AC 2011-904: THE IMPACT OF ENGINEERING-BASED SCIENCE INSTRUCTION ON SCIENCE CONTENT UNDERSTANDING

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Merredith Portsmore is a Research Assistant Professor in Education at Tufts University as well as the Director of Outreach Programs for Tufts Center for Engineering Education and Outreach. Merredith has the unique honor of being a "Quadruple Jumbo" having received all her four of her degrees from Tufts (B.A. English, B.S. Mechanical Engineering, M.A. Education, PhD in Engineering Education). Her research interests focus on how children engage in constructing solutions to engineering design problems. Her outreach work focuses on creating resources for K-12 educators to support engineering education in the classroom. She is also the founder of STOMP (stompnetwork.org), and LEGOengineering.com (legoengineering.com).

Mr. Christopher George Wright, Tufts University
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Chris got all three of his degrees at Stanford Univ., where he worked with John Eaton on his thesis looking at particle motion in a boundary layer flow. From Stanford, he went to Tufts as a faculty member, where he has been for the last million years, with a few exceptions. His first sabbatical was spent at Harvard and a local kindergarten looking at methods of teaching engineering. He spent half a year in New Zealand on a Fulbright Scholarship looking at 3D reconstruction of flame fronts to estimate heat fluxes. In 2002-3 he was at Princeton as the Kenan Professor of Distinguished Teaching where he played with underwater robots, wind tunnels, and LEGO bricks. In 2006-7, he spent the year at ETH in Zurich playing with very very small robots and measuring the lift force on a fruit fly. He received the 2003 NSF Director's Distinguished Teaching Scholar Award for excellence in both teaching and research. Chris is involved in several different research areas: particle-laden flows (a continuation of his thesis), telerobotics and controls, slurry flows in chemical-mechanical planarization, the engineering of musical instruments, measuring flame shapes of couch fires, measuring fruit-fly locomotion, and in elementary school engineering education. His work has been funded by numerous government organizations and corporations, including the NSF, NASA, Intel, Boeing, Cabot, Steinway, Selmer, National Instruments, Raytheon, Fulbright, and the LEGO Corporation. His work in particle-laden flows led to the opportunity to fly aboard the NASA 0g experimental aircraft. He has flown over 700 parabolas without getting sick.

Chris also has a strong commitment to teaching, and at Tufts has started a number of new directions, including learning robotics with LEGO bricks and learning manufacturing by building musical instruments. He was awarded the Carnegie Professor of the Year in Massachusetts in 1998 and is currently the director of the Center for Engineering Education Outreach (www.ceeo.tufts.edu). His teaching work extends to the elementary school, where he talks with over 1000 teachers around the world every year on ways of bringing engineering into the younger grades. He has worked with LEGO to develop ROBOLAB, a robotic approach to learning science and math. ROBOLAB has already gone into over 50,000 schools worldwide and has been translated into 15 languages. He has been invited to speak on engineering education in Singapore, Hong Kong, Australia, New Zealand, Denmark, Sweden, Norway, Luxembourg, Switzerland, the UK, and in the US. He works in various classrooms once a week, although he has been banned from recess for making too much noise.

Linda Jarvin, Tufts University

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The impact of engineering-based science instruction on science content understanding and attitudes

Educators and policy makers have called for engineering education to be incorporated even into the elementary grades[1], but young students also need access to engaging, high-quality instruction in science. In our research, we have explored the use of engineering activity within primary-level science instruction. Specifically, we investigated how engineering-design-based instruction impacts children's science content achievement and attitudes in the domains of simple machines, material properties, animal adaptations, and sound. In this paper we report on two studies. The first includes two different groups of teachers to address a specific research question: *are attitudes toward science and gains in science content knowledge different for students in classrooms using engineering-design-based science curriculum than for students in classrooms using their district's* status quo *science curriculum?* The second study includes a single cohort of teachers over two years to investigate a similar but separate research question: *are attitudes and knowledge gains different for students who experience engineering-design-based science curriculum than for students of the same teachers who experience their district's* status quo *science curriculum?* Both studies compare two kinds of elementary-school science instruction; the first uses different teachers in the same year to do so, while the second uses the same teachers across different years.

