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Cues, Links and Memory Stores: A Description of How Students Explain in Science

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Introduction

What do students do when they explain? What cognitive processes are used to generate an explanation? Answers to these questions will enable us to understand why some students explain poorly and to help them to become more proficient in applying their knowledge to explain.

There are quite a few types of explanations (see Brown & Armstrong (1984) for a typology). In science, each discipline has its preferred mode of explaining. For physics and physics education, the deductive-nomological (D-N) model is a common model. According to Hempel (1965), the best examples of explanations conforming to the D-N model are based on physical theories of deterministic character. In physics education, Strube (1989), in his content analysis of explanations found in physical science textbooks, noted that "explanations seems to be centred in these texts on the development of science as formal deductive systems where the application of axioms and laws leads to deducible results"(p.201). A D-N explanation of a phenomenon is formed by invoking some particular facts of the phenomenon (the antecedent conditions) and some general laws. The phenomenon to be explained is deducible from these two groups of explanatory facts. Thus we can see that the ability to apply scientific theories, laws and principles learned in physics education is very essential for explaining physical phenomena.

Two educational models are useful for describing the generation of scientific explanations. One is by Benjamin Bloom, the other is by Merlin Wittrock and Roger Osborne. According to Bloom (1956), the problem-solving process in answering questions in the "Application" category involves perception of the problem presented, restructuring of the problem in a familiar context, classification of the problem as familiar in type, selection of abstraction and finally solving the problem. Osborne & Wittrock's (1985) generative learning model gives other important clues on the psychological processes of generating explanations. For them, "the generative learning model is centrally concerned with the influence of existing ideas on what sensory input is selected and given attention, the links that are generated between stimuli and aspects of memory store, the construction of meaning from sensory input and information retrieved from long term memory" (p.64). The combination of Bloom's model and Osborne & Wittrock's model highlight the importance of cue perception, memory store retrieval and link formation in the process of forming explanations. The type of cues attended to will affect the restructuring and classification of the problem presented. Similarly, the type of links that are formed to connect the stimuli and memory store will also affect the outcome of the process of forming explanations.

Research on alternative frameworks in science education has shown consistently that secondary school students, despite having been instructed in scientific theories, laws and principles, do not readily apply their acquired knowledge when they explain everyday phenomena (e.g. Champagne, Gunstone & Klopher, 1983; Driver & Oldham, 1986). Instead of scientific principles, a large proportion of students apply what has been termed by Linn & Songer (1991) as action knowledge and intuitive conception when they form explanations. Further, Solomon (1986) found that secondary school students had a tendency to use precausal explanations - reaffirmation, teleology, tautology and simple juxtaposition - when they explain, especially when they encounter new and unfamiliar contexts. These two studies on alternative frameworks in science education and others suggested that both the content and method of explanation used by students are different from those that are acceptable in science. This article will not focus on the content of students' explanation - an area that has already been well-documented in the last 20 years of research (see, for example, Wandersee, Mintzes & Novak, 1994; Driver, Squires, Rushworth & Wood-Robinson, 1994). Instead it attempts to extend our understanding of how students explain by focusing on the psychological processes involved.

While it is important to know the psychological processes that students use when they explain, it is more important, from a pedagogical point of view, to know how we, as teachers, can help students to become more proficient at generating scientific explanations. Getting students to abandon their alternative frameworks in favour of the scientific framework has been the focus of conceptual (or conception) change research. A number of conceptual change techniques has been reported in the journals (see Wandersee, Mintzes & Novak, 1994:191-193, for a review). These techniques can be classified broadly into two categories: one involving externalising and modifying the cognitive structure, the other involving monitoring and controlling learning. These techniques are useful (some even say, effective) at remediating students' misconceptions. As good as they claim to be, they are only reactive techniques. They are employed to change students' conceptions when these conceptions are discovered. They are powerless at getting students to avoid using non-scientific conceptions. In this study we hope to extend our knowledge of conceptual change techniques by exploring the possibility of developing pro-active techniques.

To do that, we need to understand the interaction of students' prior knowledge with knowledge presented in formal instruction. According to Gilbert, Osborne & Fensham (1982) and Osborne, Bell & Gilbert (1983), this interaction can result in five broad categories of unanticipated instructional outcomes. They are: the "Undisturbed Children's Science Outcome", the "Two Perspectives Outcome", the "Reinforced Outcome", the "Mixed Outcome" and the "Unified Scientific Outcome". All these outcomes, we believe, are the result of students learning concepts and principles to different levels of understanding. Klausmeier (1985) theorised that concepts and principles in formal instruction can be learned at four successive levels of understanding: concrete, identity, classificatory and formal. In order to do higher order skills such as problem solving and explaining competently, concepts and principles have to be learnt to the classificatory level, if not the formal level.

