Longitudinal Study to Develop and Evaluate the Impacts of a "Transformational" Undergraduate ECE Design Program: Study Results and Best Practices Report

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Previous research identified influencers for transformative learning: critical awareness of culture, professional identity development, participation in communities of mentoring and learning, holistic skill integration through reflection, and development of professional integrity through affective awareness. To implement these Evidence-Based Instructional Practices (EBIPs), instructors at Oregon State University conducted a longitudinal study. Emancipatory Action Research (EAR) methodology was used to measure the effects of these influencers when integrated into a Capstone Design engineering program. The researchers found that both interventions did have significant impacts on students' progression through a process of transformative learning because they reached a "crossroads of questioning."

Keywords: Electrical Engineering, transformative learning, capstone courses, design, experiential education, program development, action research

INTRODUCTION

Oregon State University's (OSU) School of Electrical Engineering and Computer Science (EECS) has been engaged in an ongoing study examining the Electrical and Computer Engineering (ECE) undergraduate degree program. The key research questions were:

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?*

In a previously-published literature review paper (Cate & Heer, 2018), key transformative educational programmatic influencers were identified. Emancipatory Action Research (EAR), a pragmatic qualitative epistemology, and a critical mixed-methods approach were also identified as best fitting methodological frameworks to guide the present study (Merriam, 2009; Somekh, 2005). This follow-up report includes the results and analysis of data collected.

During the second year of the study, two program changes were investigated: students who had previously completed a two-term Junior Design "mini-capstone" experience; and students had the opportunity to participate in Communities of Practice that supported their technical skills, professional development and engineering identities. The present study applies transformative learning theory as an overarching framework (Mezirow, 2009). Data collection and analysis takes into account the need for researcher transparency as well as calculations of statistical significance and the effect size of transformative learning factors. In addition, qualitative themes are examined to add depth of context to the interpretation of the transformative learning process.

BACKGROUND

Prior work by the present researchers has included extensive literature and case study review in the areas of transformative education theory and experiential engineering education (Cate & Heer, 2018). Within this review, transformative learning theory as it applies to this study is

> *a sort of epistemology (or paradigm for knowledge creation) in and of itself* [which] *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* (Cate & Heer, 2018).

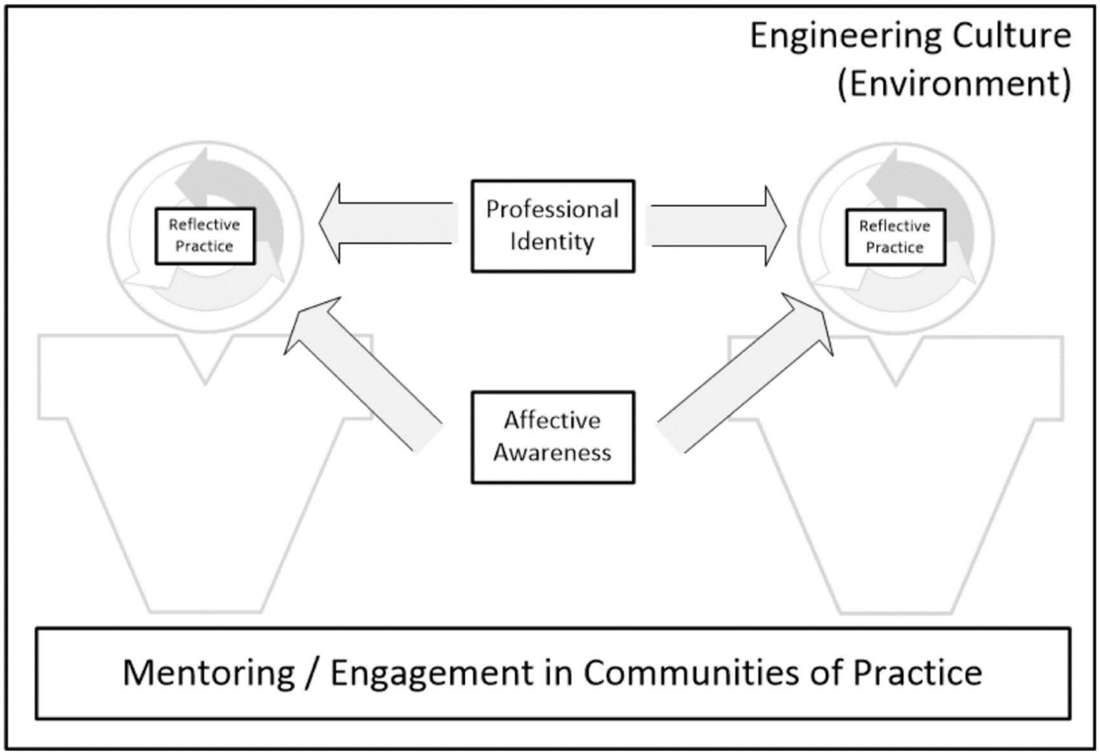
The practice of transformative learning (according to Jack Mezirow) is defined as "transforming a problematic frame of reference to make it more dependable in our daily life by generating opinions and interpretations that are more justified" (Mezirow, 2009). According to both Mezirow (2009), Merriam (2004) and practitioners of engineering education who have applied transformational learning theory to their own studies (Illeris, 2014; Goodman, 2015; Stevens etal. 2008; Agrawal & Harrington-Hurd, 2016; Malur, Meena & Deekshit, 2014), true transformative learning touches deeply into participants' sense of identity, community, and overall worldview, rather than just depositing content into the surface of a learner's awareness. Additionally, experiential learning programs facilitate this depth when reflective practice is integrated with application of content knowledge into practice (Adams, Turns & Atman, 2003; Adams et al., 2011; Norback & Hardin, 2005; Johns-Boast & Flint, 2013; El-Abd, 2016; Bolinger et al., 2010; Freire, 2005; McDermott, Snyder & Wenger, 2002).

