Students' approaches to learning science: responding to learners' needs

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If teachers understand students' different approaches to learning, they can adapt their teaching accordingly

Students learn science with varying degrees of success. This difference in success is often attributed to differences in the students' abilities, effort, and the learning environment of the school and home. Indeed, all these factors interact to influence the way students learn, that is, their learning approaches. Differences in these learning approaches determine, to a large extent, how successful students are in their academic achievement. Factors such as students' abilities and personalities may be beyond a teacher's sphere of influence. However, factors such as teaching methods, which can also influence students' learning approaches, are within the teacher's control. Knowing what it is that students do differently during the learning process that leads to different learning outcomes and what influences such differences in behaviour would help teachers to understand the learning process better and tailor their teaching to respond to their students' learning needs. The purpose of this article is to cull some salient findings from research on students' learning approaches in science and draw out some implications for instructional practice.

ABSTRACT
This article reports on students' approaches to learning science. In particular, it highlights the findings of three related research studies conducted by the author and teases out the implications for instructional practice in science classrooms. Areas of focus include: (a) the nature of students' approaches to learning; (b) a comparison of the qualitative differences between deep and surface learning approaches; (c) the learning strategies associated with a deep approach; (d) the role of student-generated questions in science learning; and (e) implications for instruction. The article also discusses some issues related to the research findings.

Approaches to learning

Approaches to learning refer to '*the ways in which students go about their academic tasks, thereby affecting the nature of the learning outcome*' (Biggs, 1994). A student's learning approach comprises the motive for undertaking the task and the congruent strategies used, and lies on a continuum from deep to surface (Marton, 1983; Biggs, 1987). The deep approach is associated with intrinsic motivation and meaningful learning where the learner focuses on understanding the meaning of the material to be learnt and attempts to relate parts to each other, new ideas to previous knowledge, and concepts to everyday experiences. In contrast, the surface approach is based on extrinsic or instrumental motivation where the learner perceives the task as a demand to be met, tends to memorise discrete facts, reproduces terms and procedures through rote learning, and views a particular task in isolation from other tasks and from real life as a whole.

In his 3P (presage, process, product) (Biggs, 1987) or systems (Biggs, 1994) model of student learning, Biggs describes both personal and situational factors as presage factors that exist prior to a particular

- How do they know that the diagram I drew, or the diagram of whoever else drew it, is 'correct'?
- Why do they defer to my explanation above all others?

We talk about how the explanation is provisional on no one coming up with a better explanation. Our acceptance of any one diagram as being definitive is an acceptance by us as a community – albeit the community in that room at that time.

A geometrical explanation for the image of the mirror being as far behind the mirror as the object is in front (Figure 9) hinges on showing that the triangle ABC is congruent with triangle BCD. This can be done in terms of a common side, BC, and the two angles at either end of that side (BCD = BCA and CBD = CBA).

Extending such work

I usually run this workshop with science teachers from overseas. They thoroughly enjoy the session. Every single group evaluates it positively. The teachers say that they learn more about the nature of science in the workshop than at any other time in their professional careers. I usually finish my two hours by making a point about how, if we are teaching science, we need to find activities and opportunities for our pupils to behave like scientists. That is, the pupils must actually present, evaluate and communicate their own ideas. They need to be actively involved in such limited controversies as these investigations allow through our little conferences. They need to experience the frustration, and joy, of finding an answer to the questions *What is happening?* and *Why does it happen?* They need to experience for themselves that in describing phenomena one may have to work at technique and be painstaking about truthfulness. Whilst description can be relatively simple, the explanation of phenomena can be frustratingly difficult and require creativity to 'see' what may not be seen.

In the science National Curriculum, geometrical optics is a mere shadow of its former self in GCE syllabuses. This should not put you off trying to adapt the questions *What?* and *Why?* to the host of other topics that are in the National Curriculum. I hope this article has cast some further light on possibilities in 'ideas and evidence'. With puns like this it is time to stop. Let me know how you get on.

