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Generation of Spontaneous Analogies by Students Solving Science Problems

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Snow (1961) described the gap between the technological and humanistic orientations in modern society as a gap between "two cultures" and viewed many modern problems as arising from the lack of communication between them. It is possible that a similar gap exists between the experts who teach introductory college science and the naive student attempting to comprehend a scientific discipline for the first time.

Recent data on persistent preconceptions in physics, for example, (Clement, 1982, McCloskey, 1983) show that students bring preconceptions with them to class, which resist modification and prevent the student from assimilating new material.

In addition to using a new vocabulary and a qualitatively different set of concepts and beliefs, it is worth considering whether the expert may also use a different set of reasoning processes from the naive student. This paper looks in particular at analogical reasoning, a component of scientific thinking in experts, and asks whether students can use this reasoning process as well. The answer to this question should speak to the larger issue of the width of the gap between the two cultures of students and experts.

The question becomes more important when we note that analogies have long been advocated as a powerful tool in teaching. There is evidence that experts can use analogical reasoning to help them resolve conceptual difficulties during problem solving (Clement, 1981). We suspect that analogical reasoning can also be used to help students resolve their conceptual difficulties. But we suspect that they need to *do* the reasoning, not just memorize the two connected sides of an analogy, in order to increase their understanding. Thus, it is an important question as to whether students can reason analogically or whether this is a process that is part of the private repertoire of a privileged group of experts.

USE OF ANALOGIES BY EXPERTS

Evidence that experts use analogical reasoning comes from several types of sources including philosophical studies (Hesse, 1966), historical studies (Dreistadt, 1968), and field studies (Knorr-Certina, 1981). Knorr-Certina's interviews indicate that the use of analogies by scientists is a major source of innovation in their work and that analogies can suggest hypotheses for new theoretical models as well as new experimental and industrial techniques.

Another source of evidence for expert use of analogies comes from thinking aloud problem-solving interviews. Clement (1981 and in press) found that a sample of ten experts in technical fields generated 39 analogies altogether in solving a problem in physics.

USE OF ANALOGIES BY STUDENTS

In the remainder of this paper, I discuss responses to a set of qualitative physics problems given to a group of 16 freshmen engineering majors who had not taken college physics. The students were asked to think aloud as they solved problems in a clinical interview setting. Each of the students worked on 6 problems. Tapes of the interviews were examined in order to determine whether they had spontaneously generated any analogies during their solution. A spontaneous analogy occurs when the subject, without provocation, refers to a different situation B that he believes may be structurally similar to the original problem situation A.

In fact, a large number of analogies were generated in solving the problems. Of the 96 problem solutions, 24 (25%) contained analogies. However, many individual problem solutions contained several analogies, so that 59 analogies were generated in all.

We were surprised at the relatively high number of analogies produced, given the fact that informal arguments and divergent thinking on the part of the students are rarely encouraged in secondary schools. Some of the observed analogies were vague and not pursued at length, but at least 34 of them were significant in the sense of being both fairly clearly articulated and used by the students to generate or add support to their problem solutions.

TYPES OF SPONTANEOUS ANALOGIES GENERATED

Further analysis of the data concentrated on these 34 significant analogies occurring in 18 (19%) of the solutions. Transcripts of the solutions are available in Clement (1978). A brief summary of the observations made from this data base is given here. One goal of this exploratory study is to propose some basic categories for describing types of analogies, based on differences observed between the analogies.

1. Personal vs. physical analogies. Given the fact that the problems used were qualitative physics problems, one might assume that the analogies would tend to be physical rather than personal in nature. However, 18 (53%) of the analogies were personal analogies referring to some sort of body action, showing a preference for anthropomorphic explanations. For example, S9, in solving a problem about the speed of an arrow shot backwards from a moving chariot, says: "If you were in a train that was starting up . . . and you run to the back of the train, the train's running underneath you, but if you run at the same speed as the train, then, uh, you're going nowhere."

2. Invented vs. factual analogies. The large majority of analogies in the sample appear to be based on a fact that the students believe from their own experience or from authority. Nevertheless, at least 6 (18%) of the cases were so novel that they were clearly new inventions, showing that students are sometimes capable of producing "custom-designed" thought experiments spontaneously. For example, one question asked which of two carts would travel faster. The carts are shot from two equally stretched elastic bands out from a rocket floating in space, and one cart has more mass. Many students answer this question incorrectly, saying that the speeds are equal since everything is "weightless," in space. One student considering this argument asked himself whether "weight [amount of matter] matters in space." For students who have not yet mastered the distinction between the concepts of mass and weight, the impulse to ask this question is an important first step in resolving this conceptual dilemma. In order to help answer this question, he generated the following analogy: "Like if I tried to push a heavy rocket in space, I'd go back more than it would." This invented thought experiment helped to convince him that the smaller object would travel faster (the correct answer).

