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Literature Review and Methods Paper: Identifying Influencers That Contribute to Transformative Learning in an Electrical and Computer Engineering Undergraduate Capstone Design Project and Selecting Action Research Methods to Frame a Study

Dr. Rachael E. Cate, Oregon State University

Rachael Cate: Dr. Rachael Cate received her MA in rhetoric and composition from Oregon State University in 2011 and her Ph.D. in Higher Education Leadership and Research from Oregon State University in 2016. She joined the School of Electrical Engineering and Computer Science at Oregon State University as a member of the professional faculty in 2016. In this role, she provides engineering communications instruction to students as they progress through the senior capstone project and develop relationships with project stakeholders in industry. She also supports transformative engineering program development, research, and implementation. In addition to her Ph. D. research interests in adult learning theory, post-colonialist critical consciousness, program design, and qualitative research, she is also collaborating on research in the areas of communications-related success factors of recent engineering graduates in industry and effective tools for instructors of integrated engineering and communications courses.

Donald Heer: Donald Heer received his B.S. and M.S. degrees in Computer Engineering from Oregon State University in 2001 and 2003, respectively. In 2003, Mr. Heer joined the School of Electrical Engineering and Computer Science at Oregon State University as a member of the professional faculty. In this role, he coordinates the TekBots® program development and implementation. In addition to his research interests in creating innovative engineering education experiences, he is also performing his Ph.D. research in the area of integrated sensor systems using nanotechnology.

Donald Heer, Oregon State University

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Rachael Cate and Donald Heer, Oregon State University

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Abstract: Electrical and Computer Engineering (ECE) design capstone instructors and course developers at Oregon State University are conducting a study to investigate the efficacy of Evidence-Based Instructional Practices (EBIPs) for supporting students' learning and success. In this 9-month study, the key research questions are: What educational experiences contribute to ECE seniors' success in the senior design capstone year? and what instructional practices best facilitate these transformative educational experiences? As a result of the study-in-progress, the researchers have identified a mixed-methods action research approach that will allow them to engage in transformative teaching and learning practices as they advance their knowledge through empirical data collection. In the literature review presented here, they have defined key transformative teaching and learning practices using best practices case study literature and theories of transformative learning intended to provide students with engagement opportunities that advance their integrity and efficacy as professional engineers through collaborative design, project management, and critical reflection. The synthesis of learning theory, best practices research, and methodological frameworks presented here represents the results of researchers' efforts to develop methods and analytical frameworks to guide their research. Transformative learning theory is identified as a foundational framework for defining and measuring success in engineering education. Key transformative education programmatic influencers identified in this review include critical awareness of culture, professional identity development, participation in communities of mentoring and learning, holistic skill integration through reflection, and the development of professional integrity through affective awareness. Emancipatory Action Research (EAR), a pragmatic qualitative epistemology, and a critical mixed-methods approach are all identified as best fitting methodological frameworks to guide future methods development. The results of this review support a deepening awareness of dynamics of transformative teaching, learning, and educational research that have broad implications for capstone and design engineering education.

Introduction

This paper presents the results of a literature review in the fields of transformative experiential education pedagogy, engineering design capstone best practices, and transformative action research methods. In addition to synthesizing research in these areas and presenting conclusions that apply to the present study and inform future research in engineering education, this paper is also itself an "artifact" and product of collaborative work undertaken by the instructors/researchers that provides insights for other multidisciplinary co-instructional teams and recommendations for deepening future research based on the value of the research

process-as-intervention intended to support co-instructors in collaboratively creating a transformative interdisciplinary instructional culture.

The senior design capstone in electrical and computer engineering (ECE) at Oregon State University consists of a three-quarter course series that takes place during the fall, winter, and springs terms of the senior year. Since 2007, over 1000 students have completed it. Beginning in the fall of 2016, in response to needs for increased support for the development of professional and communication skills, a co-instructor in the field of technical communication was added to the course series. For the past two years, the co-instructors (one in technical design and project management and the other specializing in professional communications and written documentation) have worked together to develop an integrated curriculum that applies transformative learning pedagogies and evidence-based best practices to support student success. Before coming into the School of Electrical and Computer Engineering (EECS), the communications instructor had earned a master's degree in writing, taught writing and communication courses at the university and community college level, and earned a doctor of philosophy degree in higher education program development, including transformative and experiential education pedagogies. The technical instructor had earned a master's of engineering and completed some coursework in engineering education. Together, they began working to create a curriculum that challenges engineering students to develop critical thinking skills in order to engage in technical problem solving, to consider what it means to be an engineer, to challenge their own assumptions and perspectives, and to prepare to enter into a community of professional engineers. This development is encouraged through discussion and writing on readings and lectures in topic areas such as team collaboration, emotional awareness, active listening, audience analysis, and personal investment in professional relationships. Reflection activities and discussions complement presentations, reports, and documentation developed by students on technical progress designing electrical systems to meet their team project needs.