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Deep and surface learning approaches compared

Differences between deep and surface learning approaches pertained to generative thinking, nature of explanations, asking questions, metacognitive activity, and approach to tasks. The characteristics associated with a deep and a surface approach to learning science, based on these five dimensions, are listed in Tables 1 to 5. The link between depth of thinking and students' actions is based on criteria commonly described by other authors in the research literature, such as active and thoughtful engagement on tasks, and reflective thinking.

Table 1 Generative thinking.

Deep approach	*Surface approach*
Student tries hard and is motivated to venture ideas.	Student remains stuck, saying 'I don't know', gives a response that does not directly answer the question and/or is brief.
Responses are longer, more sustained, and dwell more on a single idea.	Responses are shorter.
Responses are elaborate, incorporating examples, self-generated analogies, daily life experiences, and past episodes.	Responses are less detailed and elaborate.
Thinking is maintained as a 'chain reaction' or 'network of ideas' where subsequent ideas are connected to the previous one(s).	'Piecemeal thinking in spurts'. Student moves from one idea to another, groping around without a sense of directional link between the isolated ideas.
Language is more precise with specific referents.	Language is usually more vague if the student is unable to think of specific referents.

Table 2 Nature of explanations.

Deep approach	*Surface approach*
Microscopic, more sophisticated, targeted, refers to a mechanism describing non-observable entities and a cause–effect relationship, or to personal experiences. Theory-like.	Reformulation of question, 'black box' variety with no mechanism (observation, rote, global, cyclic), or macroscopic. Sometimes vague with non-specific referent.
More detailed and elaborate, incorporating examples, analogies, real-life experiences.	Not elaborate.
More forthcoming. Self-explanations (i.e. spontaneously generated requiring little or no prompting).	Usually given only when solicited. Requires more probing to produce a more complete explanation.

Table 3 Asking questions.

Deep approach	*Surface approach*
Wonderment questions: focus on explanations and causes (cf. facts), predictions, resolving discrepancies in knowledge, application, or planning. Reflect curiosity, puzzlement, scepticism, or speculation.	Basic information questions: focus on factual recall of information or procedures.

Table 4 Metacognitive activity.

Deep approach	*Surface approach*
Student displays more cognitive self-appraisal and regulatory control of the learning process through ongoing reflective thinking.	Student displays less self-monitoring and self-evaluation.

Table 5 Approach to tasks.

Deep approach	*Surface approach*
Student is more persistent with a single idea.	Student oscillates between ideas.
Student attempts to generate ideas on his or her own.	Student is more dependent on external resources for ideas.
'Hands-on, minds-on' learning. Student engages in 'on-line theorising', spontaneously generates explanations or theories for cause–effect relationships to account for phenomena and anticipates outcomes.	Less 'minds-on' learning.
Student does not ignore puzzlement but ruminates over it.	Student may ignore puzzlement.
Student shows more sophisticated level of observation, extending to inferred patterns and trends. Discriminates more finely between differences. Thinks ahead, anticipating outcomes.	Student notices mainly gross, macroscopic features of a phenomenon.
Student attends to multiple foci.	Student has a single or more limited focus.
Talk/comments pitched at conceptual, analytical, and metaconceptual, beyond observational and procedural levels.	Talk/comments pitched mainly at the observational and procedural level.

When students used a deep approach, they expressed their ideas more spontaneously, the ideas were more elaborate and they were generally more forthcoming with less prompting needed. They also gave more elaborate 'microscopic' explanations, which described mechanisms and cause–effect relationships or referred to personal experiences. For example, in trying to explain how salt would lower the melting point of ice and raise the boiling point of water, a student using a deep approach referred to daily life experiences such as the use of salt in melting snow and in sterilising baby bottles. On the other hand, explanations associated with a surface learning approach tended to be reformulations of the questions, of a 'black box' variety which did not refer to a mechanism, or 'macroscopic' descriptions that referred only to what was visible. An example of the latter would be when a student attributed the depression of melting point of salted ice simply to 'more ice' being present.

