

Alternative Conceptions on Excretion and Implications for Teaching

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Research on children's understanding of science subject matter shows that students develop alternative conceptions for a number of reasons. This paper illustrates how such knowledge can be used to improve the design of classroom instruction. Students' problems in understanding the concept of excretion are probed with a multiple-choice item followed by an interview. The results suggest that understanding may be promoted by using instructional strategies that build on students' existing knowledge, elicit conceptual development, discriminate the use of everyday language in a scientific context and establish meaningful connections between new and old concepts.

Introduction

Research on children's understanding of science subject matter in the past two decades shows that students hold many informal ideas that deviate from proper scientific concepts even after teaching (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Garnett, Garnett, & Hackling, 1995; Sanders, 1993; Wandersee & Mintzes, 1987). Different workers have used different terms to describe these erroneous views, such as misconceptions (Lawson & Thompson, 1988), preconceptions (Hashweh, 1988), prescientific conceptions (Good, 1991), alternative conceptions (Gilbert & Swift, 1985) and alternative frameworks (Driver & Easley, 1978). This confused state of terminology has created some barrier preventing practising teachers from comprehending the research findings in this field and applying them inside the classroom. The variety of terms now in use, on the other hand, is related to the different underlying

idiosyncrasies held by different groups of science educators, which reflect the complex nature and multiple causes of children's informal conceptions (Wandersee, Mintzes, & Novak, 1993).

The term *misconception*, for example, is easily understood by both practising teachers and the general public, but it provides little information on the nature and origin of children's misunderstandings. The terms *preconceptions* and *prescientific conceptions* are preferred by some workers because they are less negative and focus our attention on the impact of informal ideas developed by children prior to teaching (Hashweh, 1988). According to this view, the learning process should make children aware of the inadequacy of such ideas before introducing the scientific views. By emphasizing on children's pre-existing ideas, however, this approach undermines the effects of other factors that may contribute to problems in understanding. The terms *alternative conceptions* or *frameworks* confer intellectual respect to children's informal ideas which are viewed as explanations constructed by children through their own experiences. Instructional strategies that take into account of these ideas can effectively lead to conceptual reorganization and the construction of formal scientific conceptions (Driver & Easley, 1978; Gilbert & Swift, 1985). As this approach is more compatible with the constructivist view of learning, the present paper will use the term *alternative conceptions* to denote in general any ideas held by children that are inconsistent or in conflict with those generally accepted by scientists.

An important outcome of the studies on children's alternative conceptions is to reveal possible causes of their problems in science learning. This knowledge will provide clues for the device of effective teaching strategies that may prevent the development of misunderstanding and lead to conceptual changes. According to the nature of learning problems, children's alternative conceptions can be put under the following categories:

1. informal ideas formed from everyday experiences which children bring into the classroom;
2. erroneous ideas developed during teaching due to lack of understanding; and
3. wrong concepts propagated by teachers and textbooks.

Erroneous views of the first type originate from children's informal ideas formed from everyday life experiences prior to formal teaching. They have been found to be highly resistant to change and can only be modified by instructional approaches that take into account such pre-

existing ideas (Hewson & Hewson, 1983; Driver et al., 1994; Mintzes, Trowbridge, Arnaudin, & Wandersee, 1991).

The second type of alternative conceptions may be caused by the lack of prerequisite concepts, which are necessary for the construction of a new idea into the cognitive structure. Accordingly, it is essential to ascertain that such concepts are mastered by students before starting a new study area (Ausubel, 1968; Garnett et al., 1995). Another possible cause is an undue emphasis on the acquisition of factual information, which encourages students to memorize new materials as isolated events. This problem may be overcome by helping students to make meaningful connections between new and existing concepts, which will lead to better understanding and integration of the learned materials (Nunez & Banet, 1997).

The last class of erroneous ideas are related to the fact that many teachers, including those with experience, show incomplete or fragmented understanding of various science concepts which they may propagate to their students through inaccurate teaching or uncritical use of textbooks (Barras, 1984; Sanders, 1993; Yip, 1996b). One way to resolve this problem is to incorporate into undergraduate and teacher training courses programmes that aim at clarifying difficult science concepts and promoting an awareness of the nature and impact of children's informal ideas on science learning.