We postulate that students who use scientific frameworks consistently in their explanations have learnt the relevant concepts and principles to a higher level of understanding than students who use alternative frameworks in their explanations. If this hypothesis is supported by empirical findings, then the implication is that proactive techniques in dealing with conceptual change should include methods of equipping students with the mental tools to think and to communicate. Without these mental tools, students would be limited to living in a world of sensory perception and communicating with superficial and trivial ideas.

In this study students respond to 2 tests on the topic of heat conduction. It begins by characterising students' written explanation in terms of the psychological processes involved in generating explanations. The characterisation involves analysing the type of cues they attend to when they answer a why-question, the memory stores they access when they search for abstractions and the type of links they make to connect the cues and the memory stores. The study also examines the relationship between the psychological processes and topic knowledge recognition. Content knowledge recognition is defined as the ability to distinguish propositions in a particular content topic from propositions of related topics.

Method

Sample

The students who participated in this study were secondary 3 students from two schools in Singapore. One is a highly-ranked school which takes in students who are in the top 10% of the PSLE. Most of the students from this school will move on to junior college. The other school is an unranked school where students are generally of a lower ability. Most of the students will join the workforce after four years of secondary schooling. Two intact classes from the first school and three intact classes from the second school participated in the study, making a total of 160 students. The school curriculum structure in each school did not permit random sampling from the classes concerned. After weeding out incomplete responses in the tests taken by the students, the responses from 141 students (70 males and 71 females) were analysed. At the time of testing, all participants had completed a unit on heat transfer, which included topics such as conduction, convection and radiation. They had also been introduced to these topics at primary 5 and secondary 1, as an outcome of a spiral curriculum structure.

Tests

The students took a battery of 2 tests, taken one at a time. The time given for the completion of the whole test battery was 15 minutes. The tests were not speed tests; all participants completed the tests within the time allocated.

A written explanation test comprising 3 questions formed the first test. All the questions were why-questions testing the application of scientific principles of heat conduction. Students' responses were analysed and coded according to the type of cues attended to, the memory store accessed and the type of links generated to connect the cues with the memory store.

Next, students took a content knowledge recognition test. Fifteen true propositions from the topics of heat conduction, convection and radiation were randomly ordered. Students had to identify five propositions related to the topic of heat conduction.

Coding of written explanations

The responses in the written explanation were coded according to the memory store accessed by the students, the type of cues in the question attended to and the links generated between the cues and the memory store.

It is postulated that students have at least three memory stores: a scientific principle (SP) store, an action knowledge (AK) store and an affected conception (AC) store. The SP store refers to the students' store of acquired knowledge of scientific principles. It contains a well-connected network of scientific abstractions that have been internalised by the student. Explanations containing scientific principles are said to be generated by students accessing the SP store. The AK store is a store of unreflected intuitive ideas. The propositions in the AK store are similar to the findings of students pre-school ideas in alternative framework research. Examples of action knowledge in the area of heat conduction include references to heat as a substance which flow from one place to another and references to observable properties of material (such as hardness and nature) when explaining differences in conductivity (see Driver et al., 1994 for a review). The AK store and the SP store correspond quite closely to the two domain of knowledge (life-world and physics) discussed in Solomon (1983). The store of affected conceptions contains ideas that are neither scientific principles nor action knowledge. It is a store of action knowledge that had undergone some incomplete and unsuccessful integration with scientific principles. Sometimes, affected conceptions are the result of careless learning on the part of the part of the student. Sometimes, they are the result of poor teaching on the part of a teacher. On a continuum between AK and SP, AC lies somewhere in the middle. Some elements of "students' science" and "teachers' science" (Gilbert, Watts & Osborne, 1982) are components of the AC store. In this study, affected conceptions refer to ideas that a competent teacher would hesitate to accept as completely correct or reject as completely incorrect.