As a result of the initial literature review, the following five influencing factors for transformative education programs were identified:

1. Critical awareness of culture
2. Professional identity development
3. Participation in communities of mentoring and learning
4. Holistic skill integration through reflection
5. The development of professional integrity through affective awareness

Fig. 1 is a visual representation of the process of these five influencers' impacts on student experiences in an electrical and computer engineering program. This model of the five influencing factors was used in the development of the study interventions.

FIGURE 1
PROCESS OF TRANSFORMATIVE LEARNING AS AFFECTED BY THE 5 INFLUENCERS: CULTURE, PARTICIPATING IN COMMUNITIES, REFLECTION, PROFESSIONAL IDENTITY, AND AFFECTIVE AWARENESS



METHODS

To evaluate the interventions adequately, both qualitative and quantitative data was needed. While quantitative analysis methods identify correlations between variables and can be used to support some interpretive conclusions based on those statistical calculations, their formulation is still far from objective. As supported by a mixed-methods qualitative epistemology (Merriam, 2009), both statistical/numerical analysis and qualitative data analysis based on themes in text content were used to create an understanding of the effects of the interventions applied in the study. One instructor-centered practice (auto-ethnographic teaching narratives) and two programmatic student-centered (the Junior Design course series and the Communities Practice program) were applied.

Qualitative Teaching Narratives

To begin the study, researchers began by writing their own personal teaching narratives. This intervention helped to set the stage for the later developments. Two primary researchers, one with a formal engineering education (Don) and the other with a formal communication education (Rachael), engaged in these narratives. These teaching narratives allow for the researchers to reflect on our own perspectives, document them for the purpose of transparency, and allow for a dialogue to promote mutual understanding between us. Rather than creating objective distance, we are providing cultural and relational context and demonstrating the personal nature of our perspectives as Action Researchers who must participate in the study through our own dialogue and learning process. Context is so important in qualitative and EAR research because all of the impacts of the study described here are also tied to this cultural factor and may not have external validity without it.

The prompts we used to focus our narratives were:

- ***What do you think are your most important educational contributions to the capstone course?***
- ***What are the values of education in your discipline that professionals agree contribute to success?***
- ***Describe your approach to educational research, including epistemological perspectives you identify with***.

Values related to educational contributions, success, and research approaches were of particular interest due to their overall impacts on personal educational perspectives. The factors provide a helpful indication of the cultural framework within which the individuals function, and the dialogic exchange between them demonstrates key points of transformation based on reflection and increased mutual understanding that impact the environment of the study.

Don's Response

The primary focus of Don's response was on helping students broaden their technical skill sets by supporting and driving learning. "My important contributions include structuring, technical direction, devil's advocate, and motivation..." he noted, "I have the [technical] knowledge." He also emphasizes the value of education as a means to getting a specific job: "Technical competency is the primary education required." His research approach hinged (originally) on the presence or absence of quantitative data and rigor as markers of "complete research" as opposed to the type of feedback that informs educational practice, which is often "anecdotal" because "analysis and data driven validation is hard to achieve." According to Don, to achieve "complete research ...I have the need to get [accurate] numerical data either through survey or through coding responses."

Rachael's Response

Rachael's response focused not on knowledge or skill acquisition but on contributing a perspective that is more open-ended or question-oriented: "I come from a very different scholarly background, where questions aren't always meant to have definitive answers, and it can be the process of questioning and keeping an open mind to evolving circumstances that is mostly highly valued sometimes." Because Rachael's training is in the humanities and social sciences, it is perhaps unsurprising that her response focuses more on holistic abilities such as critical thinking and ethical responsibility. She notes values that inform her work are "Critical awareness of situations that enable learners to make ethical decisions about their own practices and also to take a holistic perspective."

Rachael's background as a qualitative educational researcher and interpretive cultural studies analyst causes her to focus her response on the impossibility of "true objectivity" in research, even when that research includes quantitative data. "As researchers," she noted, "We also have to examine ourselves. There's no getting around our biases...there is a danger in not examining the assumptions we've brought to the table even in formulating our questions in the first place." According to this formulation, "true research," whether it is quantitative or qualitative, social scientific or engineering is not infallible and must include an investigation into researcher perspectives, assumptions, and biases of methods in order to have validity. In addition, numbers alone do not have reliable meaning without qualification to support interpretation.

Key Transformations

The goal of education in the discipline and the underlying values that drive that goal are central to defining "success" for student achievement. The split between focus on holistic awareness for the purpose of self-actualization and specific skill competency that relates to candidacy for jobs reflects the split between humanities/social science and engineering education disciplines. However, there were also some important shared views. Both responses demonstrated the view that learning is a process and educators should facilitate that process by helping students to have insights for themselves, rather than simply being told what to think. This is a common groundwork for a view of what transformative learning should look like in practice that has enabled us to agree on the educational goals of the interventions in this study.

As researchers, in understanding the differences between our perspectives, we have cultivated a more inclusive perspective to apply to our teaching. Shared educational values that resulted from our dialogue have influenced our class culture by emphasizing both introduction of practical skills for job preparedness and also reflection and critical thinking activities that build strong leadership practices through increased situational awareness and deep engagement with ideas.

Regarding the analytical methods, we now agree that a pragmatic multi-methods approach is most appropriate. As such, this study incorporates both a deep respect for both the interpretive nature of qualitative research and the value of numerical analyses to identify overall trends in order to achieve an analytical lens that is pragmatic and integrative.