Under a grant funded by the National Science Foundation, we collaborated with local teachers to develop a set of four engineering-design-based science curriculum units for third- and fourth-grade classrooms[2]. In engineering-design-based science, the process of solving the design problem provides opportunities for students to learn and apply new science concepts and practices. Our approach to incorporating engineering problems into elementary-grade science instruction reflects the theoretical perspectives of situated and distributed cognition, and it also draws heavily upon the Learning by Design™ approach to middle-school science[3]. Other previous teaching experiments, including those of Roth[4], Penner et al.[5] , Krajcik et al.[6], and Crismond[7], also influenced our work.

Each of our four curriculum units poses an overarching engineering design challenge as the context for science investigations, uses interlocking construction (LEGO™) elements for prototyping, requires approximately 12 hours of instructional time, and addresses a particular science domain. The *Design a Musical Instrument* unit 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 learning objectives for each unit are aligned with local and national standards of science learning[8]. The units are described in detail in a previous publication[2].

Methods

Design of Study 1

The first study, conducted in Year 1, featured a quasi-experimental study design in which one experimental group of teachers taught science with the new engineering-design-based curriculum units, while another group of comparison teachers taught the same science content with their typical district-selected curriculum units. For this study, 14 third- and fourth-grade teachers from six urban public schools in the northeastern United States volunteered to implement at least one of the four new engineering-design-based science units. They attended a 30-hour workshop on the content and pedagogy of these units. Before and after unit enactment, their students completed identical paper-and-pencil science content tests as well as attitudinal surveys. During the same academic year, these pre-post tests and surveys were also administered in 12 comparison classrooms (from six public and two private schools) of the same grade levels and in the same geographical area. We refer to these as comparison classrooms because their science instruction did not involve LEGO engineering design activities but was intended to meet the same learning objectives (on animal adaptations, simple machines, material properties, or sound). The science curricula taught in the comparison classrooms were the *status quo* curricula, chosen by the teachers and district supervisors. It is important to note that in Study 1, the experimental teachers were a separate group from the comparison teachers.

Design of Study 2

The second study spanned Year 1 and Year 2 and featured a delayed, cohort comparative study design. For this study, all 12 of the comparison teachers from Year 1 volunteered to teach at least one of their science units in Year 2 with the new engineering-design-based science curriculum. Thus they comprised a "delayed" cohort; each teacher in this cohort provided baseline data as she used her typical science curriculum to teach her Year 1 students, and then she provided experimental data as she used the engineering-design-based science curriculum to teach her Year 2 students the same science content. These teachers attended a curriculum training workshop during the summer between Years 1 and 2. In both years, their students completed paper-and-pencil science content tests and attitudinal surveys before and after curriculum enactment. These tests and surveys are described below. The same instruments were used in Year 1 and Year 2.

Test and Survey Design

There was one science content test form for each of the four science domains. Each test included a mixture of multiple-choice and open-response items, and each curriculum learning objective was assessed by one item. This resulted in nine items each for the sound and properties tests, and ten items each for the animals and simple machines tests. Items were reviewed for content validity by a team of researchers including engineers, math and science teachers, an educational psychologist, and education researchers. The tests were piloted with students not involved in the curriculum evaluation study and then modified to improve clarity and distracter choices. Using the pilot-test responses, rubrics were created for the open-response items. Two independent raters scored an overlapping sample of 1/3 of all open-ended responses. Rubrics were revised until interrater reliability was above 80% for all open-ended items.

The attitudinal survey was identical for all four science domains. It included 12 Likert-scale items on which students indicated their level of agreement with statements about attitudes toward science, such as, “I can explain science ideas.” All engineering-based and comparison students completed these items. The engineering-based students also indicated their agreement with five additional statements about the use of engineering in science class, such as, “I like using engineering to learn science.”

Data Analysis

For both studies, using the general linear model, we analyzed science content test scores by means of a repeated-measures ANOVA, with curriculum treatment (engineering-based vs. comparison) as the between-subjects factor, and pre- and post-test score as the within-subjects factor. This allowed us to control for prior science content knowledge (pre-test score) in determining whether curriculum type had a significant impact on the magnitude of science content learning.

