

Enhancing Campus Collaborations Through Design Research in Engineering Education Reform

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Abstract

Successful collaborations are important to implementation of systemic reforms in undergraduate engineering education. Evidence for this exists with the formation of national coalitions of engineering programs and campus collaborations between professionals in engineering and education. Electrical Engineering and Computer Science at Oregon State University has worked in collaboration with university science education researchers to implement large-scale curriculum reform based on a *platform for learning*TM. This collaboration between engineers and educators has been enhanced through the use of an emerging educational research paradigm called design research. Design research uses a team to manage a series of iterative cycles of educational design, implementation, and evaluation. Each cycle provides the empirical evidence needed to improve instruction, and refine educational theory. Data is gathered within the context of an authentic complex educational setting enhancing its explanatory power over data gathered through more traditional methods of educational research and evaluation. Educational design research has proven to be particularly effective at OSU since it provides a common point of reference for discussions about education between engineers and education researchers. This paper summarizes the design research process as it is used at OSU to reform engineering education. The paper points out the parallels between this method of educational research and engineering design that have enhanced this campus collaboration. Design research and the specific illustrations of its use in engineering education reform at OSU provide additional tools for reforming higher education and, in particular, engineering programs at other universities.

Complexity and Collaboration in Reform

Proposals for reform in undergraduate science and engineering education during the last three decades are common. Yet, undergraduate education looks very much the same today as it did prior to reform agendas. This is not to say that change is non-existent. The published literature describes new instructional techniques or assessment adopted by individual faculty, a small team, or even a multiple institution consortium. Entire courses or degree programs are frequently developed to accommodate proposed reform. However, even when backed by NSF funding, these reforms have proven difficult to institutionalize and disseminate beyond pilot projects.¹

At issue with reform and its dissemination is a tension between the complexity of an educational problem and the desire for simplicity in a solution. A study of curriculum reform in the

Foundation Coalition illustrates this very issue.² The initial model for curriculum change used by institutions in the coalition involved implementation and evaluation of small pilot projects followed by adoption. The model became increasingly complex over time as the realities of scale and institutional differences were factored into adoption plans. Simple pilot projects did not address the diversity among faculty and students at the larger scale and so curriculum had to be modified from the original concept. The Foundation Coalition adapted to the complexities confronting its institutions. Addressing complexity as the Foundation Coalition did can strengthen reform efforts. In complex reform more is being attempted so there is a greater likelihood of success as opposed to simple changes that may not make much of a difference.³ Failing to address complexity in conjunction with reform can relegate the reform to the level of a single instructor.¹

Complex reforms require methods of evaluation that provide evidence for success without significantly altering the context of the change that is being implemented. A common approach to evaluation is to compare a pilot group to a control group. Sheila Tobias suggests that such a scientific approach to reform evaluation attempts to reduce complex educational issues to a simple set of problems that should have universal solutions. Consequently, reform means development of a set of products or a high profile innovation that depends on focused effort and external controls that go away when the funding ends.⁴ This scientific approach to reform also seems to dominate undergraduate engineering education.⁵ An alternative to scientific methods of evaluation is needed to address complex reform.

Generally, researchers view collaboration as a positive force when dealing with complex issues and change. There are examples of how K-12 schools have successfully negotiated complex change through collaborative processes.³ A study of departmental culture in higher education identifies characteristics of departments that support effective teaching. Collaboration is woven among those characteristics.⁶ Informal collaborations are valuable in business.⁷ However, those collaborations are between individuals of similar background and common knowledge base. Teachers work with other teachers. Department faculties work with faculty in the same department. Employees of a business work with other employees within the same division of a company. Could collaboration between different groups (engineers and education researchers) prove as fruitful?