The ECE Junior Design Course Series

In order to support transformative learning for capstone students, we implemented a two-term course sequence in the junior year, or ECE Junior Design. As a precursor to ECE Capstone Senior Design, the two-term junior sequence created a scaffolding experience where students were introduced to project engineering with a lower-stakes, short-term set of experiences.

Students were introduced into the culture of design and team project engineering based on the structure of the experiential course setup and assignments included. They were guided through steps to help them develop professional identity, including readings on the topic and assignments focusing on job preparation and career development. They worked on teams to solve technical and project management challenges, and they were given the opportunity to reflect on these topics in required writing assignments. They also read and had class discussion around the topic of emotional intelligence and affective awareness, especially centering on necessary teamwork skills. All of this instruction, guidance, and experience took place in the two terms before the senior year and served to prepare students for the ECE Senior Design year experience. As a hypothesis, by introducing influencers for transformative education to students earlier, the ECE Junior would increase the efficacy of the transformative learning experience for participating students.

For seniors during the 2017-2018 academic year, the ECE Junior Design intervention had not been developed when they were juniors, and so it was not available to them. Therefore, the 2018 spring survey is a control group. There were also some seniors in the spring of 2019 who had not been enrolled as juniors the previous year, so their responses were added to the control group for the ECE Junior Design intervention as well. The remaining ECE Senior Design students in the spring of 2018 who had gone through the ECE Junior Design series are considered the experiment group for this study.

The Communities of Practice Program

The final intervention developed to support transformative learning in students was the Communities of Practice (CoP) Program. The Communities of Practice established were modeled after disciplinary communities of practice outlined by McDermott, Snyder, and Wenger (2002). The explicit mission of the program is to:

> *Prepare students to succeed in their careers and to adapt to an ever-changing world by providing opportunities to engage in inclusive and collaborative communities wherein they accumulate proficiency by putting knowledge into practice. Within these communities, students, together with industry and university experts, explore knowledge of a specific topic area, identify personally meaningful problems, take initiative, design technical solutions, obtain support, implement solutions, develop mentor relationships, serve as leaders in professionalism and innovation, and showcase meaningful contributions to computing and engineering disciplines.*

In 2018-2019 round of the program pilot, five communities were established:

- Analog and Power Systems
- Mechanical Engineering
- Cloud and Application Systems

- Embedded Systems
- Internet of Things

Students had the opportunity to participate in one or more of these communities and receive credit for ECE Senior Design (a total of 10% of the course grade). As members of the communities, they held meetings, initiated projects, hosted guest speakers, contacted mentors, created and participated in online forums, added to online blog content, and discussed projects they were working on. By completing these tasks, they were checked off by graduate student "community coordinators" for course credit.

This pilot program began in AY2018-2019 academic year. Therefore, students who took the survey in the spring 2018 ECE Senior Design course term had not had the opportunity to participate, making this group a control group for the CoP program. In addition, some students opted not to participate in the CoPs during the 2018-2019 year, so their data was also added to the control group for the CoP intervention. Those who identified themselves as having participated in one or more CoPs during the 2018-2019 academic year were included in the experimental group for the CoP program intervention.

DATA AND ANALYSIS

Quantitative and qualitative data were collected and analyzed to determine the efficacy of the programmatic influencers applied and of each of the intervention programs specifically as EBIPs for promoting transformative education. Though most of the results here are specific to this case and have unproven broad generalizability, some statistical significance has been demonstrated that suggest the efficacy of the interventions to other programs of engineering.

Survey Instrument and Data Collection

The survey instrument was derived from the concept of transformative learning described by Mezirow (Mezirow, 2009) and further developed to investigate the influencers of transformative learning. Questions regarding students' experiences of mentor relationships, leadership roles assumed, feelings of alienation, confidence in skills, and professional identity were included. See Tables 1 and 2 for wording of questions selected to demonstrate quantitative results. Qualitative follow-up questions were also included to add depth of context to these questions, and these are discussed at greater length in the section below as well.

Data Analysis

Analysis of quantitative data from the surveys, including a control group and intervention group, includes a measure of statistical significance of each intervention for a set of dependent variables related to transformative education. The p value $< .05$ for significance demonstrates a level of confidence that factors listed are significantly correlated (but does not demonstrate the strength of the change in data sets based on these factors). To calculate this strength as well as to show the strength of effect on variables that did not test positive for generalizable statistical significance (but were possibly the result of the intervention in this case), effect size analyses have been used.

Effect size, or the change in mean values within the data set divided by the standard deviation, does not account for the probability that the given results might appear at random within the sample (Coe, 2002). The control group/intervention group model serves to create a quasi-experimental scenario where the greatest common factor of change between the two data sets is the program experience. As such, one may infer that the effect change between the data sets may be due to the overall effect of the experience. Included in the control group were both responses from students who did not have access to the interventions and those responses from who did have access but who chose not to participate.

While quantitative data demonstrates general trends regarding the participants' experiences and perspectives, qualitative data provides depth of context on which to base interpretations. Our interpretation of their significance within Mezirow's framework for transformative education (Mezirow, 2009) and the five influencers for transformative education is included in the "Results" section below.

Limitations

A limitation of the analytical methods used in this investigation is an omission of breakout by population demographics of the respondent, barring an ability to draw further conclusions about variation within the data set (i.e. might women participants have seen more or less improvement in scores than men?). While this type of multivariate factor analysis may be important to understand the effects of the program within the context of a future research study, it is outside the scope of the present analysis.

