Making Sense of Design: A Thematic Analysis of Alumni Perspectives

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Abstract:

In this paper, we present the findings of a thematic analysis on how alumni make sense of design in light of their undergraduate experiences in the Engineering Projects in Community Service (EPICS) program. These findings are part of a larger embedded, sequential mixed-methods study on the overall alumni experience in EPICS and how this experience prepared them to enter the workplace. In this large-scale study, we interviewed a diverse range of alumni (n = 27), which were purposefully sampled from participants of a previous survey (n = 523). Our semi-structured interview protocol was informed by both the survey responses of alumni and the objectives of this larger investigation. As EPICS is a design course, the topic of design was explicitly probed throughout the survey. Moreover, interview participants often recounted how their design experiences in EPICS informed their current design experiences. Through the thematic analysis, we recognized themes related to design to be quite pervasive in the interview accounts.

The objective of this particular paper is to articulate how authentic design experiences, such as EPICS, affect alums in how they understand and practice design in their careers. We discuss the *multiple* and also *common* ways that alumni understand and enact design because of their experiences in EPICS. The dominant way in which the participants understood design was as a cyclical, iterative process (i.e., lifecycle) – following the life of a designed artifact, system, or process. However, the alums demonstrated a lucid yet subtle recognition that the knowledge of design is shared by many stakeholders, including design teammates, customers, employers, etc. We discuss these findings in detail, and we elaborate on how their perspectives of design might inform how they *do* design.

Introduction:

Design is a topic of significant interest among engineering educators and engineering educational researchers. One reason for such interest is that, as put by Dym, Agogino, Eris, Frey & Leifer, "[d]esign is widely considered to be the central or distinguishing activity of engineering" (p. 103)[1]. Indeed the National Academy of Engineering reinforces this statement by describing engineering as "design under constraint" (p. 24)[2]. The report continues, "The engineer designs devices, components, subsystems, and systems, and to create a successful design, in the sense that it leads directly or indirectly to an improvement of our quality of life" (p. 24)[2]. And the very essence of these statements manifests itself through the Grand Challenges of Engineering, which include such challenges as "restor[ing] and improv[ing] urban infrastructure", "prevent[ing] nuclear terror", and "advanc[ing] personalized learning"[3]. Such challenges are rendered incredibly complex by deeply integrated technical and non-technical dimensions, and they beckon future engineers to design solutions to these challenges that bear direct significance to "improving the quality of our life" (p. 24)[2].

As design may be considered a core activity of engineering practice, it is no surprise how well-recognized voices call for design to be a central focus of engineering education[4,5]. Indeed, engineering programs accredited by ABET are required to demonstrate that their graduates demonstrate "an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" (p. 3)[6]. Additionally, while ABET "[does] not prescribe specific courses" in the engineering curriculum, they do explicitly note how "[s]tudents must be prepared for engineering views practice through a curriculum *culminating* in a major design experience based on the knowledge and skills acquired in *earlier course work* and incorporating appropriate *engineering standards* and *multiple realistic constraints*" (p. 3, *emphasis* ours)[6].

The way in which leaders of engineering practice and education (e.g., ABET, NAE) express their views of design certainly affect how design is taught and learned in undergraduate engineering programs. At the same time, undergraduate design experiences seem to shape pre-professional engineers' of design, which s/he carries into industry. In this paper, we explore the perspective on design from alums of the Engineering Projects in Community Service (EPICS) program at Purdue University. We are specifically concerned with how EPICS has shaped their perspectives of design, and thus, how they might actually *do* design in their careers. We also recognize that their recollected accounts of how EPICS are shaped by their current workplace experiences.

Thus, this investigation probes how these alums make sense of design in light of their experiences in EPICS and in the workplace. We begin by exploring how design is traditionally learned in post-secondary engineering programs, and how these traditional experiences might engender certain perspectives on design. We then situate this investigation in light of other well-recognized studies on engineering design and articulate the conceptual framework employed for this investigation. Following a description of our research context, questions, and methods, we present the results of a thematic analysis regarding how EPICS alums perceive design. Finally, we discuss how the nature of their EPICS experience and design perceptions might translate into *doing* design, and we elaborate on the implications of our findings for those who develop engineering curriculum.

