Spontaneous Student-Generated Analogies

Cody Sandifer
Department of Physics, Astronomy, and Geosciences, Towson University, Maryland
csandifer@towson.edu

The purposes of this qualitative study were (a) to investigate the factors that support the generation of spontaneous analogies (SAs) by students, and (b) to investigate the factors that interfere with comprehension of the analogy target of an SA. To promote the generation of SAs, eight algebra-based physics students were asked to participate in two group problem-solving sessions and one individual explaining session. Overall, 18 spontaneous analogies were generated. Two factors appeared to support the spontaneous generation of analogies: (1) sufficient prior understanding of the analogy target, and (2) the existence of previous analogical examples from other students. Two factors appeared to interfere with the comprehension of the SA analogy target: (1) an incorrect perception of the type of analogy between target and base (attributes, relationships), and (2) an incorrect understanding of the analogy base.

Introduction

The use of analogy as an effective pedagogical tool has long been of interest to the physics education research community. Dozens of studies have explored how teachers use analogies to help their students attain a conceptual understanding of physics. [e.g., 1-2] However, few investigations have been conducted on the generation of analogies by students.

The ability to spontaneously generate and analyze analogies is a wonderful metacognitive tool [3-4], whether that analogy is generated for one's own sake or for the sake of others. Research has shown that some science students are able to spontaneously generate analogies [5-6], but details are still missing as to why the analogies are generated, and how/why the generation of SAs aids student comprehension. This paper seeks to broaden our understanding of SAs by addressing the following questions:

1. What factors support the generation of spontaneous analogies by students?
2. What factors interfere with comprehension of the analogy target of a spontaneous analogy?

Theoretical Framework: Analogies

The structure of analogies. Generally, analogies are in the form of metaphors or similes. Regardless of their exact form, analogies have two components: the *target* and the *base*. [7] The target is the unfamiliar domain under mental investigation. The base is the familiar domain to which the target is compared.

In an analogy, the base domain and target domain are equated in some way. This "equality" can be a mapping of *attributes* (e.g., water is like electricity; they both flow) and/or a mapping of *relationships* (e.g. a hydrogen atom is like our solar system; there is a similar "orbiting" relationship between electron/nucleus and planet/sun).

Analogy construction as a dynamic process. Clement [8] outlines four major processes in the use of analogies.

1. *Generating the analogy.* A base is constructed that is potentially analogous to the target. A tentative relation is set up between base and target.
2. *Establishing confidence in the analogy relation*. The validity of the analogy relation between base and target is examined critically and is confirmed at a high level of confidence.
3. *Understanding the analogous case.* The base is examined and analyzed.
4. *Applying findings.* The subject applies conclusions from the base to the target.

Research Methods

Participants. The participants consisted of eight students enrolled in an algebra-based physics course during the summer session. The students' names were Dan, Ernest, Holly, Karen, Katherine, Melissa, Paul, and Wilma. (All names are pseudonyms.) All participants were juniors or seniors taking college physics for the first time.

Data collection. Students participated in two group problem sessions and one individual explaining session; these sessions were conducted outside of class. During the group problem sessions, groups of students worked for one hour on qualitative and quantitative mechanics-related questions and problems. During the individual explaining sessions, each student explained energy and force concepts one-on-one to a student ("Lynn") who had never taken physics. All activities were audiotaped, and appropriate artifacts (scratch paper, etc.) were stored for reference.

Data analysis. Students' spontaneous analogies were identified and broken down into target/base. The qualitative identification and analysis [9] of supporting/interfering factors was done by making several analytical passes through the data (i.e., the session transcripts); during these data passes, the researcher carefully checked for supporting evidence, consistency, and alternative explanations. Data collection and data analysis were performed solely by the author.

Results and Discussion

Eighteen SAs were generated in this study. Seven analogies were of the relationship type, six analogies were of the attribute type, and five analogies were mixed (both attribute- and relationship-based).

Factors supporting the generation of SAs. I identified two factors that supported the generation of SAs. Space limits the evidence that can be provided for each factor, but evidence has been provided where possible.

Factor 1: To generate an SA, it helped to possess sufficient prior understanding of the analogy target.