In addition, as educational practice and program development research, the analyses included here rely on the interpretive lens of the researchers. While quantitative data has been collected to provide a broad descriptive picture of self-reported participant experience and instruments developed based on strong theoretical frameworks, there is still a wide margin of variability within participants' own interpretation of the meaning of questions and approach to answering them. Therefore, the qualitative data is used primarily to provide a meaningful basis for in-depth understanding of participants' experience within appropriate context, with a greater degree of reliability. While this approach still leaves the perspectives and biases of the researchers' interpretations in question as a reliable approach to interpreting the data, this subjective bias is mitigated through the transparency of the narrative explanation included in the data analysis section of the report, as is recommended for qualitative research analysis in educational program evaluation by Patton (Patton, 2008).

Survey Results

Both quantitative and qualitative data have been analyzed to create a broad understanding of the effects of the two interventions on the objective of transformative learning. Statistical significance with a p value of $< .05$ and effect sizes $> .4$ both indicate intervention participation as a predictive factor of transformative learning. These results are included below. However, the quantitative results alone do not help researchers to understand how or why transformative learning has happened (Merriam, 2009). As such, for both interventions qualitative responses have also been analyzed to allow the researchers to better understand why an effect has occurred and to further interpret the meaning of the relationship between variables.

To facilitate a more in-depth understanding of the implications of this response on the process of transformative learning, the following qualitative questions were asked:

- *What about your experience has been successful?*
- *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.*

For both of these questions, the responses were coded and sorted based on the theme of focus related to transformative learning.

Junior Design Course Series

Results indicate that the Junior Design course series had a positive impact on the transformative learning of engineering students who participated. Table 1 shows the effect size calculations for factors of transformative learning measured in the survey, specifically for the control groups compared to those who participated in the Junior Design course series. Those variables that tested positive for statistical significance based on the Chi-square test at $p < .05$ are indicated with an asterisk. The following section describes the results of these calculations and, for each of the selected variables, includes qualitative content that relates to the respective variables and facilitates the interpretation of their meaning.

Students who reported having taken Junior Design also reported that they were more likely to have questioned their engineering choices. This was statistically significant with a p-value of .02 using a Chi-squared test. The reported Glass effect size was .45. Based on the effect size, this means that of the group of students who reported taking Junior Design, 66% of the group would report questioning their choices more than the average student who did not report taking Junior design.

According to Mezirow (Mezirow, 2009), questioning choices is a step in the transformative learning process. Fig. 2 provides a visual breakout of the control group response vs. Junior Design participants' responses to this question.

TABLE 1
EFFECT SIZE CALCULATIONS FOR SELECTED DEPENDENT VARIABLES BASED ON WHETHER A STUDENT REPORTED TAKING ECE JUNIOR DESIGN (INTERVENTION) OR NOT (CONTROL)

Question	Control Mean	Intervention Mean	Control Std. Dev.	Effect Size (Glass Delta)
I have been successful in my progress as an individual student to-date.	.6	.4	2.4	0.09
I have an on-going, meaningful relationship with at least one engineering mentor.	.4	.8	1.9	0.22
I have taken on leadership roles as a part of the ECE capstone course.	1.4	1.5	1.5	0.07
I see myself as an engineer.	1.8	1.8	1.2	0.12
I feel alienated from my peers.	1.4	1.4	1.1	0.0
***I have questioned my engineering choices.**	2.4	2.9	1.1	0.45
I am confident in my approach to engineering challenges.	3.5	3.3	1.0	0.0
I have learned a new skill and then used it to solve an engineering challenge.	3.9	4.0	0.9	0.11
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?	0.7	0.6	0.6	0.12
What grade do you expect to receive for this course?	3.8	3.6	0.4	-0.5

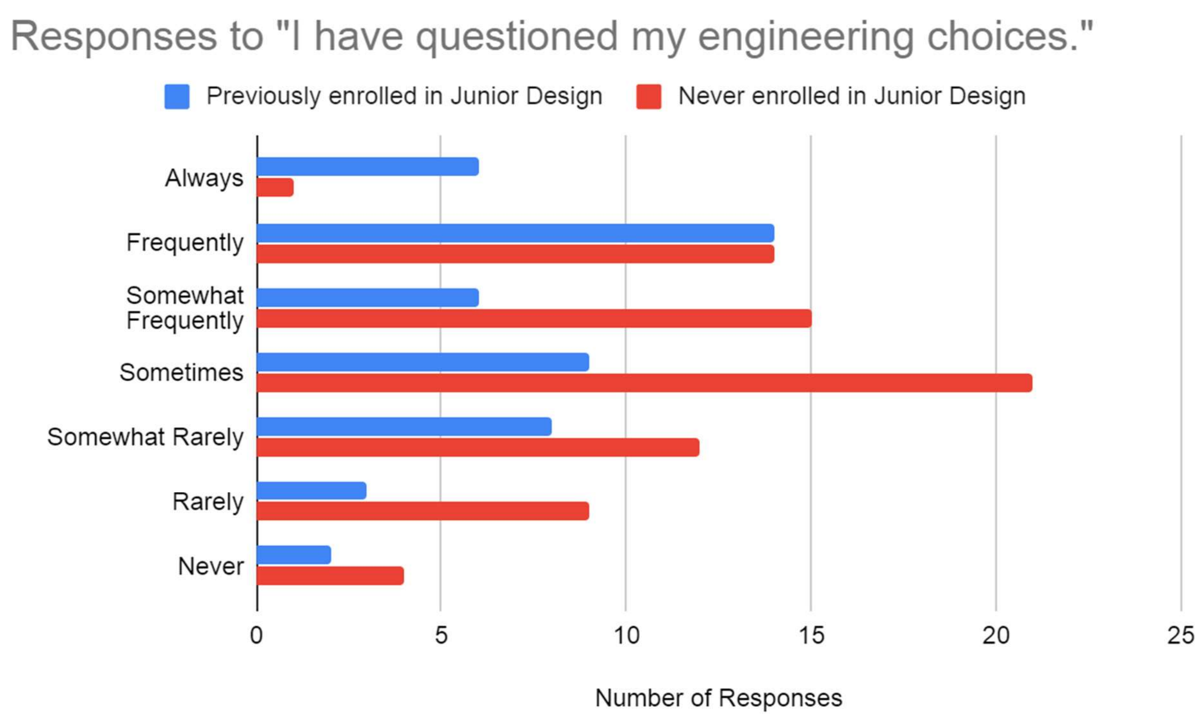
* Indicates Dependent Variables that have a p-value of less than .05 when applying a Chi-squared test to the data.