3. Individual differences. There was wide variation in the number of analogies produced by different individuals. Five of the 16 students produced no articulate analogies (although several of these hinted at analogies that were not clearly articulated), while one student produced 13 of the 34 significant analogies studied.

4. Correct prediction. Six (18%) of the 34 significant analogies were incorrect in the sense that they supported an incorrect answer from the physicist's point of view. However, possibly a larger proportion of the original entire sample of 59 analogies would be judged incorrect, since only clearly articulated analogies were considered in this sample.

5. Analogy evaluation. In five cases (15%), students criticized or evaluated an analogy after it was constructed. For example, one student compared the chariot problem to throwing an object from a car, but then indicated wind resistance could be a primary factor in the latter case. However, the high percentage of students who did not give evidence for evaluating the appropriateness of their analogies suggests that this may be an area where analogical reasoning needs to be improved by instruction.

*6. **Progressive refinement.*** At least three of the students generated a sequence of several analogies to solve a problem. In producing these sequences, these students demonstrated an ability to progressively refine their explanations by criticizing and improving the first analogies they produced. The student who generated the situation of pushing himself away from a rocket in space for the launching carts in space problem provided one example. Earlier, this student had said that the cart problem was related to the situation where pulling a heavier object is usually harder on the earth. But he appeared to drop this analogy and move on to his thought experiment in space, presumably because he mistrusted the validity of an analogy to a situation on the earth. A few analogies were fairly powerful in the sense that they seemed not only to help the student solve the problem but led to generalizations indicating that some conceptual change was taking place. For example, the student above who generated the thought experiment of "pushing a rocket in space" generated several others of similar nature. At the end of his interview, he announced his belief in the general principle that the amount of matter in an object does make a difference, even in space as well as on the earth, thereby spontaneously overcoming a common misconception.

CONCLUSION

A number of recent research studies have concentrated on examining differences between experts and novices. In the present study however, the emphasis has been on examining a way in which experts and novices are alike—both can generate creative solutions by analogy during problem solving. It is unlikely that novices would produce appropriate and successful analogies as often as experts. And students are probably less likely than experts to criticize an analogy.

However, in considering the earlier general question about the size of the gap between experts and students we can still conclude that the ability to generate spontaneous analogies is shared by many experts and students, despite the fact that it can be one of the most sophisticated tools of scientific problem solving. Rather than showing that students made use of analogies that were presented to them, the examples in this study show that students actually formed analogies spontaneously in thinking aloud problem solutions. A few of the students even generated chains of several analogies and constructed custom-designed thought experiments.

These are creative problem solving processes that have also been observed in the solutions of expert scientists and mathematicians (Clement, 1981, 1986, in press). These findings support the position of Perkins (1981) that many creative reasoning processes are ordinary thinking processes used with special purposes in mind, not unanalyzable acts of "genius." This suggests that analogies are an intuitive form of reasoning that could be tapped or taken advantage of in instruction to a greater extent than is currently done.

Analogical reasoning has important potential applications in education. Scholars such as Hesse (1966) argue that analogies play an important role in thinking via scientific models; this suggests that they may play an important role in science instruction. Teachers use analogies instinctively because they believe that relating new topics to situations students are already familiar with makes new knowledge understandable and is an important way to help new knowledge become deeply rooted. In addition, the ability, when faced with an unfamiliar problem, to think of an analogous problem for which one already has a solution method, is an important method for widening the scope of transfer. The successful transfer of established knowledge and skills to new areas is recognized as a key indicator of understanding.

Some of the pedagogical directions that seem worth pursuing in this area are as follows.

1. One can attempt to form compelling analogies between a number of examples when introducing an abstract principle.
2. Catalogues of analogies generated by students can be assembled, organized by topic areas. The best analogies could be used in teaching and curriculum development as intuitive examples that make sense to students.
3. One can also assemble catalogues of intuitive knowledge structures possessed by students that are in rough agreement with scientific theory (such as the idea that a greater force can produce more motion in an object starting from rest). Such intuitions could serve as anchors for grounding more complex ideas if they can be extended to other situations by analogy. See Clement (1987) for a description of a teaching experiment using this approach.

The fact that many students did generate and use analogies in this study suggests that students possess a store of practical knowledge from concrete experiences which is quite rich, and possess the ability to relate this store of experiences fairly flexibly to new situations. Thus, there is reason to be optimistic that it is worthwhile to design curriculum units which attempt to use analogies in instruction.

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