How Students Experience Design in Engineering Curricula:

A design experience, as required by ABET, typically presents itself as *capstone* design course[1]. The traditional ways of enacting capstone design experiences are often either (1) having the students devote their design to a project of their or the instructor's choosing or (2) partnering with industry groups who designate an authentic project for the students[1,7]. Design is also often taught in the first-year of the engineering curriculum as a first-year design experience in order to provide students with "some flavor of what engineers actually do" and provide an experience "where they [can] learn the *basic elements of the design process*" (p. 103)[1]. However, there are alternatives to these traditional practices, such as service-learning courses that partner students with community groups where the design focus emanates from the relationship of the students and partnering group(s)[8,9]. Other alternatives include programs that connect the curricular experience to design competitions (e.g., NI Student Design Competition[10]) and programs in which students design in an international setting[11,12]. Yet the dominant practice of teaching design comes through the capstone and first-year design courses described above.

While we recognize the inclusion of such capstone and first-year design experiences in traditional engineering curricula to be significant for learning engineering design, we also how recognize that the nature and motivations of such experiences might foster certain perceptions of *design itself*. Such perceptions that come from a traditional design experience certainly may bolster students' ability to design in some ways, but they may also limit their knowledge, skills, and ability in relation to design. For example, if students staunchly view design as only being "based on knowledge and skills acquired in earlier coursework" (p. 3)[6], they might be blind to other dimensions of design, such as creativity and identifying multiple approaches to a given problem[13]. If engineering students exclusively view design as a *process with rigid, linear steps*, they might reject strategies of informed designers, such as "do[ing] design in a managed way, where ideas are improved *iteratively* through feedback, and strategies are used *multiple* times as needed, *in any order*" (p. 748, *emphasis* ours)[14]. If engineering students view the users of their designed technology as *social constraints* rather than core to the design itself, they may only recognize how these users provide "information, assistance, and/or support" rather than considering how their "needs should be reflected in the design"[15]. We might reasonably posit, then, that what students *do* in design tends to reflect how they perceive *design itself*.

Frameworks from Studies on Engineering Design

Within the engineering education community, there are several studies that investigate activities that engineering students and professionals *do* as part of design. For example, Atman and her colleagues have published a number of articles on the processes enacted by students and professionals when approaching the problem of designing a playground for an imagined community[16-18]. Among a myriad of findings associated with this series of studies, they reveal how design experts spend significantly more time than students in scoping a design problem and gathering information[16] They also have found that senior engineering students spend more time on design problems consider more alternative solutions to a problem than freshman[17,18]. Downy & Lucena, through their ethnographic study on a senior design course, found how engineering students tended to resist design learning and resort to deterministic problem-solving learned in their core coursework[13]. Additionally, Mehalik & Schunn[19] present a number of other such studies on engineering design in their meta-analysis of studies concerning fifteen common stages found in their design process. Their meta-analysis makes clear what the engineering education research community tends to emphasize (or not emphasize) concerning certain stages of design design. Recently, Crismond & Adams[14] have published a framework for a literature-grounded understanding how beginning and informed designers approach a variety of "strategies" in design, such as "understand[ing] the challenge", "generat[ing] ideas", and "reflect[ion] on the process" (pp. 748-749).

While we recognize these studies as significant to unpacking engineering design, we distinguish our investigation from such studies by focusing on perceptions of *design* itself rather than the tasks, activities, stages, or strategies of design. We approach our investigation by examining how alums make sense of design through their experiences in EPICS and subsequently in their careers. Such a framework broadly aligns with other studies on design. Zoltowski, Oakes, & Cardella[15] have conducted a phenomenography exploring the multiple ways that students experience and understand human-centered design. And Daly, Adams, & Bodner[20] have also conducted a phenomenographic study of design professionals, both inside and outside engineering, in order to represent their multiple, articulated understandings of design. Furthermore, Lawson & Dorst[21] have articulated multiple perspectives of design (engineering and beyond), including “design as problem solving”, “design as learning”, etc. Similarly, in this investigation, we focused on how alumni of EPICS articulate their perspectives on design.