In order to better understand and meaningfully interpret the significance of this response, it is helpful to take themes from qualitative responses into account. For example, several students who had taken Junior Design expressed their questioning (both themselves and their choices) directly when asked about the effect of the Senior Design Course series. For these students, "questioning choices" was clearly related to their confidence as engineering majors and the choice they had made to become engineers:

- *"It makes me personally feel less confident in my knowledge and technical skills compared to my peers."*
- *"It has made me further doubt my abilities to be successful in engineering."*
- *"I learned that I have a long way to go in the journey of being the best engineer I can be but I am at least off the ground in that journey."*
- *"It made me more confident in myself and showed me that I have what it takes to be an engineer. It also reassured me that I chose the right degree since even though it was hard I really enjoyed it."*
- *"[Course experience] questions my choices, but reaffirm choices made."*

Less confidence in comparison to peers in this case is a result of the opportunity to work alongside those peers and see their abilities. Therefore, it makes sense that those exposed to their peers at greater length through Junior Design would be more likely to question their own abilities. Along the same lines, those with more exposure to the risks of design engineering would be more likely to have a realistic doubt of their potential for success. For at least some of these students, though, the questioning phase has resulted in reaffirmed (stronger and more resilient) confidence in their choice to become engineers, as demonstrated by the final two quotes above.

FIGURE 2
STUDENTS WHO HAD TAKEN THE JUNIOR DESIGN COURSE SERIES REPORTED QUESTIONING THEIR ENGINEERING CHOICES MORE OFTEN THAN THOSE WHO DID NOT



Other responses seem to refer to "engineering choices" as technical decisions made within the design process. As with questions of confidence in overall engineering ability above, these responses also indicate a crossroads of questioning encountered by participants who had completed the Junior Design course sequence. Some of these students described the crossroads thus:

- *"I realized that making decisions without analyses is basically shooting in the dark."*
- *"I generally feel more confident in my critical thinking and adaptability."*
- *"Engineers work as relatively free agents. Projects are supervised, but ultimately the choices made on a small scale are my own to make, and that's a lot of pressure to deal with if something goes wrong. Having justification for every decision made is critical, however there's no such thing as a perfect engineer- everyone makes mistakes."*
- *"It made me understand the design process in a way that I wouldn't have thought before. To me an engineer solves problems using different approaches and tries to solve their problems with the tools at hand. In this course experience I believe that I used my skills to approach problems in different ways."*
- *"Engineering isn't about being able to solve a specific problem, its about being able to come up with original solutions to original problems."*

All of these responses demonstrate an increased awareness of the importance of applying critical thinking (rather than just basic logic) in engineering design decisions. They also indicate new (transformed) perspectives on problem solving in engineering and the relationship between the professional identity of the engineer-as-critical thinker.

While reporting having questioned engineering choices demonstrates students' status along the transformative learning process, it is unclear how positive this finding is on its own. If students are not questioning their choices while being supported by a community and guidance to continue developing their confidence, for example, they may find a fork in the road where, after having questioned their choices, they may lose a feeling of efficacy and become dissatisfied in the engineering major on the whole. At this point in the interpretation of data, it is important to point out that these are both possible outcomes of the Junior Design intervention. However, it is our point of view that either outcome is ultimately more positive than a scenario in which, in the absence of a sufficiently transformative learning experience, students choose to stay in the major having never come to increase their awareness through a "*crossroads of questioning*."

In addition, it is clear that respondents understand their own agency as learners and as engineers in a new, transformed way (even though this may seem like "a lot of pressure" at times). Having experienced real design processes, these Senior Design students who had taken the Junior Design course series as well have expressed their understanding that problem solving is not easy, it can be difficult and ambiguous to find the "right answers" in design engineering, and also that that is OK. But it does mean it is their professional responsibility to weigh all decisions critically.

As a reflection on how these responses differed from some of those from participants in the non-Junior Design (and non-CoP) control group, it was noted that the control group responses tended to focus less on questioning (themselves as engineers or design choices) or critical thinking. They focused more instead on development of professional skills such as communication, teamwork, project management, and documentation and also included more complaints about these as "busy-work." This trend may reflect the less advanced stage of these respondents along the process of transformative learning. Having had less exposure to the aforementioned leadership skills than Junior Design participants, they may have been encountering them (in application in design engineering) for the first time in Senior Design and had less time to consider their deeper significance.

As a final note on the responses of Junior Design participants, it is worth mentioning that there was also a large (negative) effect size change in the result recorded for the question of what grade students expected to receive for the Senior Design course. While there is no additional qualitative data available related to this question in particular, it may be fair to assume that a strengthened awareness of the design process and impacts of decisions made may carry over to more realistic and informed awareness of their status as students in the course as well. On the one hand, having had less opportunity to experience the outcomes of their own real design choices, students in the control group may have been overly optimistic. On the other hand, students who had taken the Junior Design courses before, having experienced an outcome and grade that were (in most cases) affected by some unforeseen circumstances and short-sighted decisions, were more likely to respond a bit more cautiously regarding their expectations for Senior Design.