Questions associated with a deep approach focused on explanations and causes (e.g. '*Why do some pen inks run faster than others?*'), predictions ('*What would happen if ...?*'), or on resolving discrepancies in knowledge, and had a greater potential to lead to an advancement in conceptual understanding. Questions pertaining to a surface approach referred to more basic factual or procedural information (e.g. '*What colour is that?*' and '*Could we pour this out now?*'). When students used a deep approach they also displayed more cognitive self-appraisal and regulatory control of the learning process through ongoing reflective thinking. In their approach to tasks, they also engaged in 'on-line theorising' 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 use of a deep approach or a surface approach were manifested in different ways. For example, one student using a deep approach tended to think of specific hypothetical examples and generate mini-theories, another asked deep thinking questions, while yet another was more inclined to draw on personal experiences in daily life. Similarly, students who adopted a surface approach might blindly follow given procedures or be apathetic in task engagement.

Strategies associated with a deep learning approach

Cognitive strategies associated with a deep learning approach included: (a) visualising and generating mental images; (b) creating analogies to explain scientific phenomena; (c) hypothesising, constructing thought experiments and predicting possible outcomes; (d) giving explanations and constructing theories; (e) invoking personal experiences and prior knowledge and applying them to new situations; and (f) asking questions. Metacognitive or comprehension-monitoring strategies included self-evaluating, self-questioning, defining a problem and establishing the main ideas, detecting and self-correcting one's errors, attending to contradictory information and alternative ideas, and considering limitations in one's own or others' ideas and critiquing them.

These different individual strategies are interrelated during deep learning and function together in an overall 'depth dynamic', and not as separate, independent entities. There is a continuous interplay of cognitive and metacognitive strategies which interact, leading to generative activity. This is unlike surface learning where such strategies are not invoked or where they are applied only as isolated responses to stimuli. Although some students were naturally more inclined than others to use deep processing strategies, this did not always occur spontaneously but was manifested only upon further probing or prompting or when the students were specifically asked to explain phenomena. Using a deep approach occasionally led a learner to form idiosyncratic, scientifically incorrect ideas, although the development of such ideas could sometimes be due to 'root' conceptions.

Student-generated questions

Students' questions included basic information questions typical of a surface learning approach and wonderment questions indicative of a deep approach. Basic information questions comprised factual and procedural questions. Wonderment questions, which were pitched at a conceptually higher level, included comprehension, prediction, anomaly detection, application, and planning or strategy questions. Basic information questions were typically either ignored or simply responded to with a short, simple answer without leading to further conceptual talk. On the other hand, wonderment questions engaged students' minds more actively, and engendered productive discourse, leading to meaningful construction of knowledge. Such questions stimulated either the questioners themselves or another student to generate an answer. Open-ended, problem-solving activities elicited more and a wider range of wonderment questions than teacher-directed activities where step-by-step instructions were given. Although the students did not always ask wonderment questions spontaneously, they were able to generate such questions when prompted to do so.

Discussion and implications for instructional practice

The findings reported above on the differences in students' learning strategies, explanations, questions, and behaviours can help teachers to be more aware of the learning approaches adopted by their students. If they recognise these, teachers can modify their instruction by using appropriate teaching strategies and nudging students towards deeper levels of thinking if the students are not already using deep learning strategies.

Typology of students' explanations

The finding that students typically give different types of explanations (reformulations of the question, black box, macroscopic, and microscopic) provides a framework within which different levels of student-generated explanations can be accommodated. This could help teachers recognise the quality of explanations that students give in relation to their learning approaches, as well as the attributes of effective and not so effective explanations. Thus, if a teacher finds that students are giving vague explanations pitched at only the black box level, he or she could guide them towards attempting to explain the processes involved in cause–effect mechanisms. That is, the explanation should answer the question of 'why' or 'how' a phenomenon occurs instead of, for example, merely restating an observation. To illustrate, a student may say that when water boils the temperature remains constant '*because it can't get any hotter*'. However, this response is not really an explanation but only a restatement of an observation. The teacher could then nudge the student to explain *why* this occurs and to account for the observation by postulating some cause–effect relationships.