Research Context and Questions:

The setting of this investigation is EPICS, located at a Purdue University. This program is a large multidisciplinary, vertically-integrated service-learning program centered on engineering and computing design. In the 2011-2012 academic year, the program had over 600 students enrolled in thirty divisions of the course for academic credit (with about 70 design teams). Over 200 of these students were returning from a previous semester. More than 70 majors were represented among the students enrolled in the course, and approximately 70% of these were engineering majors. The program began in 1995 through university’s electrical and computer engineering department, and more than 3,000 alumni have graduated from EPICS in its 17 years of existence. This service-learning program has been nationally recognized[8] and cited by others as an exemplar for providing a platform of real-world, engineering experience for students[5, 8, 22, 23].

While several in engineering education have championed EPICS and similar programs for providing such an authentic design experience, no prior studies have investigated how such experiences shape the design knowledge, ability, and identity of alumni of such programs. We conducted sizeable study of alumni of EPICS to generally understand how their experience in the program prepared them for professional practice. The study has been approved by the Institutional Review Board of Purdue University. The findings from this study have been rich, and they are represented in other sources[24,25] and will continue to be represented in future work. In this paper, however, we investigate the questions:

RQ1: How do alumni of EPICS make sense of and articulate design in light of their design experiences in industry?

RQ2: How do these early-career engineers make sense of and articulate design from their experiences in EPICS?

Methods:

We approached this broad investigation by employing an embedded, sequential mixed-methods approach[26,27], specifically QUAL(quan), which involves conducting a rich qualitative investigation to address the research questions. The role of the quantitative data was secondary in order to (1) aid in the sampling of interview participants and (2) lend secondary support to the findings of the qualitative investigation. In this section, we briefly highlight the survey that was completed by 523 alumni of EPICS. We emphasize, however, the sampling strategies used to identify the interview participants as well as the qualitative data collection (via interviews) and subsequent analysis.

Survey:

This investigation began with the development and administration of a survey sent out to EPICS alumni. Detailed descriptions of the questionnaire’s development, administration procedures, and target population are represented elsewhere[24,25]. The survey was administered online using Qualtrics software and garnered complete responses from 523 alums, over 70% of which agreed to be contacted for a follow-up interview [25]. Once these responses were collected, we turned our attention to selecting participants to interview about their experiences in EPICS and how they generally prepared them for professional practice.

Sampling Strategy:

In order to identify interview participants, we purposefully sampled cases of survey respondents that were willing to be contacted for an interview. We began with a process of analyzing the responses to two open-ended items from the survey: (1) "[If applicable], [h]ow did your experience with EPICS influence your career choice?" and (2) "What ways has EPICS influenced you personally and/or professionally? Please use this space to provide any thoughts on this point that you have not already provided in the survey." (for the survey in its entirety, see other work on this study[23]). Of those who agreed to be interviewed (n = 389), 327 provided responses to these questions. While reviewing these responses, we specifically were looking for those with detailed responses to the questions. In this regard, we employed somewhat of an "extreme case" sampling strategy, where we were selecting cases of respondents that could articulate what they learned (or did not learn) from their experiences in EPICS[28]. By this, we mean that we were seeking participants who articulated significant, transformative learning in EPICS. We were not looking for positive responses to these answers, and in fact, we selected several participants who described a negative experience with the program.

Once we had each selected potential participants, we identified those participants that were selected by all of the first three authors (n = 20), participants that any two of these authors had selected (n = 36), and participants that only one had selected (n = 74). Having identified these potential participants, we then evaluated the variation among them with respect to demographics, number of semesters in EPICS, level of education, major, nature of workplace, and year of graduation. We were employing a "maximum variation" case selection strategy, ensuring that our participants were not excessively over-represented in any one of these dimensions[28]. Because we had many descriptors, we were primarily concerned with variation among demographics, number of semesters in EPICS, and year of graduation. We were secondarily concerned with the other listed dimensions.

