Children Learning Science through Engineering: An Investigation of Four Engineering-Design-Based Curriculum Modules

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Abstract: This research investigates the use of engineering design challenges as the basis for primary school science learning environments. We used pre-post tests to compare engineering-based students' science content gains to those of students using their district's typical science curriculum. Across the domains of animal adaptations, simple machines, material properties, and sound, the engineering-based science students showed significant pre-post learning gains, and for all domains except sound, their gains were significantly higher than those of comparison students.

Introduction

Recent investigations of the use of technological design activities as contexts for secondary science instruction have produced promising findings (e.g., Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). Primary students may be even more receptive to design-based science instruction, since children of this age have been found to exhibit less apprehension toward designerly endeavors than do adults or adolescents (Baynes, 1994). When children engage in design activities that require specific scientific expertise, they may make progress toward two important learning outcomes: knowledge of and skills in engineering design (Pearson & Young, 2002) and improved understanding of the science they use in the service of design completion (Layton, 1993).

We have developed four new curriculum modules to investigate the impact of using engineering design in primary-grade science learning environments. Our approach to incorporating engineering design problems into primary-level science instruction draws upon the Learning by Design™ approach to middle-school science instruction (Kolodner, 2006). It also reflects the perspectives of situated cognition (Brown, Collins, & Duguid, 1989) and socio-constructivistism (Driver, Asoko, Leach, Mortimer, & Scott, 1994). We view science learning as comprised of both social enculturation into practices and personal construction of ideas. Engineering design is one social activity that requires the use of both science practices and science content knowledge.

Method

We are exploring the research question: what are the consequences of using engineering-design-based activities as contexts for specific science content instruction in the upper primary grades? To investigate this question, we have collaborated with local teachers to develop and implement four design-based science curriculum modules for third- and fourth-grade classrooms. Each module poses an overarching engineering design challenge as a motivator for science investigations within a particular science domain, uses interlocking (LEGO ™) construction elements and electronic sensors as tools for prototyping, and requires approximately 12 hours of instructional time. The *Design a Musical Instrument* module centers on the science of sound, *Design a Model House* focuses on the properties of materials and objects, *Design an Animal Model* emphasizes the structural and behavioral adaptations of animals, and *Design a People Mover* focuses on the force-distance trade-offs of simple machines. The module learning objectives are aligned with local and national science content standards.

Fourteen third- and fourth-grade teachers from six urban public schools in the northeastern United States volunteered to implement at least one of the four engineering design-based science modules. Before and after module enactment, their students completed paper-and-pencil science content tests. These pre-post tests were also administered in twelve comparison classrooms of the same grade levels and in the same geographical area. We refer to these as comparison classrooms because their science curricula had been chosen by teachers and district supervisors to meet local and national science learning standards on animal adaptations, simple machines, material properties, or sound, but they did not use LEGO-engineering design activities. That is, the comparison teachers used their typical science instruction methods to address the same learning objectives addressed by the engineering-design-based modules. There was one science test form for each of the four science domains. The material properties and sound tests each had four open-response and five multiple-choice items. The animal adaptations and simple machines tests each had five open-response and five multiple-choice items. Each item addressed one learning standard from the relevant science domain.

Results

The students' responses to the open-response items were scored by two raters according to a 2-point rubric. Inter-rater reliability and percent exact match were above 0.8 for all questions. Multiple-choice responses were

scored either 0 or 1 point. Total test scores were computed by summing the item scores and dividing by the maximum possible number of points. Thus, all tests scores are represented as percentages.

Overall, paired t-tests revealed significant gains from individual pretests to posttests, across all four domains and both treatment groups. However, there was a main effect of treatment on the magnitude of pre-post gain score. On average, in three of the four science domains (material properties, simple machines, and animal adaptations), the engineering-design-based science students improved significantly more (p<.01) than the comparison students, as shown in Figure 1. In the domain of sound, the engineering students' average gain was higher than that of the comparison students, but this difference was not significant. However, as shown in Figure 2, the engineering students earned equivalent sound posttest scores, despite having significantly lower sound pretest scores than the comparison students. Thus, after the engineering-design-based curriculum module on sound, students were able to achieve at levels equal to those of comparison students who had previously been outperforming them. In fact, on the posttests, students in engineering-based science classrooms achieved at statistically equal or higher levels in all domains but animal adaptations.
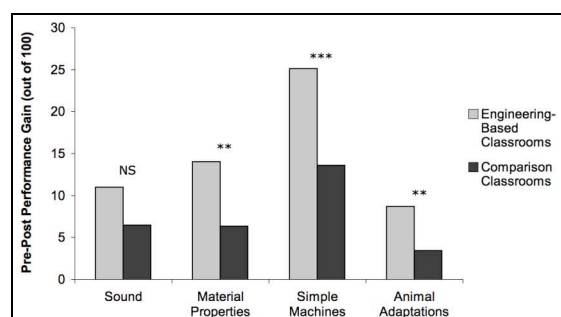

Figure 1. Average learning gains after engineering-design-based and comparison science instruction.
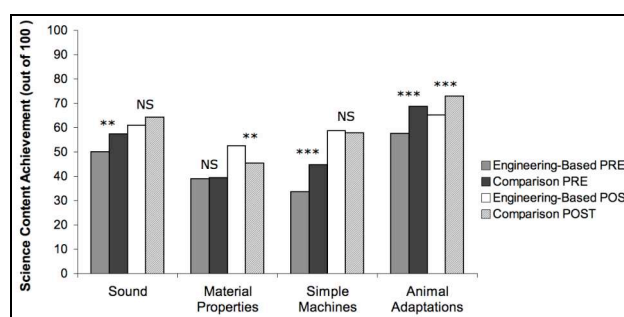

Figure 2. Average pretest and posttest scores in engineering-design-based and comparison classrooms.

Discussion

These results suggest that using engineering design as the basis for science learning environments may facilitate children's learning in the domains of sound, material properties, simple machines, and animal adaptations. However, for young students, the impact of engineering-design-based science curricula appears to vary across science domains. In this study, animal adaptations was the only domain in which students in engineering-design-based classrooms performed significantly lower at posttest than did comparison students, despite having shown significantly greater gains from pre- to posttest. We speculate that students in the comparison classrooms outperformed students in the engineering-based classrooms on the animal adaptations posttest because this domain is within the discipline of life science, which primary grade teachers have traditionally favored. Though the engineering-based *Design an Animal Model* curriculum was effective, comparison curricula were also effective because primary grade teachers have developed strong instructional programs for life science. In contrast, in the discipline of physical science, which includes the sound, material properties, and simple machines domains, there may be more room for design-based science to make an impact on children's learning.

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