Learning Through Engineering Design and Practice (LEAP)

Introduction

This example of a systems orientation addresses design-based research and evaluation methods in a National Science Foundation funded middle-school engineering education effort aimed at creating and sustaining novel teaching and learning experiences. Design-based research methods are especially appropriate in: a) exploring possibilities for novel learning and teaching environments; b) developing context-based theories of learning and instruction; c) advancing and consolidating design knowledge; and d) increasing our capacity for educational innovation. By the program grounding its work in the needs, constraints, and interactions of local practice, the processes employed in this design-based research effort provide a lens for understanding how theoretical claims about teaching and learning can be transformed into effective learning in educational settings.

In the project, a team of experts drawn from multiple disciplines came together to share important practices and content knowledge. Disciplinary experts were drawn from materials science, industrial engineering, mechanical engineering, computer science, sustainability, science education, mathematics education, cognitive psychology, counseling, and education research methods. K-12 science and mathematics teachers worked with university experts to design and implement novel teaching and learning experiences in engineering education. The novel teaching and learning experiences were offered over a two-year period to 116 students organized into four cohorts in four middle schools as a year-round extracurricular program.

The program utilized the engineering design process as the fundamental construct for engagement with the novel teaching and learning experiences. The program provided experiences where participants learned engineering and information technology skills through activities such as simulating desert tortoise behaviors, researching and developing designs to mitigate the urban heat island, and designing autonomous rovers capable of navigating Mars-like terrain. They also participated in leadership development activities over the summer serving as docents for younger children at the local science center, a research internship with the university, and an industry internship with a local energy and water service provider. The program used the project-based approach, cognitive apprenticeship, and the learning cycle for instructional planning. Educational tools used included technology-based construction kits that included software for programming, motors, sensors, resistors, capacitors, solar panels, graphing calculators, calculator based rangers, accelerometers, temperature and UVB-ray probes, and found objects.

Research Design for Curriculum Development

Using the situations described above, the project team engaged in evidence-based curriculum development. They embedded a quasi-experimental design within the development based on desired outcomes for students. Embedded assessments included the use of pre-post assessments of: content knowledge, subject produced drawings of perceptions of engineers at work, engineering notebooks, career behaviors survey, and tinkering and self-efficacy questionnaire.

The core focus was on ensuring that the curriculum that was developed led to the desired results for students in this setting.

The design-based research approach allowed for multiple iterations of the novel teaching and learning experiences leading to a more robust middle-school engineering education innovation. This education research approach lead to insight about what occurs when we devise complex interventions in messy settings. Efforts to design, use, and do research on educational tools and materials in real settings can promote the adoption of innovations—in our case middle-school engineering education curricula and strategies.

External Evaluation Design: Confirmation of Effectiveness, Scale-Up, and Sustainability

Concurrently with the project team's curriculum development and implementation-based research, the external evaluation team provided an external perspective on the effectiveness of the findings of the research team in the first two years. In the second, third, and fourth years (once the innovative curriculum showed good evidence of effectiveness) the external evaluation team focused on spread and sustainability. The external evaluation team used observations and focus-group interviews as data collection methods with participants, teachers, school administrators, and others.

Confirmation of Effectiveness

During the first and second year the external evaluation team gathered additional data and engaged in additional analyses to triangulate with the project team's research findings about student learning and to provide further perspectives as the project team refined the curriculum.

Spread

Once it was evident that the curriculum development was progressing toward a significant product, the external evaluation team shifted its focus to scale up of the curriculum and to sustainability. Spread involved two tracks:

- **greater use of the curriculum within the school system**. The focus in the school system involved looking at the interest and capacity of the district, schools, and teachers to use the curriculum. The issues ranged from the financial and political support of the district leadership, the interest of the principals in the schools where the program was operating, and the nature of professional development needed for teachers to use a curriculum that was much more project-based than is typically used in the schools. The existence and/or building of both infrastructure and teaching capacity were important.
- **transfer of the curriculum to Boys and Girls Clubs.** The focus in the Boys and Girls Clubs is on how the different population of students, the competing activities for students, the relationship of the Clubs to the community and parents affect the viability of the curriculum in this setting. The evaluation involves the use of systems thinking and attending to systems dynamics.

Sustainability

Sustainability has taken on four primary meanings in the external evaluation:

- **Program sustainability:** The focus here is on whether the program be continued in the district beyond the life of the grant. The issues relate to the nature and extent of a supporting infrastructure for after school programs, budget priorities, and political support.
- **Sustainability of learning of participating students:** A key challenge for the program is how to sustain the middle school students' interest in STEM-related careers (especially engineering) so they actually pursue such careers and further education beyond high school.
- **Sustainability of collaborations:** The project involved extensive collaborations as noted above. The issues relate to how those collaborations can continue to spur other innovations over time.
- **Sustainability of teaching capacity:** Means of embedding the teaching methods of project based learning through the district professional development structure was explored to sustain the capacity to use curriculum of the type developed through the project.

Attention to Paradigm Shifts

Society is in the midst of major shifts as the Industrial Age Bubble (Senge, et al., 2007) gives way to new conceptualizations of how society is sustainable environmentally, economically, and socially. Aspects of this profound, deep shift are present in nearly all disciplines and applications. The fundamental conceptual shift in this project was primarily for the teachers and students involved in the research/development work. The shift was from (a) teacher-directed de-contextualized learning to student-engaged project-based learning and (b) from fixed skills and knowledge as learning outcomes to the desired outcomes being that students are actively engaged; develop the capacity to explore and figure things out; and act like an engineer.

A key part of determining effectiveness, scalability and sustainability involves attention to fundamental conceptual shifts.

References

Senge, P., Smith, B., Kruschwitz, N., Laur, J., & Schley, S. (2008). *The necessary revolution: How individuals and organizations are working together to create a sustainable world.* New York: Doubleday.

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