Studies on children's understanding of life science have revealed that students harbor many alternative conceptions relating to basic biological concepts after teaching (e.g. Driver et al., 1994; Sanders, 1993; Songer & Mintzes, 1994; Westbrook & Marek, 1991). An area that constantly causes learning problem is concerned with the concept of excretion. For instance, many students fail to distinguish between excretion and egestion even after deliberate instruction, and their ideas on excretory wastes are confusing (Soyibo, 1995). Despite the fact that such students' errors are well known to biology teachers, no effective instructional strategy has so far been devised to deal with this problem and many students continue to show the same misunderstandings year after year. This situation suggests that research findings on children's alternative conceptions have not been adequately translated into classroom practice and school science learning has not been duly benefited from such efforts.

It is with this background in mind that the present study is launched to address the issue of how information about children's problems in conceptual development can guide the planning and sequencing of classroom

instruction and activities that will promote meaningful learning. This two-phased study attempts to explore the understanding of the concept of excretion among a very large number of children on one hand and probe into the underlying conceptual problems in a smaller sample on the other hand. The first phase involved an analysis of the student profile of choices made on a multiple-choice item in a public examination. It would provide information about the nature, prevalence and distribution of misconceptions among students of different abilities. The second phase was a structured interview conducted on a small number of students. It aimed at exposing possible learning difficulties of the students that would have impeded conceptual changes and caused formation of erroneous ideas. Based on the information about the nature and causes of erroneous ideas thus identified, suggestions are put forward to guide the selection and sequencing of instructional materials.

Method

A Multiple-Choice Item on Excretion

The Hong Kong Certificate of Education Examination (HKCEE) is a public examination for all Form 5 leavers (age 17+) who have completed a 5-year secondary curriculum. The Biology examination consists of two papers: Biology I is made up of structured questions and Biology II is a multiple-choice paper consisting of sixty items. The 1996 Biology examination was taken by 32,508 candidates who had followed a 3-year course of Integrated Science in the junior secondary level and a 2-year course of Biology in the senior secondary level. The first phase of the present study involves an analysis of candidates' performance on an item in the 1996 Biology II of the HKCEE, which is concerned with the concept of excretion (Figure 1).

Figure 1 A Multiple-Choice Item Assessing the Concept of Excretion

Which of the following is an excretory process?

- A. exhalation
- B. removal of undigested wastes
- C. release of saliva
- D. vomiting

While the frequency of choices made by the students on the distracters may reveal the prevalence of certain misunderstandings on excretion, the pattern of responses across ability groups can provide some insight into the nature of the misconceptions. According to their overall performance in this paper, the candidates were divided into ten ability groups of equal numbers; the first 10% ability group included candidates with the lowest scores while the top 10% ability group was made up of those with the highest scores. The numbers of candidates in the ten ability groups choosing each option are presented in the form of a graph. The patterns of performance thus obtained would illustrate how well an option, whether it be the key or a distracter, discriminated the high-ranking and low-ranking candidates.

The Interview

The second phase of the study was an interview conducted on 32 students near the end of their first year of the HKCEE biology course. These subjects were chosen randomly from two schools of average academic standard. They had completed about half of the 2-year syllabus including the topics on nutrition, gaseous exchange and excretion. In the course of classroom instruction, their subject teachers had specifically highlighted the distinction between the processes of excretion and egestion, which had been asked in past HKCEE biology papers in several occasions. Before taking the interview, the subjects worked on the multiple-choice item on excretion. The interview was made up of a set of preplanned questions and follow-up probes. The preplanned questions were introduced in the same order and the follow-up probes were used when the subject showed problems in comprehending the interviewer's questions or when the meaning of a response was ambiguous. The interview for each subject lasted about 10 minutes and was tape-recorded, with the subject's consent, for later analysis. The subjects' responses in the interviews were evaluated to identify the nature and causes of misconceptions on excretion. Sample questions used in the interview included the following:

- You consider that ... (quoting the actual wording of the option chosen by the subject) is an excretory process. Why do you think so?
- How would you distinguish between "excretion" and "egestion"?
- Can you name two other substances that are excreted by your body?