Communities of Practice

Results indicate that Communities of Practice did have a positive impact on the transformative learning of engineering students who participated. Table 2 shows the effect size calculations for factors of transformative learning measured in the survey, specifically for the control groups compared to those who participated in Communities of Practice. Those variables that tested positive for statistical significance are indicated with an asterisk. Like the previous section, the following section describes the results of these calculations and, for each of the selected variables, includes qualitative content that relates to the respective variables and facilitates interpretation.

"I Have Questioned My Engineering Choices."

As with the Junior Design course intervention, students who had participated in Communities of Practice, when separated out from all those who had not, were also more likely to have questioned their engineering choices and to have questioned them more frequently.

The results for the CoP intervention are similar to those for the Junior Design course intervention, the effect size (.63) for questioning choices being even greater for participants of CoPs. Again, this result can be interpreted as an indication that students who participate in the communities advance in the transformative learning process and come to crossroads of questioning. Like having had the opportunity to gain team engineering project experience in Junior Design, being involved in a CoP seems to have facilitated increased awareness of the importance of critical thinking and taking responsibility for choices as an engineer that may not have easy answers, including the choice to become an engineer and weighing individual design decisions.

There is a similar depth in responses from the CoP participant group to the Junior Design group with regard to an indication of transformative perspectives and increased agency:

- *"Overall it was a chance for me to apply the skills that I've learned and see how it went. There was a lot of failure but I learned a lot about where I am at."*
- *"Seeing everyone solving problems together made me reflect upon myself."*
- *"I think this experience has made me better at troubleshooting. I believe every engineer should know how to read and interpret a datasheet, ask questions, create a plan, and execute that plan effectively."*

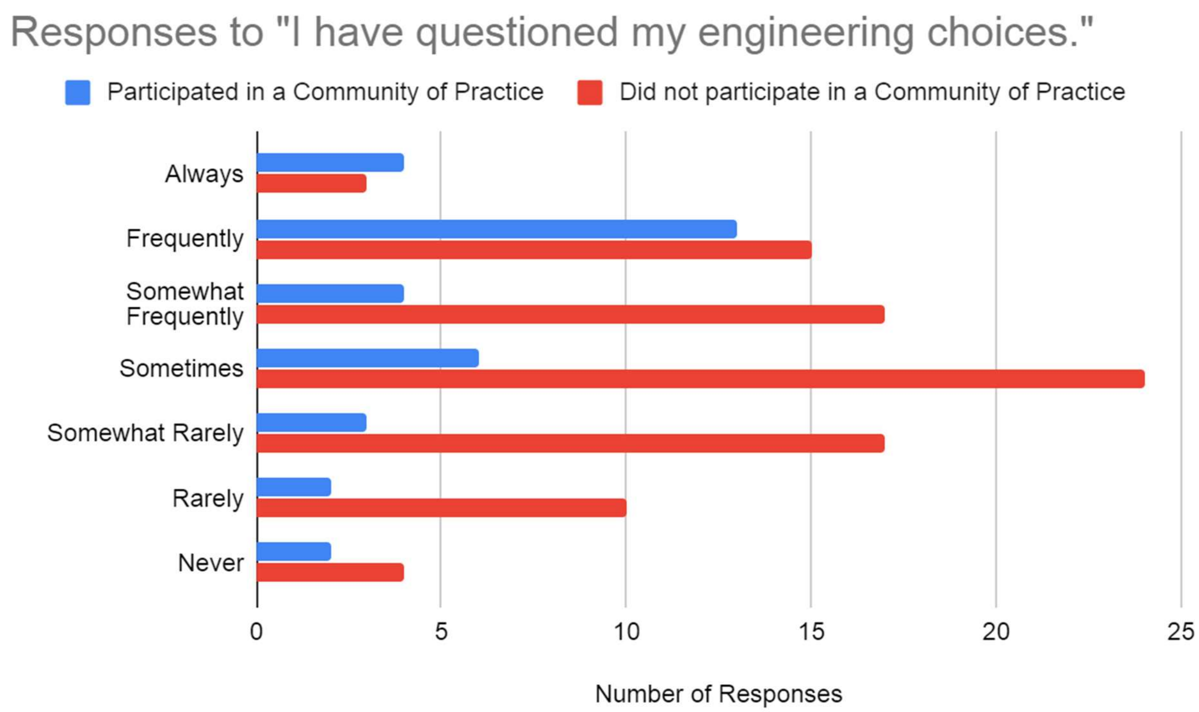
TABLE 2
EFFECT SIZE CALCULATIONS FOR SELECTED DEPENDENT VARIABLES BASED ON WHETHER A STUDENT REPORTED PARTICIPATING IN COMMUNITIES OF PRACTICE (INTERVENTION) OR NOT (CONTROL)

Question	Control Mean	Intervention Mean	Control Std. Dev.	Effect Size (Glass Delta)
I have been successful in my progress as an individual student to-date.	.5	.7	2.3	.09
I have an on-going, meaningful relationship with at least one engineering mentor.	.5	.8	1.8	.12
I have taken on leadership roles as a part of the ECE capstone course.	1.5	1.4	1.4	.07
I see myself as an engineer.	1.9	1.7	1.1	.18
I feel alienated from my peers.	1.3	1.6	1.0	.3
***I have questioned my engineering choices**	2.4	3.1	1.1	.63
I am confident in my approach to engineering challenges.	3.5	3.3	.9	.22
I have learned a new skill and then used it to solve an engineering challenge.	4.0	4.0	.9	0
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?	.7	.5	.6	.33
***What grade do you expect to receive for this course?**	3.8	3.5	.4	-.75

* Indicates Dependent Variables that have a p-value of less than .05 when applying a Chi-squared test to the data.