This factor is expected in cases where students who already understand a concept generate analogies to help improve the understanding of their fellow students (as was the case with 6 of the 18 analogies in this study). What may not be intuitively obvious, though, is that sufficient understanding of the target also supports students in generating analogies for themselves. In this study, students who had a weak understanding of a target concept did not generate SAs to help them better understand that concept; in contrast, students who had a promising understanding of the target concept were able to generate an SA to improve their understanding of that concept even further.

This factor is supported by different pieces of evidence, including the fact that students with a good understanding of the course concepts (Holly, Wilma, Dan) were more successful at generating and applying analogies than the students with little understanding of the course concepts. Additional evidence includes the fact that all students were less successful at generating SAs during sessions that involved difficult topics (e.g., the centripetal forces involved in circular motion).

Factor 2: Some SAs were triggered by analogical examples from other students.

This factor appears in the first group problem session with Ernest, Holly, Karen, and Wilma. In this session, the group members discussed what would happen if you threw a ball up in the air in an accelerating train. Of interest is the fact that this session was the first and last time that Ernest generated any SAs, all of which were triggered by analogical examples from other students. The following is an excerpt that illustrates this point:

> Holly: ...like when you jump up in an elevator, the floor...you know, when you jump up and you're going down an elevator you stay the same place as the elevator goes. Haven't you ever done that?
>
> Ernest: Yeah.
>
> Holly: Also, like when you do "The Drop" at Magic Mountain, if you drop a penny, if you throw a penny up right when it goes it can totally stay in the air the whole time. The penny's falling with gravity and so are you.
>
> Ernest: Yeah. I think this would have a lot to do with how high you threw it, because I remember...I remember one time I was coming home from a baseball game...I was sitting in the back of a pickup truck, and we came to a stoplight, and I was playing with my mitt. I was throwing it up in the air. And the

light turned green, and the truck started moving. And as long as I threw it not that high, it would come right back to my hand. But then one time, the last time, I started to think "hmmm"...I wonder if I threw it really high...really high what would happen. And the truck was accelerating the whole time, right? It went really high and fell on the ground.

Wilma: It did? Behind you?

Ernest: Yeah.

In this excerpt, Ernest - a student experiencing tremendous conceptual difficulty with the summer physics course - is seen recalling an analogical real-life experience that is triggered by Holly's SAs. Given the existence of this type of SA triggering, it may be that group interactions play a crucial role in helping certain students generate SAs of their own.

Factors that interfered with comprehension of the SA analogy target. Overall, 7 of the 18 SAs in this study failed to help students improve their understanding of the analogy target. In these 7 cases, two factors stood out as interfering factors.

Factor 1: Having an incorrect perception of the type of analogy (attribute, relationship) interfered with comprehension of the analogy target.

An example of this sort of mismatch occurs in the following exchange between Wilma and Lynn during Wilma's explaining session.

Wilma: Kinetic energy is energy of motion...kinetic energy and potential energy are being changed back and forth...so it's almost like you have two buckets of water...and you're constantly pouring them back into each other because they're just being converted back and forth -- but they're not being lost. There's a little bit being lost, like heat and friction.

Lynn: OK. With the buckets -- if you have the buckets back and forth -- with this bucket that's empty now...does the bucket have energy?

Wilma: Does the bucket have energy? I guess it does -- stored up energy.

Lynn: So, the bucket has stored up energy? Does it have kinetic energy when something's getting poured into the bucket?

Wilma had been attempting to explain the concept of conservation of energy in terms of two buckets of water -- one bucket for potential energy (PE) and one bucket for kinetic energy (KE). Water (energy) can be shifted from bucket to bucket (transferred from PE to KE), yet the total amount of water (energy) neither increases nor decreases.

The usefulness of the analogy, however, was lost on Lynn. The problem lay in Lynn's focus on the attributes of the water itself rather than the relationship between the two buckets. Wilma meant the "bucket" analogy in a strictly metaphorical sense, without meaning to imply that the physical nature of water (pouring, etc.) was important to the analogy.