Taxonomy of question types

Students' questions could be categorised according to varying conceptual levels that reflect their apparent depth of thinking. Such a classification could help teachers to be more sensitive to the type and level of questions that students ask (namely, basic information or wonderment questions), to recognise the learning approaches adopted by their students, and to encourage students to ask wonderment questions at a deeper level. So, if teachers find that their students are asking questions pitched at mainly factual and procedural levels (e.g. '*What do I do next?*'), they could encourage deeper thinking by providing stimuli to elicit wonderment questions (e.g. '*What would happen if ...?*'). Such stimuli might include inquiry activities that arouse curiosity in students, such as science experiments, eye-catching demonstrations and pictures, discrepant events, real-life specimens and concrete materials, thought-provoking or puzzling scenarios, unusual happenings and natural phenomena, and daily events that impinge on science concepts.

The teacher can also craft specific tasks related to these inquiry activities to stimulate students to ask questions that require them to explain, compare and contrast, hypothesise, predict, apply, and engage in deeper thinking. The teacher can also make students aware of the importance of asking higher order thinking questions, and teach them questioning strategies such as the syntax of question formulation and how to generate questions that would prompt them to, for example, compare and contrast, infer cause and effect, note pros and cons, evaluate ideas, explain, and justify. It is also important that the teacher model how to ask higher level questions as question-asking skills may be better caught than taught.

Nature of tasks

The nature of tasks that teachers set and the cognitive demands required of the students influence the type of questions that students ask, and thus to some extent the learning approach and learning strategies that they adopt. Consequently, this influences how actively students' minds will be engaged. If the assigned tasks require students simply to follow given procedures, the students will focus on how to perform the activity in accordance with the teacher's wishes and how to achieve the 'correct' results. Learning in such a context would lead students to ask mainly procedural questions to make sure they do things 'right', according to the teacher's expectations. There will be little exploration, thoughtful construction, or inquiry based on the students' own ideas. To encourage deep thinking in students, teachers should present laboratory activities in such a way as to encourage inquiry and problem-solving rather than following instructions to obtain an expected answer.

Variation in deep approaches and catering to individual differences

Even students who used a deep approach tended to be deep in different ways, reflecting individual differences (e.g. theorising as against drawing on personal experiences in daily life). This implies that students may be more prone to deeper thinking in some dimensions and contexts than in others. By being aware of the multidimensional nature of, or variation within, deep approaches, teachers could help students deepen their thinking by starting from contexts and dimensions where they already show some depth of thinking, that is, by tapping into the learner's 'conceptual ecology'. For example, if a teacher is aware that a particular student's strength lies in generating analogies, visual imaging, or relating to personal experiences, she can encourage the student to think in that direction during the cognitive processing of ideas. In this way, students with different learning styles and modalities would be encouraged to think more deeply in ways that are natural and perhaps more interesting for them.

As Woolnough (1997) has pointed out, students are different in their preferred ways of learning and this needs to be recognised in the way we treat individual differences in our teaching. By providing opportunities for a variety of teaching and learning strategies, we can encourage students to be mentally active and to work in the way that suits them best (Woolnough, McLaughlin and Jackson, 1999).

Assignment of students to groups

Wonderment questions can stimulate either the questioners themselves or another student to generate an answer, thereby bringing to the fore other deep learning strategies which have hitherto been latent, and potentially leading to talk at a higher conceptual level. An implication arising from this finding relates to how students are assigned for group work. If a teacher is aware that a particular student shows some depth in asking wonderment questions, would grouping this 'inquisitive' student with others who question less, help to steer the other group members in their thinking and co-construction of knowledge? Or would such a student dominate the group and hinder the others from asking questions? There is no clear-cut answer to this and the grouping might need to depend on the particular group of students involved, taking into account each individual's unique characteristics.