The capstone project experience centers around relationships between teammates, stakeholders, and managers. Apart from the the inclusion of a co-instructor in communications, the capstone design course at Oregon State University is structured similar to that of other universities. In the beginning of the fall term, students are assigned both a project and a project team consisting of 3-4 students who will work together until the end of spring, or 30 course weeks. Students are introduced to their project stakeholder(s), the person or group of people who proposed the design projects. In some cases, the stakeholders are industry representatives who partner with the university it the hope of filling research needs and/or identifying talent. In other cases, faculty from within the school of EECS or other schools within the university with technical needs propose projects and mentor project teams. Whoever the stakeholder is, the teams endeavor to learn their preferences and expectations so that they can best address their needs, and this experiential environment is continually monitored and adjusted by instructors to prepare students for engineering environments outside of school. As recommended by Merriam, Caffarella, and Baumgartner, the course intentionally provides authentic opportunities for communication with technical and and non-technical audiences that promote holistic skill integration [1].

Co-instructors/researchers set out in this study to support students' educational success by developing and transformative evidence-based instructional best practices (EBIPs). The first step in development was reviewing literature to identify transformative experiential education best

practices for engineering design that are research-supported, responsive, and can be shown to consistently improve students' preparedness to participate as professional engineers. In tandem with this best practice and transformative pedagogy review, researchers also reviewed methodologies that could support the educational intervention and study. As the research has evolved, researchers have realized that, because instructors and students participate collectively to create the community of learning and culture of the design course, they also undergo transformation collectively. Therefore, the methods and interventions indicated in the study should examine not only class activities and surveys, but also our collaborative work as we come together to integrate cross-disciplinary perspectives. Literature reviews, collaborative conversations, and co-authorship (including the present paper) represent the artifacts that have been produced through our efforts to understand each other and build co-instructional practices that raise our collaborative pedagogical awareness.

A key hypothesis of this study is that the action research process [2], including reviews, methods development, interventions and analysis, will result in a transformative teaching and learning community and transformative learning among participants (instructors and students), evidenced by increased emotional, cultural and professional awareness. Preliminary results presented here from the literature reviews and collaborative composition process identify key instructional influencers in transformative education best practices for engineering capstones (culture, mentoring and engagement in a community of learning, professional identity development, reflection, and affective awareness and professional integrity development).

Our Research Questions

The questions that researchers (as program developers) are investigating in this is study are:

1. *What educational experiences contribute to ECE seniors' success in the senior design capstone year?*
2. *What instructional practices best facilitate these transformative educational experiences?*

The first question relates to overall program goals for the School of EECS. Oregon State University, as a land grant public university, has a special focus on student success. However, the term "success" has multiple definitions dependent on cultural, personal, and institutional values. As such, the qualifications for the criteria on which to define and judge standards of success are of key importance to the logical foundations and methodology of the study. In order to move forward to the second question (the question with most practical implications), the concept of transformative learning as a measure for success must be established. "Success" for the purpose of this study is defined as documented transformative learning as represented in Mezirow's theory of transformative learning [3][4] along with course completion.

The second question further clarifies the practical implications of the investigation. To answer this question, researchers have first sought to understand what makes engineering design courses truly "transformative" for students. A literature review was focused on an examination of concepts that contribute to educators' understanding of the transformative learning process, as well as survey case studies and resulting best practices from documented efforts to development effective transformative engineering capstone courses. To support research methods, literature is

also presented on the topic of methodological approaches that can be effectively used to build knowledge of transformative learning experiences and instructional practices in engineering capstone courses.