Findings

Results of Study 1

Figure 1 shows the main findings from the repeated-measures ANOVA for Study 1, the comparison of students in engineering-based classrooms and students in *status quo* comparison classrooms during the same academic year ($n_{engineering} = 378$; $n_{compare} = 264$). There was a significant main effect of time of test, $F(1, 640) = 303.921$, $p < .001$. That is, across all students, the post-test scores were significantly higher than the pre-test scores. There was also a significant main effect of curriculum treatment on test score, $F(1, 640) = 7.889$, $p < .01$. The comparison students began with significantly higher science content scores than did the engineering-based students. Most importantly for our research question, there was a significant interaction between treatment group and time of test, $F(1, 640) = 23.276$, $p < .001$. The increase in science content score from pre-to post-test was much greater for the engineering-based students than for the comparison students. This means that although the engineering-based students began the units with less science content knowledge than the comparison students, at unit completion they had equivalent science content knowledge, as measured by paper-and-pencil tests.

Furthermore, analysis of the attitudinal surveys from Study 1 revealed that the engineering-based students had positive attitudes toward science and engineering ($n_{engineering} = 232$; $n_{compare} = 228$). After unit completion in Year 1, students in the engineering-based science classrooms and comparison classrooms showed no significant differences in their agreement with the statement “I am good at science” ($p = 0.80$) or with the statement “I can use what I learn in science class in my life” ($p = 0.32$). However, the engineering-based students did show significantly stronger agreement with the statement “I feel creative during science class” than did the comparison students ($p < 0.05$). Furthermore, 98% of the engineering-based science students agreed that “engineering challenges are fun,” and 96% “like[d] using engineering to learn science.”

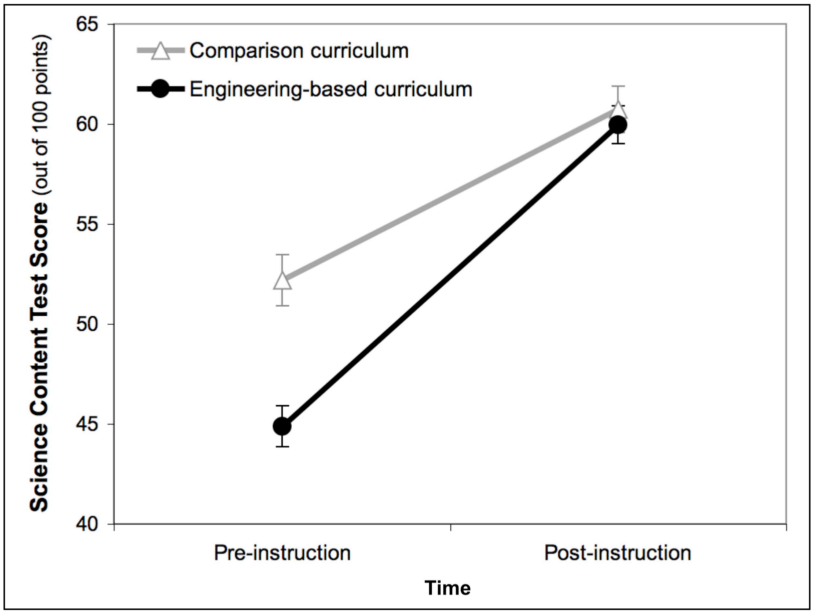

Figure 1. Mean values of science content knowledge (score out of 100 points) by time of test for Year 1, with different comparison and engineering-based teachers ($n_{compare} = 264$; $n_{engineering} = 378$)