Results and Discussion

The Multiple-Choice Item

This item, assessing the concept of excretion, seems to be a straightforward, low-level question asking for simple recall of information. The students' responses across ability groups are summarized in Figure 2. Inside the legend box, the value within each bracket indicates the percentage of candidates choosing a particular option, and the key is marked with an asterisk. The graph of the key, i.e. option A, shows a good correlation between the scores of individual ability groups and their rank orders, indicating that this item effectively discriminated the abilities of the students. This is supported by a relatively high discrimination index of 0.4 for option A. The point biserial correlation is used to calculate the item-test correlation, which serves as the discriminative index of the item as follows:

$$D = \frac{y_1 - y}{\sigma} \sqrt{\frac{p}{q}}$$

where

y_1 = mean paper score of candidates getting the item correct

y = mean of paper

σ = S.D. of paper

p = $\frac{\text{difficult index of the item}}{\text{total number of candidates attempting the item}} = \frac{\text{number of candidates selecting correct answer}}{\text{total number of candidates attempting the item}}$

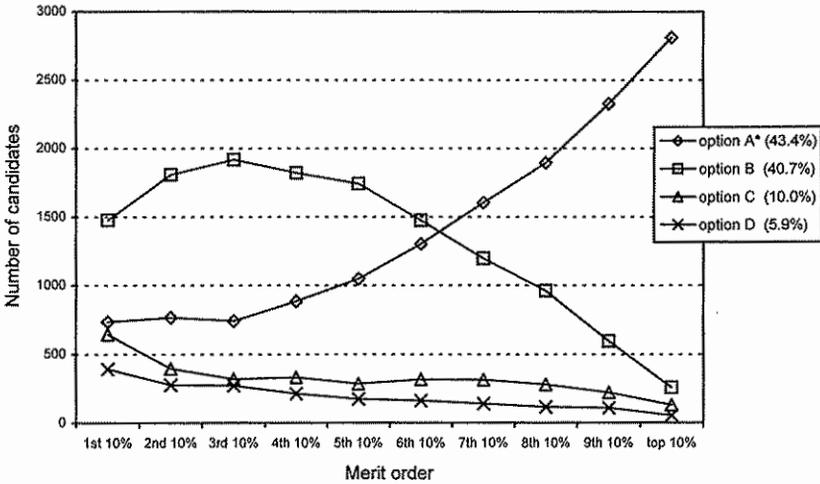
$q = 1 - p$

As a rule of thumb, a discrimination index greater than or equal to 0.2 is usually considered as acceptable.

The concept of excretion is fundamental to the secondary biology curriculum and is usually introduced to students at a very early stage of the course when teaching about the characteristics of living organisms while the mechanisms of excretion are elaborated at a later stage (Chan, Chu, & Kong, 1994; Pang, 1993). The poor performance on this item is therefore rather surprising as it was correctly answered by less than half of the candidates (43%); most students did not view exhalation as an excretory process. One possible reason for the low success rate is that many students were not able to relate the removal of carbon dioxide during exhalation to an excretory role, as exhalation was learned in the context of ventilation and not linked with excretion.

Option B was a very strong distracter as it attracted about the same number of candidates (40.7%). These students wrongly considered the

Figure 2 Performance on the Multiple-Choice Item on Excretion



undigested waste as an excretory product. The graph for this option shows that this erroneous view was prevalent among the middle- and low-ability groups. This pattern suggests that the idea of metabolic waste is a difficult and abstract concept for the average student and is not well understood even after formal instruction.

A smaller but significant proportion of the students, by choosing option C, considered wrongly that the release of saliva was an excretory process. This indicates that some students tend to consider that secretions made by the body usually contains some unwanted materials, which does not hold true for saliva. This reflects some confusion about the nature and roles of secretion and excretion in biological processes. It is interesting to note that this conceptual problem was shown by students of all ranks to a similar extent, which means that even some of the high ability students had difficulties in distinguishing the two processes.

The Interview

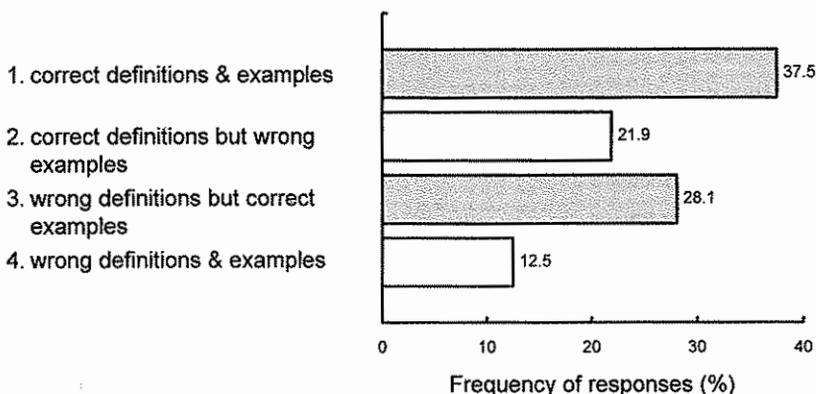
The 32 subjects involved in the second phase of the study worked on the multiple-choice item before attending the interview. The overall performance of this small group of students showed a similar pattern as that of the larger population who took the Certificate paper, with most of them