Collaborations between science educators and other departments and faculty on college and university campuses exist. Researchers in science education have studied faculty teaching methods, how students learn, how faculty and students perceive their disciplines, and how specific activities impact learning and teaching. The list of types of interactions is extensive. The author of a recent dissertation in Mechanical Engineering used procedures for educational research to analyze the interactions between undergraduate students and hardware in simple design projects.⁸ The author of the dissertation explicitly linked the use of these procedures to her interactions with cognitive scientists on campus. Another study describes the results of a mutually conceived collaboration between education researchers and a faculty member in an engineering department.⁹ The purpose of this collaboration was to assist the engineering faculty member to understand and implement pedagogy appropriate to his teaching assignment. On a broader scale, IEEE convened the Deans Summit II where deans of colleges of education and engineering met to discuss the potential of collaboration.¹⁰

The two studies and Deans Summit II illustrate the significant roles of non-engineers in collaborations in engineering education. Education researchers with knowledge in studies of learning and teaching can contribute skills in research methods and pedagogy to engineers. However, these functions do not happen free of problems. Engineers and non-engineers use different vocabulary, have different priorities, and have different conceptions of research.⁵

Design Research and Reform

Efforts to reform engineering education must accommodate the complexity of the educational environment and support collaborative work with educational researchers. At the same time engineers and educational researchers need a common language and concept of research in order to maintain something more than a fleeting interaction. Engineering may provide a model for these collaborations that is rooted in design. The complexity of educational systems in many ways resembles the complexity of engineered systems. Design methods in engineering help engineers tackle complex systems that involve multiple interacting factors. Engineers are driven by goals more than hypotheses and tend to look for workable solutions to specific problems rather than universal solutions.⁴

Recent criticism of scientific approaches to curriculum design, implementation, and evaluation have been accompanied by an alternative approach often referred to as design or development research.¹¹ Central to the idea of design research is that the design of the curriculum and the research on the effectiveness of the curriculum are not separated. Design and research are iterative processes that provide feedback for each other through cycles of design, implementation, and evaluation. The design is based on theories of learning while the research on the design provides clarification of the theory as it is put into practice. Clarification then informs changes in the design. Design research accommodates the complexities associated with changes in curriculum.

Practitioners of design research use several strategies to deal with the complexities. One such strategy involves the use of a design team.¹² On the most basic level, a design team consists of a designer and a researcher who interact for an academic year. Such a small team may be sufficient for curriculum design associated with one teacher in a single classroom. Teams associated with more systemic reform over longer periods of time may need additional expertise and a much longer time commitment of its members.

In either extreme of curriculum reform, the function of the design team is similar. The team uses data gathered during implementation to refine the underlying theoretical assumptions and consequently adjust practice to accommodate those refinements. This brings up a second strategy for dealing with complexity. Formative evaluation becomes an essential tool that provides the information for design research.¹¹ The purpose of formative evaluation is to use empirical evidence to inform the development process.¹³ Even though formative evaluation uses empirical evidence, it is not necessarily scientific. The validity of the evidence in formative evaluation relies more on triangulation of data sources than on experimental designs. Results from traditional large-scale surveys may be compared to student interviews and classroom observations. Formative evaluation is less rigid in its application than the more traditional

summative evaluation that is often used in pilot projects. As a result, formative evaluation is more likely to promote rapid applications of solutions to instructional problems.

An Example of Design Research at OSU

A complex curriculum reform within the School of Electrical Engineering and Computer Science (EECS) at Oregon State University (OSU) illustrates how a design research approach is used to manage change and promote collaboration with educational researchers. The reform is based on the use of a platform for learning that is a “unifying object or experience that weaves together the various classes in a curriculum.”¹⁴ The specific platform is a small robot purchased by students in their first electrical engineering course and enhanced through successive courses during the undergraduate program.^{15, 16} The development of the platform involves hardware design, software design, design of instructional materials, and professional development of teaching assistants.

The platform for learning evolved out of initial efforts in 1996 to bring an interesting robotics application of electrical fundamentals to an introductory electrical engineering course. The commercially produced robot was replaced by a new curriculum and locally developed hardware in 2000. About that time, the primary author was asked to assist EECS with evaluation of the platform for learning. Since then, graduate students and faculty from the Department of Science and Mathematics Education (SMED) at OSU have been involved in evaluation research related to the curriculum reform.¹⁷

An essential aspect of educational design research is the development of theory. More traditional approaches to curriculum development and implementation only apply theories of instruction and learning to new settings. A curriculum that incorporates cooperative learning is evaluated for the effect on student learning. The evaluation usually does not shed light on how cooperative learning functions to improve student outcomes in the particular curriculum being evaluated. On the other hand, a goal of design research is to apply and develop theories. The platform for learning is the theory of instruction that is being developed and applied at OSU. The design research process clarifies the theory and helps to measure student outcomes.