Students' written explanations were also examined for evidence of cues attended to. Three types of cues are proposed for the classification of cues attended to by students to the stimuli in the questions: central cues (CC), peripheral cues (PC) and irrelevant cues (IC). Central cues are those elements in a question that defines the questions. If the question has to be reworded in fewer terms, the central cues must be the ones that remain unchanged. They are the basic elements in a question, without which the question will lack focus and the question may admit more than one scientific answer. Peripheral cues are those elements in a question that provide additional details. These details are like garnishes on a plate of gourmet cuisine. They do not define the question and they can be easily replaced by other details without seriously altering the main idea and supposition of a question. When answering a question with a scientific explanation, there is no necessity to attend to peripheral cues. Irrelevant cues are cues that are not found in a question. Students bring irrelevant cues into a question when they interpret a phenomenon in the question using their knowledge of past experiences. The use of irrelevant cues can be inferred from an answer that contain references to terms not mentioned in a question. In the question, *Explain why cooks do not burn their bodies when they stand close to a hot stove while cooking food?*, the central cues are "heat from the hot stove not reaching the cook's body". Peripheral cues of this question include cook's clothes, size of the flame, structure and material of the stove and the type of food being cooked. Irrelevant cues of this question include the cook's ability to perspire, the emission of steam from the food and the condensation of steam in the air, amongst others.

Two types of links generated by students were studied. They were internal links (IL) and external links (EL). Students made internal links when they looked only for connections among the elements in a question. The phenomenon in a question was explained by connecting the parts of the phenomenon with one another. There was no attempt to link the parts of the question with something else so that there might be a new perspective for viewing the phenomenon. Examples of explanations with internal links include redescription of the phenomenon to be explained in different words but with similar meanings and other precausal explanations (Piaget, 1928:225) such as juxtaposition and reaffirmation. Students make external links when they connect the phenomenon to be explained with some other real or possible happenings. The phenomenon is taken as a whole and there is an attempt to view this whole from a new perspective. Explanations generated by external links are explanations that have "semantic movement" (Solomon, 1986). Such explanations move away, in terms of meaning, and then return with some new perspective for viewing the problem.

Analysis of data

After the written explanations were coded and checked for reliability, descriptive statistics were used to give an account of the students' written explanation.

In the content knowledge recognition test, we studied the group performance of students who consistently accessed a particular memory store, attended to a particular cue and generated a particular link in the written test. For example, students who accessed their AK store in the three questions of the written test were grouped together and their mean score of the content knowledge recognition test was calculated. We also examined the group scores of the content knowledge recognition test of students who were fairly consistent in using a particular memory store, cue or link. For example, students who accessed their AK store in two out of three questions of the written test were grouped together and their mean score for the content knowledge recognition test was calculated.

Results

Characteristics of students explanations

Analysis of the 423 explanations in the written test showed that majority of the explanations were generated in ways that were scientifically unacceptable. Less than half of the explanations (41%) were generated by accessing the SP store. The percentages of explanations generated by accessing the AC store and the AK store were 33% and 26% respectively. As for the generation of links, more explanations were generated by external links (68%) than by internal links (32%). When we studied the cues attended to by students, we found that half the explanations were generated by central cues (51%); the percentages for peripheral cues and irrelevant cues were 40% and 9% respectively.

Table 1 describes how students typically generate written explanations. We found that more explanations were generated by attending to central cues and accessing the SP store (28%) than by attending to other cues and accessing other memory store. When we examined the memory store accessed and the links generated when students write explanations, accessing the SP store with the external links generated the most explanations (38%). The combination of external links and central cues generated more explanations (40%) than any other combination of cues attended and links generated.

Table 1 also showed some disappointing results. About a third of the written explanations and about a quarter of the written explanations were generated by accessing the AC and AK store respectively when we disregard the cues attended and the links generated. After studying the type of explanations generated by students, we examined the proportion of students who were consistent in their access of a particular memory store, their attention to a particular type of cues and their generation of a particular link. Table 2 shows that only 10% of the students use scientific principles in all the three explanations. While this percentage might not appear very encouraging, what is pleasing to note was that even smaller percentages of the students access their AK store and AC store consistently (3% and 4 % respectively). A systematic search found a large group of students (71%) who accessed a particular memory store in 2 out of 3 explanations. However, there were more students accessing their SP store than students accessing their AK store or AC store, even though they were not very consistent. As for the generation of links, a fairly large group of students (36%) could generate external links consistently. Combined with students who generate external links in 2 out of 3 explanations, we had a sizeable proportion of students who had a general tendency to write explanations with some "semantic movement". The same can also be said of students who attended to central cues in a question. In all, the general indication shown by results in Table 2 seemed to indicate that we had fairly small proportions of students who were very consistent in using unacceptable processes of generating explanations; what we had was a large proportion of students who were not consistent in the way they generate explanations.