It is also possible that grouping students who manifest depth in different dimensions would lead to an optimum learning environment where each student can contribute in different ways to a more productive discourse. As Wood and O'Malley (1996) have suggested, individual differences can '*provide opportunities for each student to de-centre from their own perspective in an attempt to co-ordinate their views with those of their peers*'. To ensure success in collaborative group learning, when selecting students for groups the teacher would need to know how each student learns in such contexts.

Stereotypical roles in group work

When working on group activities, students may be inclined to assume roles that are congruent with their natural disposition, personality, and learning approach. Thus, for example, if a student wants to adopt a surface learning approach, he or she may be content simply to play a passive role and be minimally engaged, while allowing another member to play a more active role and carry out more challenging aspects of the task. Likewise, the more active student may also be satisfied in being able to dominate most of the thinking required for the given tasks. Put together, both members would seem to be comfortable with their roles and work reasonably well together. However, this natural state of affairs may reinforce and perpetuate individual differences in learning approaches and allow the learning gap between them to widen even further. Teachers need to be alert to such arrangements and to consider group composition, roles and task structure, to avoid accentuating differences that may disadvantage some students.

Latency of deep thinking processes

Student-generated questions and use of deep strategies are not always spontaneous. They are sometimes manifested only during another person's prompting or probing as a result of the interaction between the students' dispositions and situational circumstances. Thus, if left to their own devices, students may sometimes find it difficult to develop deep processing strategies on their own and may not use such strategies as often as teachers would like them to. This implies that teachers cannot fully rely on students' spontaneous use of deep strategies but may need to provide prompts and scaffolding, and explicitly orient students towards asking questions as part of class activities.

Providing scaffolding to encourage deep processing

Teachers can provide prompts to guide student discourse and explicitly require students to ask questions, predict, explain, and theorise during activities rather than hope that these would occur spontaneously. Students could write their predictions and questions before performing an activity to help them direct their own inquiry and use their questions as a springboard for investigation and discussion. They could also write questions as they work on their tasks. At the end of the activity, they could write questions regarding what had puzzled them, or what they wanted to know more about. Teachers could also ask students to explain how and why certain phenomena occur and to provide explanations for their own questions.

Providing students with a task structure may benefit different students to varying extents. Learners who already know how to use deep processing strategies may find them irrelevant or stifling because they may interrupt independent reasoning and distract them. On the other hand, others may find the scaffolds helpful in stimulating and guiding their thinking.

Non-canonical ideas in deep approach – is using a deep approach productive for all learning situations?

Using a deep approach can sometimes lead a student to form ideas that are scientifically incorrect. This may occur because the student does not simply accept standard answers unthinkingly and thus generates alternative ideas, although it also depends on his or her starting point. However, other deep processing strategies can help such students detect conflicts between evolving ideas and what is correct. On the whole, this may have a compensatory effect and lead to improved learning in the long term. After all, great scientists and deep thinkers such as Newton had inappropriate conceptions before constructing more adequate conceptual models. Teachers are mainly concerned about content mastery and the correctness of students' ideas. But in teaching that stresses inquiry and sense-making, invariably some of what students say and do will be incorrect. Reasoning is often messy when students grapple with nascent ideas in their groping and exploration as they construct meanings, develop conceptual knowledge, and restructure their conceptual frameworks to accommodate new understanding. However, as inquiry, such a process may be seen as fruitful and productive.

Conclusion

The use of deep processing strategies is necessary for meaningful learning in science. To encourage deep learning and minimise surface learning amongst their students, teachers need to know what 'good' learners do when they are engaged in a task, and then devise teaching strategies that will elicit these deep processing behaviours. In addition, it is important that teachers recognise and encourage deep learning in their students when they detect it. If teachers are aware of the subtle differences in their students' thinking, verbal responses, and behaviours, they can be more perceptive of their students' learning approaches and give more appropriate responses to them. In this way, they can adapt their teaching to cater to individual differences in learning approaches so as to foster deeper levels of thinking in their students. Furthermore, if deep thinking is to be encouraged and sustained, it needs to be rewarded, especially in tangible ways. Only when students experience the satisfaction of thinking at the 'deep end' will they be encouraged to 'venture out of the shallows'.

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