choosing the key (option A) and option B. As the purpose of the interview was to probe into students' reasons for making their choices, the main focus of the evaluation is to analyse the underlying conceptual problems and misunderstandings of the students. According to the responses given in the interviews, the subjects can be categorized into four groups which reflect different degrees of understanding of the excretory process. The nature of the four categories, the number and percentage frequency of the subjects in each group are summarized in Figure 3.

The subjects of the first category provided scientifically acceptable definitions for excretion and egestion. They were able to give two correct examples of excretory wastes of the body, which include carbon dioxide, urea, mineral salts and bile pigments. When asked about the nature of the undigested waste, they could point out correctly that it was not a waste substance produced by activities of body cells and so should not be classified as a metabolic waste. This group of subjects was considered to demonstrate an adequate level of understanding of the concept of excretion. However they constituted only a small minority of the sample population.

The subject of the second category appeared to be able to define excretion and egestion correctly, but further questioning revealed that they simply learned the definitions by rote and the examples they gave for excretory substances were incompatible with their definitions. For instance, they considered the undigested material in faeces as an excretory

Figure 3 The Distribution of the Subjects' Responses in the Interview



waste. According to their understanding, egestion was a special mode of excretion, being the elimination of undigested waste from the gut while excretion also involved the removal of urine.

Many of the subjects in this group, as well as a few of the subjects in the first category, were uncertain whether carbon dioxide in the exhaled air should be considered as an excretory product or not. This is consistent with the results obtained in phase I in which most students failed to consider exhalation as an excretory process.

The failure to relate exhalation to an excretory function may be attributed to the fact that exhalation is taught in Hong Kong in the context of ventilation. When explaining the mechanism of gaseous exchange, teachers and textbooks seldom state explicitly that carbon dioxide is a metabolic waste or refer to the process of removal of carbon dioxide during breathing as excretion. This reflects that teachers tend to present different topics in isolation with little attempt to make meaningful connections between the various themes of the curriculum during classroom instruction.

The subjects of the second category also gave a variety of wrong examples of excretory products such as sweat, urine and bile. These responses may not reflect the existence of wrong conceptions but rather suggest the subjects' imprecision in the use of terms which may lead to confusion about the nature of metabolic wastes.

The subjects of the remaining two groups failed completely to distinguish between excretion and egestion. They did not seem to have a clear concept of metabolic waste and tended to consider that excretion denoted the removal of any wastes from the body. Although the subjects of the third category were able to give correct examples of excretory wastes, further questioning during the interview revealed that their answers were not based on a sound understanding but were elicited by memory or by chance. For example, some stated correctly that carbon dioxide was an excretory waste but they could not justify their answer with a valid reason. On the other hand, many of them were not certain whether the undigested waste in the faeces was a metabolic waste or not. Despite special attention having been given by the teacher to clarify excretion and egestion in the lesson, the persistence and prevalence of the alternative conceptions on excretion is both surprising and disturbing. It supports the view that the didactic and teacher-centered approach may not be effective in promoting conceptual changes.

Pedagogical Implications

Considering that excretion is a fundamental concept in biology and is usually introduced to students at the very beginning of the biology courses in Hong Kong (Chan et al., 1994; Pang, 1993), it is disappointing to see that most of the students, having completed the secondary curriculum, still fail to develop a proper understanding of this concept, as demonstrated by the performance of students on a multiple-choice item on excretion and evaluation of their responses in a subsequent interview. What makes this basic concept so difficult to our children? What are the barriers to their conceptual development? Has anything gone wrong in the process of classroom instruction? Some aspects of these questions may be answered by examining the contexts in which the idea of excretion is introduced to our children from a constructivist point of view.