Literature Review Results: Transformative Influencers and Methodology

Transformative learning theory is the foundational basis for the study. As a sort of epistemology (or paradigm for knowledge creation) in and of itself, transformative learning theory guides us to understand "success" as a product of not just quantitative measures or qualitative analysis, but of a shift in understanding that necessitates an ongoing revision of perspectives [1]-[8]. In particular, transformative learning theorist Jack Mezirow defines transformative learning as "transforming a problematic frame of reference to make it more dependable in our daily life by generating opinions and interpretations that are more justified" [4, p.20]. According to Mezirow, critical reflection on assumptions and held beliefs is key to the process of transformation, and this process can be characterized through ten "phases of meaning." These phases are:

1. A disorienting dilemma
2. Self-examination with feelings of fear, anger, guilt or shame
3. A critical assessment of assumptions
4. Recognition that one's discontent and the process of transformation are shared
5. Explorations of options for new roles, relationships, and actions
6. Planning a course of action
7. Acquiring knowledge and skills for implementing one's plans
8. Provisional trying of new roles
9. Building competence and self-confidence in new roles and relationships
10. A reintegration into one's life on the basis of conditions dictated by one's new perspective [4, p.22]

Oregon State University and the School of EECS are committed to providing transformative learning experiences. As Mezirow and other transformative theorists have pointed out, the process of transformative learning is deeply personal and also cultural and collective [3]-[7]. As researchers and educational practitioners, we must also participate actively in the process of transformation on a personal, cultural, and collaborative level. We have adopted Mezirow's transformative learning theory as a guiding approach not only to the development of curricula during the course series-as-intervention and analysis and interpretation of data but also to our own practice of deepening and illuminating our collaborative process as co-instructors and researchers. In the following sections, we present a synthesis of engineering capstone course EBIPs and methodologies that informs the framework of our study, justifies our methods, and provides foundations for future engineering education program research.

Transformative Learning in Engineering Design Capstone Courses

The applications of transformative learning to the present study were explored through an investigation of case studies published in the past fifteen years by educational researchers and practitioners in the field of engineering design capstone program development [9]-[23]. Within a subset of these case studies and research papers, transformative teaching and learning experiences were investigated, and results were presented that indicate programmatic, curricular

and instructional practices that have an impact on the quality of transformative experiences [17]-[23]. Based on these studies, key influencers for transformative learning in engineering design capstone courses include:

- the culture of the engineering program and of the design course [8][11][20]-[23]
- mentoring and engagement in a community of learning [8][11][13][16][18][19][21]-[23]
- professional identity development [8][11][13][16][18]-[23]
- reflection practice integration [8][10]-[11][20]-[23]
- affective awareness and professional integrity development [8][10][11][20]-[23]

The prevalence of these influencers across best practice and theoretical research indicates that they have strong impacts on transformative teaching and learning. While they have been separated out because of our need to focus narrowly on each one in order to deepen our understanding, they are all closely tied. For example, the culture of the engineering program and design course have a strong impact on mentoring relationships and communities of learning, professional identity for students, how much critical reflection is valued or practiced, and also whether affective awareness or professional integrity are addressed adequately (or at all). In addition, it is unclear how and to what extent engagement in disciplinary mentoring and communities of learning during the capstone year plays a role in professional confidence or integrity.

Based on this review, we have structured our capstone course to incorporate all of these influencers. (The learning interventions we have applied will be discussed in a future article, as this report's focus is the review). We have also created a survey tool (sample in Appendix A) that gathers data about them and as well as students' progression along Mezirow's phases of meaning. The next stages of our study will allow us to verify the influencers of transformative learning identified in our review. Based on the personal, cultural and collective nature of transformative learning, though, it has also become clear that there can be no truly objective design, intervention and data analysis for transformative teaching and learning communities in the positivist sense. Therefore, rather than proceed as if we could be objective researchers, we have embraced our role as participants in the study as well. As we continue to gather data and collaborate as instructors/researchers, we engage in the phases of meaning along with our students. As such, our next step has been to turn our attention toward a review of transformative action research methods to identify a strategy to match the needs of the study.

Emancipatory Action Research and a Mixed Methods Approach

Based on our research questions and positionality as researchers/instructors, we sought to find a methodological framework that would support us in engaging in transformative teaching and learning and progressing through the phases of meaning in a community with our students. At the same time, we also required a framework for testing the influencers as catalysts of these developmental steps. Because the study is being conducted on teaching practice, through teaching practice, action research methodology [2][24]-[25] seemed a good fit. Action research refers to situations in which there cannot be definitive separation between research subjects and researchers, as all are active participants in the community of teaching and learning, and all are being impacted by their relationships with each other [24].