The tendency for self-reflection and self-assessment is particularly highlighted in these responses. One possibility is that time spent focusing on the topic of engineering as a profession and in self-initiated consideration of the significance of belonging to a community of other engineers who are linked by an affinity for areas of practice has, for these participants, catalyzed a process of advanced reflection that has broadened their awareness in transformative ways.

FIGURE 3
STUDENTS WHO HAD PARTICIPATED IN COMMUNITIES OF PRACTICE REPORTED QUESTIONING THEIR ENGINEERING CHOICES MORE OFTEN THAN THOSE WHO HAD NOT



As with participants in Junior Design, as well as the response to "What grade do you expect to receive for this course?" had a negative correlation with participation in CoPs. In fact, there was statistical significance and a larger effect size associated with CoP participation. If interpreted in the same way as for Junior Design, this result could reflect the CoP participants' more advanced awareness of their own limitations and potential risk for failure as beginner design engineers with much to learn.

"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?"

The CoP group's specific qualitative responses may help to elucidate some unique effects of the CoP intervention. While both intervention groups focused on questioning and critical thinking, the CoP group seemed to include more of a focus on community awareness as well. One response, in particular, exemplifies the depth of reflection on this theme:

> *"Being an engineer is not just about solving technical problems. It's about providing solutions - technical or not - to any problem, in the most efficient way possible. A good engineer can solve technical problems, but only a great engineer can solve both technical*

and social problems, or create something greater than the sum of their parts (a team of engineers, and not just engineers, which is an area I feel I fell very short on my goals on)."

This response demonstrates an awareness of social systems theory at play in teams and communities of engineering. This student is conscious not only of the specific technical decisions they must make based on concrete calculations to address a clearly-defined need, but also of the situational and circumstantial aspects of engineering in a broader social context. As implied here, along with an awareness of this social context also goes an increased sense of responsibility to work together with a community to solve problems and achieve change that would be impossible for any one individual working alone. In addition, the student explains how this increased socio-ethical awareness also led to a more realistic view of accomplishments and shortcomings in these areas.

CONCLUSIONS

Considering all of interventions implemented in this study along with their respective outcomes, several key insights arise that have implications for future practice and research. Each intervention contributed to processes of transformative learning by supporting opportunities for transformative educational influencers (Culture, Participating in Communities, Reflection, Professional Identity, and Affective Awareness). Qualitative teaching narratives created a foundational culture of transformative learning, the Junior Design course series provided experiential learning opportunities where reflection on decisions, professional identity, and teamwork (building affective awareness) were necessary, and Communities of Practice gave participants the chance to reflect on practice, professional identity, and the value of community while working together. While the Senior Design course experience on its own is transformative in providing the same opportunities as those mentioned in Junior Design (except on a larger-scale and longer-term), each individual intervention expanded upon the transformative value of Senior Design in specific ways.

Qualitative Teaching Narratives

The narratives and dialogue supported a strong foundation for the rest of the study by making the perspectives of the researchers more transparent and facilitating an instructional culture of self-awareness and transformative learning. This practice had direct effects on program development and the learning environment. As such, it was not just a method for creating transparency regarding researcher positionality but, effectively, an intervention in this EAR study.

During the process of narrative creation and sharing, we reflected on our practice, gained new perspectives, and questioned our own assumptions about the meaning and value of engineering education. We were both transformed as teachers and as researchers as a result.

Junior Design Course Series and Communities of Practice

The Junior Design course series and Communities of Practice clearly had an effect on students' process of transformative learning. Results indicate that participants in either of these interventions had progressed further along Mezirow's transformative learning stages than the control group. Specifically, they reached a "crossroads of questioning" including building critical thinking and self-awareness that can become a gateway to increased confidence in engineering skills and professional identity.

Both the Junior Design course series and Communities of Practice were experiential programs that intentionally incorporated all of the transformative learning influencers, and both programs created effective opportunities for students to make progress through the stages of transformative learning. Regardless of what particular shape such opportunities take, it may be that sincere instructional focus on providing opportunities that incorporate the key influencers for transformative learning is on its own the most important instructional practice to promote transformative engineering education.

Regarding the separate results of the Junior Design and Communities of Practice interventions, the first seems effective for our Senior Design students because of an extension of time devoted during which they could progress. The second intervention, CoPs, seems effective due to the special focus devoted to reflection on transformative topics and the opportunity to do this within a structured community of peers and mentors. More investigation into participants' experiences within the CoPs is currently underway to help researchers better understand how the communities can be optimized.

RECOMMENDATIONS FOR FUTURE WORK

Through their participation in either or both of interventions designs in this study to promote transformative educational practices for our ECE Capstone Design program, we found that students came to a crossroads of questioning, deepening their awareness of professional identity, social responsibility, belonging and community, beyond what was developed by the control group population. We also deepened our own awareness of transformative learning and the shared culture that we must intentionally create as we support our students and empower their learning processes through programming opportunities. For these reasons, we suggest that all of the interventions mentioned in this study be included in a list of vetted best practices for engineering education and we encourage other instructors, program developers, and researchers to take them up and to adapt them to their needs. Though programs may take various forms, a multidisciplinary, experiential approach that incorporates an approach to culture, participation in communities, reflection, professional identity, and affective awareness is key.