A design research perspective that incorporates a design team, formative evaluation, and iterative cycles of design has been an important component of the reform process. The design team of 10 to 12 individuals meets for one to two hours weekly during each academic term. The team includes the EECS director, faculty, undergraduate and graduate students, representatives from SMED, and outside experts. All members of the design team are involved in projects related to the curriculum reform. These projects include educational evaluation, hardware development, and curriculum development. Team meetings tend to be informal in that there is seldom an established agenda. Each team member shares progress on individual projects or observations related to implementation of the reform. The sharing is often punctuated by impromptu discussions. The meetings are concluded after each person has been able to contribute.

There are several attributes of the team that help in the management of this complex reform process. Students comprise about 50 percent of the team. The heavy student involvement benefits the design research process through immediate feedback about the implementation of

the curriculum. Some of the students are either taking courses that use the platform or are teaching assistants in those courses. The feedback is often used to make immediate changes such as clarification of instructions or alterations of lecture content. Other times the feedback is used to revise curriculum materials for future use.

A drawback to heavy student involvement is the frequent turnover. Each year several new students may join the team while others leave. This means that each new team members has to be indoctrinated into the theory of platforms for learning and the dynamics of the team. This is accomplished in several ways. Team members have given presentations to community and industry groups. New team members are invited to attend these presentations and encouraged to participate. During the summer, many current and future team members are hired by EECS to develop new hardware, software, or support materials for the curriculum. During the summer, the students present their projects and defend their work in terms of the value related to platforms for learning.

Another attribute of the team that helps in management of complexity is the use of expertise outside of EECS. One regular participant in the design team is a retired engineer with expertise in wireless systems. He has provided valuable assistance in developing hardware that would incorporate radio frequency elements into the platform and insight into how these elements might enhance the educational program. Participants from SMED provide expertise in evaluation techniques and help interpret data from a cognitive perspective.

Much of the work of curriculum reform in terms of hardware development or writing occurs outside the design team meetings. Design team meetings focus more on formative evaluation. The most important function of formative evaluation is to provide immediate feedback about teaching and learning. This feedback is used to make changes in the curriculum. In contrast, summative evaluation is designed to test the overall effectiveness of the curriculum. Formative evaluation is based on empirical evidence, but often that evidence is collected through observations or interviews rather than large-scale surveys.

One example of formative evaluation occurred during a design team meeting in February of 2002. One of the team members brought up a problem that he observed with a design assignment given to a class of freshmen EECS majors. The assignment was to design a circuit that could be added to the robot platform so that the robot would react to light. The circuit seemed simple enough and students had background related to the circuit from lecture. The problem was that students had no idea how to even begin designing the circuit. The engineers in the team shared their personal experiences with design and the faculty from SMED shared their understanding of the cognitive issues involved. Those initial observations lead to modifications in labs that would slowly introduce students to design as the class progressed. In this case, changes were made in response to a simple observation rather than a formal evaluation process.

Another example of formative evaluation demonstrates how the data can be used to improve instruction and develop theory. Interviews revealed that the students in the same class mentioned previously spent more time learning how to solder than learning electrical concepts. In response, labs were modified to reduce instructions so that students had to make more decisions about construction of the robot while they were assembling it. These and subsequent

observations have also revealed that a platform for learning must have a certain level of complexity in order to engage students in learning.

A platform for learning provides students with an opportunity to develop engineering “soft skills” such as a sense of community, ability to innovate, and ability to troubleshoot. The concept of these skills and their incorporation into the curriculum has changed since the first implementation of the platform into introductory classes. Troubleshooting is a case in point. Initially the curriculum was designed to teach troubleshooting by inserting an error into the digital logic used by the robot platform. The plan was implemented as a single lab. Formative evaluation of the that lab indicated that students seemed to be no better at troubleshooting after doing the lab then before doing the lab. At the same time, observations of other labs where the robot platform was being used indicated that students became easily frustrated with troubleshooting problems on their robot. Detailed assembly instructions as well as debugging instructions seemed to have little impact. In the following design cycle, the design team concluded that students needed an explicit process to help them troubleshoot and that teaching assistants should be trained in methods to help students use the process.