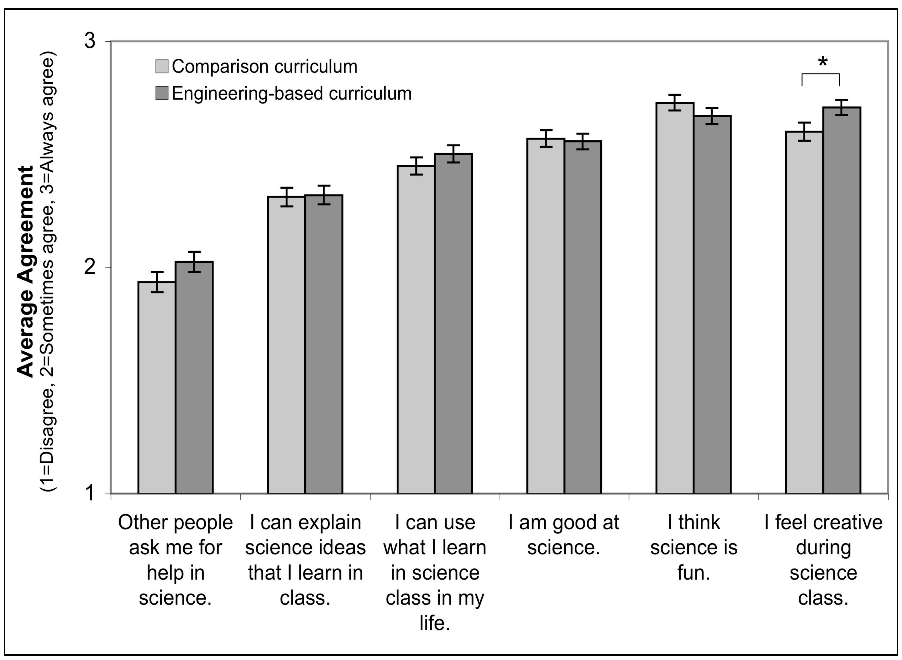

Figure 2. Mean science attitudes at completion of science curriculum unit in Year 1, with different comparison and engineering teachers ($n_{compare} = 228$; $n_{engineering} = 232$; * $p < 0.05$)

Results of Study 2

Study 2 was the delayed cohort comparative study in which teacher participants used their typical curriculum in Year 1 and the engineering-design-based curriculum in Year 2. We compared the test and survey responses of Year 1 students in comparison classrooms to the test and survey responses of Year 2 students in engineering-based classrooms. As of the writing of this draft paper, analysis of the open-response test items from Year 2 has not yet been completed. Thus our report here of test results includes only the multiple-choice items. In the final paper our report of test results will also include the open-response items.

Figure 3 shows the main findings from the repeated-measures ANOVA for Study 2, which included 12 *status quo* comparison classrooms from Year 1 and the same 12 classrooms using the engineering-based curriculum in Year 2 ($n_{compare} = 270$; $n_{engineering} = 316$). Looking only at the multiple-choice items (for this draft report), we found a similar trend to that found in Study 1: students in the Year 2 engineering-based classrooms achieved significantly greater gains on science content tests than did their counterpart students in the Year 1 comparison classrooms. As in Study 1, there was a significant main effect of time of test, $F(1, 584) = 147.682$, $p < .001$; across all students, the post-test multiple-choice scores were significantly higher than the pre-test scores. There was no significant main effect of curriculum treatment on multiple-choice score, $F(1, 584) = 2.661$, $p = .103$; the comparison and engineering-based students began at pre-test with similar scores. However, most importantly, there was a significant interaction between treatment group and time of test, $F(1, 584) = 8.649$, $p = .003$. The pre/post gain in multiple-choice score was greater for the engineering-based students than for the comparison students. This means that students *with the same teachers* showed greater performance gains, as measured by multiple-choice items on paper-and-pencil tests, when their teachers used the engineering-based science curriculum than when their teachers used their typical science curriculum.