Within the field of action research, the distinction of *emancipatory* action research (EAR) [24] has been used to refer to studies that are intended to emancipate or empower participants in addition to investigating and presenting practices. An intention of this study is to empower participants through realization of agency, confidence, and transformative awareness of professional identities and practices, so the "emancipatory" distinction applies as well. In addition, a key characteristic of action research (and qualitative study methods more broadly) is a foundation in reflection and critical examination of educational paradigms and epistemologies within which research questions are posed and assumptions of meaning are made [2][24]-[25]. This characteristic is shared between action research and transformative learning theory. For these reasons, we have applied EAR to inform our study's methods as we investigate and engage in transformative teaching and learning. As we consider the research process, the instructional interventions, the data collection, and the analysis of results, we will refer to EAR as a guiding conceptual framework. We will consider our own positionality and development through the phases of meaning and incorporate them into our research practices, including periodic collaborative reflection, data collection and interpretation of results.

Because culture, identity, emotional development, critical thinking, and collaborative relationships in community are central topics of our study, a qualitative epistemological perspective is needed to account for the depth of understanding and awareness of researchers' positionality and biases needed to interpret results with validity [2]. At the same time, there are elements of the study for which quantitative data can be gathered to indicate overall trends in learning. In order to both investigate overall trends and to use qualitative data to deepen understanding, a pragmatic approach (which incorporates both elements of positivist scientific and qualitative epistemologies) is needed [2]. In addition to needs derived directly from our research questions, the benefits of a pragmatic mixed methods approach also extend to supporting the collaborative process between co-instructors/co-researchers who come from different epistemological backgrounds in the fields of engineering and education. The transformative value of our study-as-intervention will result from a negotiation and cooperative process of mutual understanding as we find the value in data and interventions and come to agreement about their significance to our questions.

After reviewing theories of qualitative [2] [24]-[26] and quantitative [27][28] research epistemology and statistical analysis methods in educational research [28], we have identified the need to gather the following data using the methods indicated:

1. Our own evolving report drafts and other documented communications will serve as artifacts of our ongoing process of mutual understanding and transformative collaboration.
2. Students' participation in and impressions of transformative educational interventions will be gathered in the form of quantitative responses to Likert scale survey questions about the interventions, including numerical counts of experience types (e.g. internships completed) and expected course grades, all tied to demographic information.
3. Numerical Likert scale data will data will also be gathered to determine students' progression through Mezirow's stages of meaning.
4. Qualitative responses to open-ended questions will accompany quantitative questions to deepen content and increase interpretive capacity for understanding.

5. Our own auto-ethnographic "testimonial" accounts or transformative learning and teaching as we have progressed through the phases of meaning as course instructors, program developers, colleagues, and researchers will also be generated at the end of the data collection phase.

Through the process of collecting and analyzing this data, it is our goal to produce a set of best practice considerations for transformative teaching and learning in engineering design capstone courses. We plan to follow up on and develop these considerations in future studies and also to expand our research by pursuing other (tangential) gaps that we have identified based on our reviews and analyses but are outside the scope of the present study.

Informed Hypotheses

Before moving on to the data collection phase of our study, it has also been useful to identify some of the hypotheses that we share as researchers about what we expect to find based on the review of the literature. These hypotheses are:

- Students who have completed internships and/or participation in clubs in the past are more likely to work well in teams, to value communication skills, to identify as engineers, to be confident in their engineering skills, and to complete the course in the spring.
- As a result of the design year, students who had not participated in internships or clubs prior will feel more comfortable working in teams, value communication more, identify more as engineers, be more confident in engineering skills (results evident in comparison between pre and post tests).
- Participation in teamwork, reflection, extracurricular activities, internships, and communities of disciplinary mentoring and learning as well as demonstration of affective awareness will all be associated with confidence in engineering skills, identification as an engineer, demonstration of professional integrity and course completion.
- As a result of our collaborative EAR project, we as researchers, instructors, and colleagues will develop new dimensions of our understanding of research questions and of ourselves that will allow us to collaborate more effectively and make pedagogical decisions more effectively to support student success.