Reconsidering the Teaching Sequence

The seven characteristics of life (i.e. nutrition, respiration, movement, irritability, excretion, growth, and reproduction) are normally introduced at the very beginning of the biology course, a time when children have few ideas of cell structure and function. Without any prerequisite knowledge on how the cell works and maintains its life processes, it is impossible for students to visualize and understand the invisible and abstract cellular processes such as respiration and excretion. Consequently, children simply memorize these "characteristics" by rote with little comprehension, as revealed by their inability to apply these attributes in a critical and sophisticated way (Arnold & Simpson, 1979). Once learned in this way, it is difficult for the children to modify or refine their understanding of the concept of life when they acquire more subject knowledge. Even tertiary biology students are found to memorize these attributes as fragmentary facts and lack a clear picture of the scientifically accepted concept of life (Brumby, 1982). Loading young children with biological terms such as nutrition, respiration, excretion, locomotion, irritability and reproduction with little concept development may also encourage memory work. This concern is particularly relevant in Hong Kong as English is a second language to the majority of secondary school students. Presenting a formidable list of vocabulary for students to commit to memory without understanding is a common practice of local biology teaching. The strong emphasis on the ability to recall leads our students to believe that biology is static and consists of a collection of unrelated ideas (Hong Kong

Examinations Authority, 1996, p. 183; Yip, 1996a). Such a belief will foster in them a negative attitude towards the study of biology, and suppress their initial interest and curiosity in attempting to understand the wonders of the living world.

Another problem with this traditional way of defining life is that it is biased towards the more noticeable features of animals such as feeding activities, movement and consciousness. Such an animistic notion of life has created problems in conceptualizing plants and other immobile organisms, including seeds and eggs, as living systems, among children of all ages and even among adults (Looft & Bartz, 1969; Smeets, 1974; Stavý & Wax, 1989; Tamir, Gal-Chappin, & Nussnovitz, 1981).

To avoid rote learning and the formation of inaccurate ideas of the concept of excretion, teachers need to reconsider whether it is appropriate and desirable for children to study the traditional seven characteristics of living organisms at too early a stage. If these are to be introduced at all, they should be limited to life processes that can be directly observed or concretely experienced by children, such as the abilities of moving around, obtaining food, responding to changes in the environment, growing in size and giving rise to young ones. The concepts of respiration and excretion as attributes of life may have to be postponed until students have secured some prerequisite ideas on cellular metabolism, so that they are cognitively ready to appreciate the significance of these processes in maintaining the living state.

Defining life in terms of the seven attributes also imposes a highly restricted view of the living system. It undermines the significance of activities occurring at the biochemical and cellular levels, such as energy transformations and the roles of DNA and other organic constituents, which are crucial for the establishment of a self-maintaining, self-duplicating and self-perpetuating system.

Using Everyday Language in a Scientific Context

The problem with the concept of excretion is compounded by a confusion about the meaning of metabolic waste. In everyday usage, the term "waste" refers to all unwanted, harmful substances. It is therefore natural for students to include undigested materials egested from the gut as a body waste and regard excretion and egestion as synonyms (Soyibo, 1995). Furthermore, the Chinese terms for excretion (排泄) and egestion (排遺) are not easily distinguishable; this can also lead to confusion in their

meanings, especially when such terms are sometimes introduced indiscriminately in the primary health education course. As the erroneous conception of waste is already established in the children's cognitive structure before formal instruction, it cannot be easily displaced even after the teacher has explicitly pointed out the differences between undigested and metabolic wastes, as revealed by the students' responses in the present study. The preconception cannot be rectified by simply telling students what is right or wrong.

An instructional strategy that has been shown to be effective is to create a cognitive conflict in which students are made aware of their existing misconception and motivated to construct a scientific view which is more plausible and productive (Hashweh, 1986; Hewson & Hewson, 1983; Nussbaum & Novick, 1982). It is difficult to convince children to accept that the undigested waste in faeces should not be treated as a metabolic waste. A useful set that challenges students to reveal and reflect on their preconception is to ask the class to imagine a situation in which a child had accidentally ingested a small coin, which later came out from the body with the faeces. The students can then be guided to realize that the coin, together with the undigested waste, has never been a part of the body and is not produced by cellular activity. Such a consideration will lead the students to realize that the undigested material in the faeces, like the coin, is not a metabolic waste and appreciate the subtle difference between excretion and egestion.