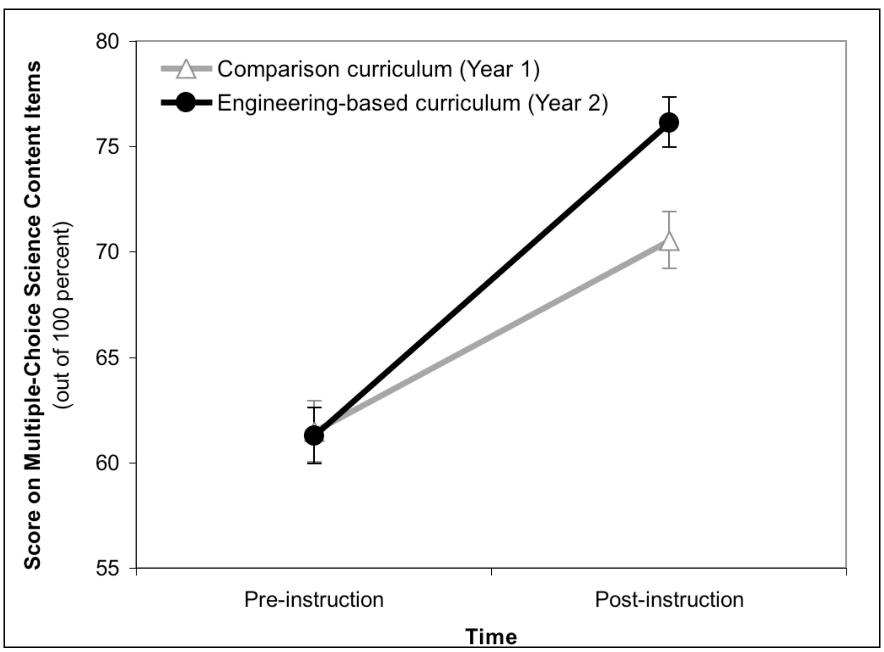

Figure 3. Mean scores on multiple-choice portion of science content test by time of test for Study 2, in which the same teachers taught the comparison and engineering-based units ($n_{compare} = 270$; $n_{engineering} = 316$)

For Study 2 we also compared attitudinal responses of the engineering-based (Year 2) and comparison (Year 1) students with the same teachers (see Figure 4). On average, both groups of students had highly positive attitudes toward science ($n_{engineering}$ = 214; $n_{compare}$ = 206). As in Study 1, students in the engineering-based science classrooms and comparison classrooms showed no significant differences in their agreement with the statements "I am good at science" (p = .518) and "I can use what I learn in science class in my life" (p = .205). In contrast to Study 1, they also showed no significant difference in their agreement with the statement "I feel creative during science class" (p = .526). On survey items specifically about the engineering-design-based curriculum, the engineering-based students in Year 2 rated the learning experience very highly, as had the Year 1 engineering-based students in Study 1. For example, 94% of the Year 2 engineering-based science students "like[d] using LEGO materials to learn science," 93% "like[d] using engineering to learn science", and 93% wanted to "do more engineering."

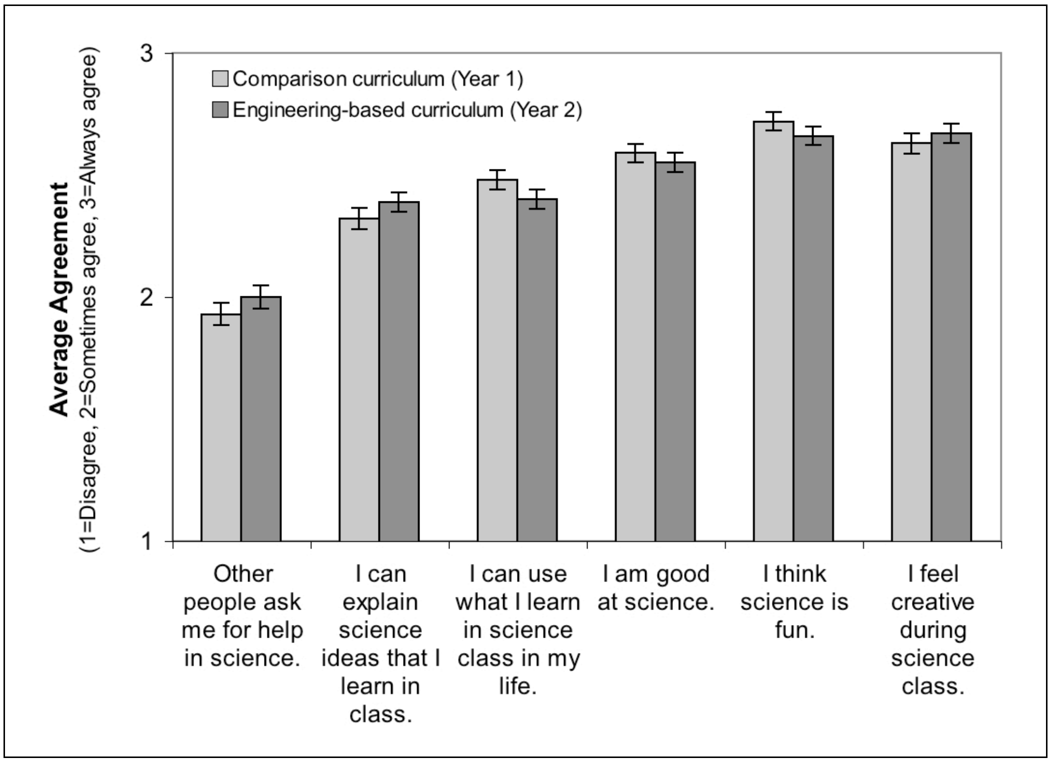

Figure 4. Mean science attitudes at completion of science curriculum unit for Study 2, in which the same teachers taught the comparison and engineering-based units ($n_{compare}$ = 206; $n_{engineering}$ = 214)

