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The Effects of Engineering Modules on Student Learning in Middle School Science Classrooms

Our project, Teachers Integrating Engineering into Science (TIES), paired middle school science teachers with university professors from the College of Engineering and the College of Education to develop three engineering design modules that included a variety of interactive learning activities aimed at engaging a wide range of students. Student scores on the module assessments were disaggregated by student population subgroups and compared to statewide science test scores. The modules consisted of Web-based simulation activities, lesson plans, a design project, and three types of assessments. Some elements of our program drew on the work of other researchers who had developed successful in-class or after school engineering programs with middle school and high school students (Chandrasekhar *et al.*, 1999; Ferreira, 2002; Hmelo *et al.*, 2000; Sadler *et al.*, 2002). We were particularly influenced by the work of McKenna and Agogino (1998) in using Web simulations to help middle school students meet science cognitive goals through engineering design.

The premise of our project was that the integration of engineering design concepts into middle school science classrooms could help close science achievement gaps among some student populations. We studied the behavioral trends and improvements in science understanding among middle school students when science content was blended with the engineering. We also examined the role of implemented team-work strategies and improved multidisciplinary skill building that were intended to encourage the transfer of knowledge for all students. The contribution to engineering education made by our study was twofold: first, we shared our experiences on the mechanics of integrating engineering design into middle school science curricula; and second, we provided evidence that such integration can positively impact student achievement for some groups of students.

Theoretical underpinnings for our work came from two well-established but quite different learning cycles that are widely used—one in engineering and one in science education. Deciding how the engineering design process would be incorporated into science classrooms where science inquiry was supposed to be the focus as mandated by state science standards required us to develop our own learning model that blended elements from the two learning cycles to create a hybrid learning system that we called the Triangulated Learning Model (TLM). The TLM blends the four elements of the Kolb Learning Cycle: 1) concrete experience, 2) reflective observation, 3) abstract conceptualization, and 4) active experimentation, often used in engineering, with the 5E Learning Cycle: 1) engagement, 2) exploration, 3) explanation, 4) extension, and 5) evaluation, often employed in science education. The result of this blending was a consensus on three major elements that became our TLM, which would be used to facilitate student engagement in the engineering design process: 1) simulation, 2) construction, and 3) connection. The TLM was implemented by the teachers in our study and was found to be a good fit for middle school science classrooms.

Our methodology required three steps: 1) developing the modules, 2) teaching the modules, and 3) assessing students on module content. Three engineering design modules were developed by teams of teachers facilitated by the university professors. The module format was standardized in terms of elements and their sequence. Three assessments were also developed and were standardized in terms of types of items and level of cognitive understanding required for each specific item. Each module focused on science topics that were aligned with local and state science standards and included a compelling design component. Modules used hot air balloons, bumper cars, and bridges as the design projects. Each module was taught in the following order using the TLM: 1) Simulation--Teacher introduced the science concepts (force, equilibrium, momentum, density, etc.) then students engaged in the Web-based simulation that required data collection on outcomes based on their selection of materials and values for other variables; 2) Construction—Based on data collection from the Web-based simulation, student designed the given system—balloon, car, or bridge—selected appropriate materials, and proceeded to build the system using the engineering design cycle; and 3) Connection—Student communicated results to others, justified outcomes based on evidence, reflected on applied mathematics and science concepts, and conceptualized abstract ideas. At the conclusion of the learning cycle, the teachers administered the three assessments: 1) unit test administered to all students, 2) structured interview to 3 randomly-selected students per class, and 3) design project score for each student based on a standardized rubric.

To analyze the data, scores for 434 students were then reported to the researchers along with student demographic data that included gender, ethnicity, socio-economic status (high or low depending upon qualification for free or reduced lunch) and special education qualification. Scores for the three TIES assessments were then disaggregated by the demographic variables and compared to the results for the same student groupings of the statewide 8^{th} grade science criterion referenced test (CRT). In order to compare the TIES scores to the CRT scores, mean performance scores from each student group across assessments were converted to a percentage of deviation for the overall mean for each assessment.

The results of the performance gap analysis comparing TIES scores with statewide 8^{th} grade science CRT scores showed mixed results. In terms of gender, males tended to score higher on the TIES assessments compared to their CRT scores, while females tended to score lower, particularly on their project scores and on their interview scores. Achievement gaps for low socio-economic status students diminished compared to the CRT scores for the individual interview and the project scores, but stayed about the same on the unit test. Results for special education students indicated dramatic improvements over the CRT scores when compared with the TIES assessment scores, particularly with the TIES project score. Results for ethnicity were somewhat perplexing. Achievement gaps were reduced dramatically for Hispanic and Black students, but gaps were increased for American Indian and White students. Asian students scored higher on the TIES assessments than on the CRT. Two major factors must be considered when interpreting the results of this study. First, the state 8^{th} grade science CRT is far more comprehensive than the TIES assessments and involves over thirty-one thousand students. The TIES assessments are specific to only the science content addressed in the modules and involved just over 400 students with members of some disaggregated groups numbering only in the single digits. However, we believe the CRT scores to be a useful benchmark for comparison purposes. Second, the types of the different assessments must be taken into consideration. We recognize that two of the three TIES assessments--the verbal interview and the design project--are very different types of assessments compared to the CRT assessment. The 8th grade science CRT is basically a pencil/paper exam, similar in nature to the TIES unit exam, so the most valid comparison is likely to be these two scores. While some of the observed differences may be more attributable to the assessment type than to the effects of the engineering design strategies, we believe that using deviation from the mean as the mode of comparison does provide a useful indicator of the relative performance of the selected student populations.

Our experience with this project has led us to make two recommendations for engineering education. First, the synergistic nature of the partnership between the two engineering faculty and the two education faculty who led the project was a major high point of this entire experience and contributed to the successful outcomes far more than any other single element. We strongly support the stance that faculty from colleges of engineering and colleges of education work together to further the cause of engineering education in the K-12 setting. Second, it was no easy task to engage the teachers in developing engineering modules for their science classes. This was a demanding challenge, particularly as they grappled with developing the story boards for the Web-based simulation that required them to increase the depth of their applied science and math understandings. Most of the teachers rose to the occasion and when the process was over, they counted that achievement as the highlight of their TIES experience. The result was greater dedication to the success of their modules and a rich understanding of the impact that engineering design projects can have on student understanding of applied science and math concepts. To engage teachers in curriculum development at this level ensures a far greater buy-in to the cause of engineering education than merely handing them a pre-prepared curriculum they might be expected to teach.

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