Learning Science by Participating in Design: A Case Where Multiple Design Subgoals Interfere with Systematic Progress

Eli M. Silk and Christian D. Schunn, University of Pittsburgh, Pittsburgh, PA
Email: esilk@pitt.edu, schunn@pitt.edu

Abstract: Two contrasting teams were analyzed qualitatively in a science unit in which students collaborate in teams to learn science concepts through a design project. The unit was focused on learning concepts of electricity by designing an electronic alarm system. The difference in the success of one of the teams to learn the science content can be attributed to their ability to focus systematic efforts on exploring one lower-level design goal at a time.

Introduction

There are an increasing number of science education researchers who investigate the use of classroom design projects as a method for learning science (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Puntambekar & Kolodner, 2005). We further elaborate on the conditions necessary for students to learn science through design by investigating an eighth grade science unit in which students learn about the nature of electricity by working in teams to design an electrical alarm system. The task is both open-ended, as each team chooses their own alarm to design based on a personal need from their everyday lives, and authentic, as electronics components and electricity concepts are, for the most part, only introduced when they are useful for solving particular design challenges. In general, we have observed that students who participate in this unit are more engaged, improve their design process skills, and learn more abstract knowledge of the physics of electricity than students who engage in a more traditional scripted inquiry approach (Mehalik, Doppelt, & Schunn, 2005). Despite these successes, some students who participate in the unit acquire considerably more knowledge of the science content than others. In order to come to a greater understanding of how all students may benefit from learning science through design, we have attempted to look in depth at two contrasting teams as they underwent their design process in this unit.

Theory

A considerable amount of work has been conducted recently in the context of making design projects more effective for student learning of science. Fortus et al. (2004) designed a curriculum in which students participate in multiple iterations of a design cycle, each focused on different content, in order to help students transfer. Puntambekar and Kolodner (2005) designed scaffolds to provide students with multiple opportunities to justify decisions in individual work and in whole class discussions. Baumgartner and Reiser (1998) articulated a set of teacher strategies important for helping students stay on task and managing the complexity of the design process.

In addition to focusing at these levels, students spend a considerable amount of time collaborating with their team members, so it is useful to take the team as a unit of analysis. A major task of individuals when working in teams is to negotiate shared conceptual structures through conversational interaction (Roschelle, 1992). In addition to the cognitive level, there are added social factors that determine the success of a collaborative team, such as the willingness to accept or discuss explanations versus ignoring or rejecting them (Barron, 2003). Although explanatory activities through conversation are necessary for team members to learn effectively, by themselves the explanations are not sufficient unless accompanied by data from crucial experiments required to support the explanation (Okada & Simon, 1997). In the case of design activities, the crucial experiments are manifested in the physical artifacts that embody the design. Our purpose for this research was to consider cognitive, social, and material level factors together by analyzing a contrasting case of collaborative design teams in detail.

Curriculum Context

All teams participating in the Alarm System unit maintain the high-level design goal of creating a working alarm system. Along the way to their high-level design goal, teams are forced to solve a variety of low-level design goals that are challenging. These lower-level design challenges include: getting an indicator component to work (i.e., a bulb to light or a buzzer to sound), getting a indicator component to be louder or brighter, getting a detector components to work (e.g., have a light detector affect the brightness of the bulb), incorporating an on/off switch that doesn't short circuit the batteries, limiting what is passed through a component so it doesn't get overheated or so it turns all the way off when the detector is activated.

Methods

The data was collected in the classroom of one teacher's four sections of eighth grade science. In each section, two student teams were randomly assigned to be videotaped for a total of eight teams. Each team was recorded with a dedicated camera that was positioned to record talk, gestures, and the physical circuit designs that were created. Each team consisted of three or four students. At the end of the unit, teams presented their final system to the class and took a post-test intended to measure their science concept knowledge. The final presentations were also videotaped, and the post-tests and student design portfolios were collected as well. We chose to focus on two teams at the extremes of the post-test performance for this analysis.

Results

Both teams were from the same eighth grade section. Team 1 included two males both of whom attended the school districts' gifted program, and one female who did not attend the gifted program. Team 2 included one male who attended the gifted program and three females, two of whom attended the gifted program. Team 1 had a mean score of 48% on the post-test, and Team 2 had a mean score of 75%. As a result, we are contrasting two groups of similar status as high-achievers according to district standards, but with stark contrast in terms of performance on the post-test for the unit. One major factor by which the two groups differed is in the amount of circuit designs that they created and tested. Team 1, the low-performing group averaged 13 circuit designs per day over the four-day period. Team 2, on the other hand, averaged over 35 circuit designs per day. Although clearly, Team 2 covered a considerably larger portion of the design space than Team 1, and therefore that factor alone may explain the difference in performance, there may also be some mediating factors involved.

The additional factor that distinguishes these two groups was the systematicity by which they explored lower-level design goals. Team 1 had a difficult time focusing on one lower-level design goal at a time, and therefore did not explore as many combinations of designs as was required to understand the underlying conceptual ideas. For instance, they had difficulty separating the design challenge of getting the bulb brighter with that of eliminating short circuits. Because of that, they never considered putting batteries in series and made claims that the bulb could not get any brighter. On the other hand, Team 2 was much more focused on one design challenge at a time. They solved the short circuit challenge first and only after all members of the team understood it, did they move on to the challenge of making the bulb as bright as possible. While pursuing one design challenge at a time, the team was able to consider thoroughly the majority of ideas suggested by the team members as possible solutions. They were also much less likely to stop their exploring and say that the design challenge was not possible with the given materials.

Discussion

Our findings suggest that there is an important influence of design goals on the systematicity by which teams collaborate to explore design challenges. Focusing efforts on one lower-level design goal at a time may be a mediating factor in allowing teams to consider a greater portion of the design space, and this lead to greater overall learning of the science concepts.

References

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*(3), 307–359.

Baumgartner, E., & Reiser, B. J. (1998). *Strategies for supporting student inquiry in design tasks.* Presented at the Annual Meeting of the American Educational Research Association, 1998, San Diego, California.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching, 41*(10), 1081–1110.

Mehalik, M. M., Doppelt, Y., & Schunn, C. D. (2005). *Addressing performance and equity of a design-based, systems approach for teaching science in eighth grade.* Paper presented at the annual meeting of the American Educational Research Association, 2005, Montreal, Canada.

Okada, T., & Simon, H. A. (1997). Collaborative discovery in a scientific domain. *Cognitive Science, 21*(2), 109–146.

Puntambekar, S., & Kolodner, J. L. (2005). Toward implementing distributed scaffolding: Helping students learn science from design. *Journal of Research in Science Teaching, 42*(2), 185–217.

Roschelle, J. (1992). Learning by collaborating: Covergent conceptual change. *The Journal of the Learning Sciences, 2*(3), 235–276.