-303.

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