One possible explanation for Lynn's focus on attributes is that novices tend to focus on surface-level features of physical situations, whereas experts tend to focus on the concepts that underlie those same physical situations. [10]

Factor 2: Having an incorrect understanding of the analogy base interfered with comprehension of the analogy target.

The discussion of the understanding of the base is broken into two sections: qualitative problems and quantitative problems.

Qualitative Problems. A case of unsuccessful analogical reasoning relating to a qualitative problem is found in the second group problem session. In this session, Dan compared a roller coaster car at the bottom of a loop with a hydroplaning car. In considering the normal force, Dan argued that the roller coaster car, due to its large speed, would not press against the track -- much as the "lift" on a hydroplaning car prevents it from pressing against the wet concrete.

Using this analogy, Dan did not increase his understanding of the problem -- in which the roller coaster car actually presses the hardest on the bottom of the track. Where Dan went astray was in his misunderstanding of the analogy base: the hydroplaning car. A car hydroplanes because of a decrease in static friction; the water/oil mixture on the road prevents the rolling tires from getting a proper grip on the road. This sliding, however, in no way affects the fact that the car presses down on the road with its weight -- which was the crucial point that was misunderstood by Dan in his comparison of target to base.

Quantitative Problems. Part of the beauty of qualitative analogical reasoning is that the relationship between base and target, in general, does not have to be exact for the analogy to lead to an improved understanding of the target. In analogies involving quantitative problems, on the other hand, we are concerned with a much more exact mapping of the attributes from base to target. That is, it is difficult to use the mathematical solution to one problem to arrive at a correct mathematical solution to another problem if the physical phenomena underlying the two quantitative problems are not nearly identical.

For example, Holly grappled with a quantitative problem involving a projectile fired off a cliff at a 30° angle below the horizontal. Holly attempted to solve the problem by equating this thrown projectile (the target) with the second half of the trajectory of a projectile thrown upwards from ground level (the base). The problem with Holly's analogy is that a projectile thrown upward from ground level travels horizontally at the top of its trajectory. In the target situation, the projectile was thrown from a cliff at a 30° angle below the horizontal. Holly's misunderstanding of the base problem led to a faulty analogy, which resulted in an incorrect solution to the target problem.

Conclusion

The generation of SAs is a fundamental cognitive strategy that can improve students' understanding of physics concepts and problems. This study attempted to deepen the PER community's understanding of the SA process and the conditions under which students' generate successful SAs, and in so doing identified two factors that supported the generation of SAs (understanding of the analogy target; analogical examples from other students) and two factors that interfered with the comprehension of the analogy target of an SA (analogy type mismatch; improper understanding of analogy base).

Recognizing the existence of these factors will help teachers make explicit the kinds of cognitive self-checks that students should undertake as they move through Clement's four-step analogical process. Specifically, students should be aware that the generation of SAs can be a helpful strategy, that one should be careful as to whether an analogy should be one of relationships or attributes, and that understanding the base can be a crucial aspect of generating a successful SA.

References

[1] Brown, D. E. (1994). Facilitating conceptual change using analogies and explanatory models. International Journal of Science Education, 16(2), 201-214.

[2] Brown, D. E., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. Instructional Science, 18, 237-261.

[3] Wong, E. D. (1993). Understanding the generative capacity of analogies as a tool for explanation. Journal of Research in Science Teaching, 30(10), 1259-1272.

[4] Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In R. J. Sternberg & J. E. Davidson (Eds.), The Nature of Insight (pp. 365-395). Cambridge, MA: MIT Press.

[5] Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. Cognitive Science, 12, 563-586.

[6] Kaufman, D. R., Patel, V. L., & Magder, S. A. (1996). The explanatory role of spontaneously generated analogies in reasoning about physiological concepts. International Journal of Science Education, 18(3), 369-386.

[7] Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. Cognitive Science, 7, 155-170.

[8] Clement, J. (1982). Analogical reasoning patterns in expert problem solving. Proceedings of the Fourth Annual Conference of the Cognitive Science Society, 4, 79-81.

[9] Sandifer, C., & Johnson, A. (2002). Using qualitative methods to make and support claims in physics education research. Proceedings of the Physics Education Research Conference, 17-20.

[10] Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5(2), 121-152.