Discussion and Conclusion

The results of pre/post test analysis in Study 1 suggest that engineering-design-based science instruction may have a greater impact on science content knowledge gain than does typical science instruction. However, the experimental and comparison groups in Study 1 were not matched for teaching expertise, teacher style, or student demographic characteristics. This means that from the Study 1 results alone, we cannot rule out these other variables as factors contributing to student achievement. Therefore, in Study 2, we controlled for teacher characteristics and student demographic characteristics by using the same cohort of teachers to enact the comparison curricula and the engineering-design-based curricula. Although the students changed from Year 1 to Year 2, they were from the same communities, attending school in the same physical classrooms, and working with the same teachers. In Study 2 the engineering-based students again showed higher science content achievement than the comparison students. Because teacher and student variables were controlled by the delayed cohort comparative design of Study 2, its results provide stronger evidence that when compared to our participating schools' typical science instruction, engineering-design-based science instruction has a beneficial impact on elementary students' science content knowledge. Combining the results of Study 1 and Study 2, we conclude that using engineering problems as a basis for science conceptual exploration fosters improved science learning for children, as measured by pre/post paper-and-pencil science content tests.

In terms of student attitudes toward science, neither Study 1 nor Study 2 provides evidence that there is a substantial difference between the attitudes of elementary-school students experiencing engineering-design-based instruction and those experiencing typical science instruction. Both groups of students, on average, have very positive attitudes toward science. One possible explanation for this finding is related to the fact that we are studying young students, in the third and fourth grades and ranging in age from 8 to 10 years old. At their age level, science has not yet become a rigorous academic discipline in which they receive daily homework tasks, are asked to complete lengthy reading assignments, or take standardized tests. In fact, science time is a break in the school day from the more high-pressure subjects of reading and mathematics. Thus students of this age may retain positive attitudes toward science no matter what curriculum package is presented to them. A second explanation for the lack of difference between the attitudes of the two groups of students has to do with the characteristics of their teachers. All of the participating teachers self-selected to join a research study of novel science curricula. Even when they were still using their district's typical curriculum, they had already agreed to participate in a curriculum training workshop and teach science through engineering the next year. Teachers who volunteer to learn and enact experimental curricula may be teachers who consistently show excitement about and positive attitudes toward science. Their sunny disposition toward science may be adopted by their students regardless of what curriculum they are using.

Integrating the science content test results with the attitudinal survey results, we see evidence that the beneficial impact of engineering design on science learning cannot be attributed to engineering's causing an "attitude adjustment" among learners. In other words, neither Study 1 nor Study 2 provides evidence that improved attitudes toward science are the mechanism by which engineering-based science instruction causes increased science content knowledge gains. In both studies, the experimental and comparison students had similarly positive attitudes toward science but different pre/post knowledge gains. This finding counters the argument that engineering-design-based activities make students feel more positive about science and thus motivate them to learn more science. Instead, some other mechanisms must be responsible for causing the engineering-design-based curriculum to foster higher learning gains among elementary students. This is an important subject for future research.

Overall, the findings of our research provide evidence that engineering-design-based science curricula are associated with significant science content gains by young, elementary-school students, and these gains exceed those achieved when the same teachers use their school district's status quo science curricula. Additionally, young students participating in engineering-design-based science curricula have attitudes toward science that are as positive as or more positive than the attitudes of comparison students. Therefore this study's findings are supportive of the usefulness of engineering-based science instruction as an effective and engaging method of science education. Further opportunities for research include investigating whether there is a differential impact of engineering-based instruction in physical science versus life science, determining the mechanisms behind the learning within engineering-design-based science instruction at the elementary school level, and exploring the characteristics of elementary classrooms that most effectively enact engineering-based science curricula.

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