Discussion: Applications and Future Research Plans

Based on the progress that we have made in the research process and literature reviews thus far, we are interested in learning how the transformative influencers we have implemented in the capstone course will contribute to or impact students' progression through Mezirow's stages of meaning and transformative learning. Based on its experiential and integrative elements, the engineering design capstone course seems to be particularly well-suited to provide transformative teaching and learning opportunities for students, and cross-disciplinary co-instruction and research projects also seem to be likely to support transformative experiences

for us as instructors/researcher that will enable us, in turn, to build increasingly more meaningful educational communities. The key insights that we will carry forward from this review include:

1. The usefulness of transformative learning theory as a way to define success in engineering design education
2. Key influencers identified in best practice research for transformative learning in engineering design capstones
3. The usefulness of EAR as a conceptual framework for transformative educational research
4. Some potential benefits of cross-disciplinary co-instructional and research processes that use transformative learning as framework within with to increase mutual understanding and negotiate epistemological and cultural approaches to instruction and research

In future phases of our study, we hope to gain a richer understanding of students' developmental experiences and the course interventions that influence them most. We also expect our ongoing reflections and collaborative conversations and reports, along with and the process of creating and analyzing our own auto-ethnographic narratives, to illuminate the transformative value and potential of cross-disciplinary collaborative teaching and learning communities in the capstone series. By creating awareness of dimensions that impact course design, curriculum, and the class environment, we hope to make discoveries that will allow us to facilitate increasingly meaningful and transformative learning experiences for students in the the years to come. We also anticipate that, by demonstrating the transformative value of our approach to working together as co-instructors and program developers to engage our students in communities of learning and raise critical and professional awareness, our study will support other engineering educators as they promote engineering students' professional and technical skill integration through meaningful design project experiences.

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Appendix A: Survey Questions

Q2.2 Age

Q2.3 Gender

Q2.4 Ethnicity

Q2.5 Had you completed an internship or other project in which you completed real-world engineering projects before taking the ECE capstone?

Q2.6 Had you worked with a team on significant, long-term (at least 3-month) project that was important for your academic or professional success before taking the ECE capstone?

Q2.7 Had you had a significant, ongoing relationship with at least one engineering mentor before taking the ECE capstone?

Q3.1 Please select all of the activities that you have spent significant time on as a part of the ECE capstone to-date.

1. Meetings or communication with teammates
2. Meeting or communication with a stakeholder
3. Meeting or communication with an instructor or manager
4. Meeting or communication with a project mentor
5. Researching technical design principles
6. Implementing the design/building alone
7. Implementing the design/building with teammates
8. Thinking about/reflecting on the design process
9. Thinking about/reflecting on working in a team
10. Thinking about/reflecting on your engineering skills

Q3.2 Which of these these activities do you think has been those most meaningful to you or your team so far overall?

Q3.3 Please explain why:

Q4.1 What grade do you expect to receive for ECE 441?

Q4.2 Rate your agreement with the following statement:

I have been successful in my progress as an individual student to-date.

Q4.3 What about your experience has been successful?

Q4.4 Please explain your response.

Q4.5 What about your experience has impeded you from being successful?

Q4.6 Rate your agreement with the following statement:

My team has been successful in our collaborative progress to-date.

Q4.7 What about your team experience has been successful?

Q4.8 Please explain your response.

Q4.9 What has impeded your team from being successful?

Q5.1 Please rate your agreement with the following statement:

I have an ongoing, meaningful relationship with at least one engineering mentor.

Q5.2 Please rate your agreement with the following statement:
I have taken on leadership roles as a part of the ECE capstone course.
Q5.3 Please rate your agreement with the following statement:
I see myself as an engineer.
Q5.4 So far as a result of the capstone course, how frequently have the following statements applied to you?

1. I feel confused.
2. I have questioned my engineering choices.
3. I feel alienated from my peers.
4. I discuss engineering challenges with others.
5. I think of multiple approaches to engineering challenges.
6. I am confident in my approach to engineering challenges.
7. I create a plan to solve engineering challenges.
8. I know how to implement a plan to solve engineering challenges.
9. I have taken on new roles in teams solving engineering challenges.
10. I have learned a new skill and then used it to solve an engineering challenge.

Q5.4 Has the ECE capstone experience to-date impacted either the way you see yourself as an engineer or what you think it means to be an engineer? Please explain your answer.