A platform for learning should also help students develop a sense of community. In theory students would work with each other to help solve common problems related to lab or their robot. A large-scale survey conducted in a digital logic class appeared to show some growth in community. This was supported by interviews but not supported by observations in the lab. As a response to the discrepancy, one design team member used literature on cooperative learning and development of community to create activities in lab and lecture that would promote interaction between students. Initial observations in labs indicate that students are working in teams more often than in the past.

The cyclic nature of design brought out the problems associated with applying a simple solution to complex problems. To learn troubleshooting, a student needed more than a single problem to solve. To develop a sense of community they needed more than a common issue. The first cycle of design, implement, and evaluate fed into a second cycle where students were given specific tools to use in troubleshooting and community development and explicit help in using those tools.

One of the factors that inhibits active collaboration between engineers and non-engineers is a lack of a common language.⁵ Engineers and educators have very different concepts of research. Engineers strive for clearly defined metrics and precise measurements. Educators often have to deal with concepts that are not well defined and very difficult to measure. As a result, educators are using language and methods that have little meaning to engineers. This was particularly evident early in the collaboration at OSU. Engineers on the design team would prefer graphs and numbers to transcripts of interviews. Educators would frequently use terms that were common in the educational literature but unfamiliar to the engineers. The tenants of design research provide some common ground for improved communication between engineers and education researchers.

Engineers and education researchers routinely work with systems where electrical or human components cannot be isolated from the system and still provide meaningful information.

Design research, unlike a more traditional scientific approach, strives to maintain complexity while trying to tease out the causes of problems. Maintaining complexity means that solutions to problems are more likely to be effective and practical, which is a shared goal of educators and engineers. Early in the collaboration at OSU, engineers were interested in defining clear metrics that could be measured using quantitative instruments in controlled studies. Frequent design team meetings allowed both educators and engineers to discuss the meaning of specific data gathered in this way. Both engineers and educators recognized the limitations imposed by survey data and the value of explanations provided by qualitative data.

Engineers and educators base their design work on theoretical perspectives in physics and psychology. For each, there is the realization that theory seldom provides a perfect explanation for reality. Design engineers may approach this dilemma by “back annotating” design criteria as it becomes obvious that some criteria cannot be met under the specified conditions. Educators will modify original curriculum designs when it is clear the approach is not producing expected learning. Design research assumes that we will modify our understanding of a system while investigating that system. Design team meetings allow engineers and educators at OSU to discuss theories about learning and teaching in a common context. The result at OSU is that some instructors have begun to modify their own instruction based on these discussions. In addition, educators have a setting where they can focus on research in education and not strictly evaluation of curriculum.

Conclusions

There is little question about the need for reform in undergraduate engineering education. The efforts to enact such reform are widespread and often heavily funded. In spite of the effort, undergraduate engineering education remains relatively unchanged in most institutions. One possible cause for this problem is the change model employed by institutions involved in reform. A frequently used model that incorporates pilot studies of curriculum followed by evaluation and dissemination results in curriculum that does not address the complexities of institutional settings. An alternative model being employed at OSU is based on a design research paradigm. Design research employs strategies familiar to engineers and educators resulting in a fruitful collaboration between the two groups.

The design research model used at OSU was not initiated at the outset of reform efforts. It emerged from those efforts. This strengthens the outcomes of the process since it was developed to accommodate the complexity of curriculum reform. However, the process has had its faults. A heavy reliance on a small design team and formative evaluation means that not all individuals affected by reform have had equal say in the efforts. This sometimes results in less than desirable outcomes when an idea is implemented. It has also taken more time to incorporate educational theory into design efforts than might happen in more traditional approaches to reform.

The process has evolved as problems emerge. One major leap in that evolution took place when the process was linked to an emerging literature on educational design research. This allowed the team to clarify expectations of outcomes and develop new strategies for dealing with curriculum reform. One specific outcome is the emergence of the design experiment. Education

researchers have begun to plan and conduct simple tests of ideas related to a platform for learning. These have included testing how students react to increasingly open-ended problems to looking at the effects of using cooperative learning activities in large lecture classes. These design experiments are examples of collaboration between educators and engineers and strengthen understanding of learning and teaching.

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