Based on the results of the three interventions, respectively, we recommend the following:

1. Instructors of engineering education seeking to facilitate transformative learning experiences for their students should create their own auto-ethnographic teaching narratives and engage in interdisciplinary dialogues to share values and understanding. Not only do these practices help to support a strong foundation for educational action research studies, they also serve as a foundation for an educational culture within which transformative learning can occur.
2. Experiential design courses should be used to teach integrated skills, and also these courses should be extended throughout the curriculum in a way that allows for maximum scaffolding, possibly beginning as early as the freshman year in some form
3. More broadly, experiential opportunities should be developed that complement engineering programs and empower students to build integrated practical and professional/interpersonal skills, to participate in an inclusive, supportive engineering community, and to reflect on professional engineering identity across multiple school terms. The more extended the amount of time devoted to this, the more likely it is that students will progress further in their transformative processes.
4. Finally, we can recommend the establishment of discipline-based communities where students can come together to discuss engineering practice for course credit to be used as an inclusive transformational instructional practice.

In the future, we would like to extend our research to an investigation of the transformative experience for students with diverse identities, such a URM and women students, so that we may better understand how to promote equity and inclusivity in our transformative educational practices. Creating a culture that is equitable and inclusive supports diverse engineering approaches and empowers all engineering students to succeed as transformative learners. In addition, we invite other research that might duplicate our work or demonstration the saliency of the transformative education influencers in other contexts. By contributing to groundwork of understanding of the experiences of engineering students, we hope to continue working to empower future engineers with transformative educational practices.

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REFERENCES

Adams, R., Evangelou, D., English, L., De Figueiredo, A.D., Mousoulides, N., Pawley, A.L., . . . Wilson, D.M. (2011). Multiple Perspectives on Engaging Future Engineers. *Journal of Engineering Education*, *100*(1), 48–88. https://doi.org/10.1002/j.2168-9830.2011.tb00004.x

Adams, R.S., Turns, J., & Atman, C.J. (2003). Educating effective engineering designers: The role of reflective practice. *Design Studies*, *24*(3), 275–294. https://doi.org/10.1016/S0142-694X(02)00056-X

Agrawal, A.K., & Harrington-Hurd, S. (2016). Preparing Next Generation Graduates for a Global Engineering Workforce: Insights from Tomorrow's Engineers. *Journal of Engineering Education Transformations*, *29*(4), 5–12.

Bolinger, J., Yackovich, K., Ramnath, R., Ramanathan, J., & Soundarajan, N. (2010). From Student to Teacher: Transforming Industry Sponsored Student Projects into Relevant, Engaging, and Practical Curricular Materials. *2010 IEEE Transforming Engineering Education: Creating Interdisciplinary Skills for Complex Global Environments*, pp. 1–21. https://doi.org/10.1109/TEE.2010.5508872

Cate, R.E., & Heer, D. (2018, June 23). *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*. 2018 ASEE Annual Conference & Exposition. Retrieved from https://peer.asee.org/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

Coe, R. (2002). *It's the effect size, stupid: What effect size is and why it is important*. Annual Conference of the British Educational Research Association, University of Exeter, England. Retrieved from https://www.leeds.ac.uk/educol/documents/00002182.htm

El-Abd, M. (2016). How course projects can successfully prepare engineering students for capstone design projects. *2016 IEEE Global Engineering Education Conference (EDUCON)*, 746–750. https://doi.org/10.1109/EDUCON.2016.7474635

Freire, P. (2005). *Education for critical consciousness*. Continuum.

Goodman, K.A. (2015). *The Transformative Experience in Engineering Education* [Dissertation, University of Colorado Atlas Institute]. Retrieved from http://atlas.colorado.edu/wp-content/uploads/2016/01/KGoodmanDissertationv4.pdf

Illeris, K. (2014). Transformative learning and identity. *Journal of Transformative Education*, *12*(2), 148–163.

Johns-Boast, L., & Flint, S. (2013). Simulating industry: An innovative software engineering capstone design course. *2013 IEEE Frontiers in Education Conference (FIE)*, pp. 1782–1788. https://doi.org/10.1109/FIE.2013.6685145

Malur, K., Alumnus, Meena, P., & Deekshit, R. (2014). A transformative approach to capstone projects in engineering. *2014 IEEE International Conference on MOOC, Innovation and Technology in Education (MITE)*, pp. 348–351. https://doi.org/10.1109/MITE.2014.7020301

McDermott, R., Snyder, W.M., & Wenger, E. (2002). *Cultivating Communities of Practice* (1 edition). Harvard Business Review Press.

Merriam, S.B. (2004). The Role of Cognitive Development in Mezirow's Transformational Learning Theory. *Adult Education Quarterly*, *55*(1), 60–68. https://doi.org/10.1177/0741713604268891

Merriam, S.B. (2009). *Qualitative research: A guide to design and implementation*. Jossey-Bass.

Mezirow, J. (2009). *Transformative learning in practice: Insights from community, workplace, and higher education*. Jossey-Bass. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=469114

Norback, J.S., & Hardin, J.R. (2005). Integrating workforce communication into senior design. *IEEE Transactions on Professional Communication*, *48*(4), 413–426. https://doi.org/10.1109/TPC.2005.859717

Patton, M.Q. (2008). *Utilization-focused evaluation* (4th ed.). Sage Publications.

Somekh, B. (2005). *Action Research: A Methodology for Change and Development*. Open University Press.

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D.M. (2008). Becoming an Engineer: Toward a Three Dimensional View of Engineering Learning. *Journal of Engineering Education*, *97*(3), 355–368. https://doi.org/10.1002/j.2168-9830.2008.tb00984.x