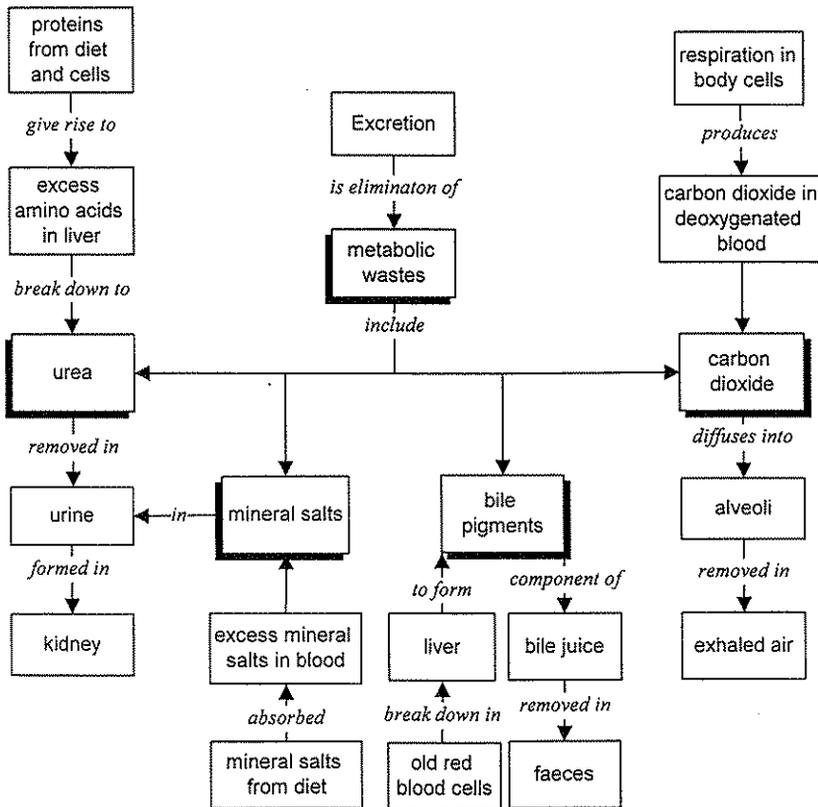
Establishing Meaningful Relationships Across Subject Areas

A basic problem of the traditional textbook-based organization of subject content in biology is that concepts and principles are learned within distinct topic boundaries in isolation. There is little attempt to integrate different themes across the syllabus for developing a better understanding of the holistic nature of body functioning. Students may have acquired detailed information about the structure and functioning of different parts of the body, such as the digestive, breathing and excretory systems, but may fail to appreciate how these systems work together as an integrated whole (Nunez & Banet, 1997). This could explain why so many students cannot establish a meaningful relationship between exhalation and excretion.

To resolve this problem of compartmentalization of concepts in the study of biology, teachers should make constant cross reference to link up

different topics. An effective and convenient way to achieve this could be by the use of concept maps (Novak & Gowin, 1984). For instance, after introducing the concept of excretion but before elaborating on its mechanisms, a concept map showing the relationships between excretion and other major body processes, such as the breathing and digestive processes, will help students to gain a better understanding of the meaning and significance of excretion in the body (Figure 4). Alternatively, students can be given a list of concept labels and asked to construct a concept map that link them together. This exercise can motivate students to explore and construct meaningful relationships between other pre-existing concepts. The concept map thus obtained can serve as an advance organizer that may

Figure 4 A Concept Map Linking Excretion and Other Metabolic Processes



facilitate the incorporation of new subject content into the cognitive structure. It also provides a chance for students to use the concept of excretion in a variety of situations, a process that has been found to facilitate conceptual changes (Driver, Guesne, & Tiberghien, 1993).

The problem of compartmentalization of concepts is exacerbated by the prevalence of examination questions that stress students' ability to re-state knowledge stipulated by the syllabus. This type of assessment tends to promote stereotyped application of knowledge within restricted subject areas. One way to discourage this learning style is to set questions that require the synthesis of ideas learned in a variety of contexts or topics, as exemplified by the multiple-choice item used in the present study and the guiding questions used in the subsequent interview. More frequent use of this type of questions will alert both teachers and students to value the importance of establishing meaningful associations between different subject areas in the process of teaching and learning.

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