Following these two phases of analysis, we developed a prioritized list of interview participants to recruit for the qualitative portion of the study. Several of our selected cases did not reply to our follow-up request to interview, but each of the of interview participants (n = 27) had each been selected by at least two of the three authors who sampled the interviewees. The aggregate descriptions of the interview participants' demographic information and year of graduation are displayed in Table 1. Similar data on the survey's sample population may be found elsewhere[25].

The nature of the participants' design experiences, both professionally and in EPICS, is shown in Table 2. As displayed on the table, our participants demonstrated a considerable range design experience in EPICS. Some, such as Aditya and Kate, were quite active in the program, functioning as team leaders and/or participating for many semesters. Others, such as Cindy and

Craig, only participated for one semester. They also varied in the nature of the design work as professionals, occupying a range of careers and roles within and outside of engineering work.

Interviews:

Semi-structured interviews were conducted by this paper's first and second authors. While the first three authors currently play an administrative role in EPICS, none of the interview participants recognized the first author as an administrator, as he began to work with EPICS when we launched the investigation. Furthermore, alums who graduated in 2005 or before did not recognize the second author as an administrator of EPICS during their time as students. The third author was recognized by nearly all the alums as an administrator in the program and, consequently, did not interview participants. In order to ensure that the alums felt safe to share critical and frustrating experiences in EPICS, the first author interviewed all alums who graduated 2006 and later, and the second author interviewed many alums who graduated before she held a visibly administrative role in EPICS.

With exception to one interview that was conducted in person, the interviews were conducted via audio or video calls using Skype software, and the audio recordings were captured through Pamela, a companion software package for Skype. The recordings were transcribed for analysis.

The interviews were semi-structured in that they had guiding questions, but the interviewers adapted the actual questions asked to what the participants articulated as salient. As we had access to the each participant's survey response, we often asked the participants to unpack an item on a survey. Examples of these survey items include "To what extent have your experiences in EPICS contribute to an ability to design a system or process from start-to-finish." or "Thinking about your undergraduate experiences, rank them in order of how well you learned to practice design by participating in the experiences." Additionally, we consistently asked the participants to discuss (1) moments in their career that triggered memories of their experience in EPICS, (2) frustrating experiences in EPICS, and (3) how their coursework or other undergraduate experiences benefited them in ways that EPICS did not. These guiding questions often elicited articulations of the alums' experiences in design, both professionally and in EPICS.

Type	Value	*n*
Gender	Male	14
	Female	13
Race	African American / Black	1
	Asian	4
	White	22
Ethnicity	Hispanic	2
	Not Hispanic	25
Year of Graduation	1995 – 1999	3
	2000 – 2003	6
	2004 – 2007	11
	2008 – 2011	7

Table 1: Aggregate Information of Participants

Name	Nature of EPICS Experience	Nature of Professional Experience
Aditya	Team leader; mechanical engineering major; over 4 semesters in EPICS.	Early-career engineer at a large corporation; participates in technical design.
Amber	Team leader; electrical engineering major; over 4 semesters in EPICS.	Began career as engineer at a large corporation; now manages a non-profit organization
Beau	Team leader; computer engineering major; 4 semesters in EPICS	Software engineer for a large corporation.
Brooke	Electrical engineering major; over 4 semesters in EPICS.	Early-career electrical engineer for healthcare corporation.
Cindy	Chemical engineering major; 1 semester in EPICS.	Early-career engineer for healthcare corporation.
Craig	Construction engineering major; 1 semester in EPICS	Early-career construction manager for construction firm
Doug	Team leader; Electrical and computer engineering major; 3 semesters in EPICS	Project manager and manufacturing plant.
Ellie	Sociology major; over 4 semesters of experience in EPICS	Owner of consulting company related to community engagement.
Emily	Team leader; Electrical and computer engineering major; 4 semesters in EPICS	Circuit design engineer at large corporation
Jeanette	Computer graphics technology major; 1 semester of experience in EPICS.	Mechanical engineering Ph.D. student with industry experience in component design. Master's degree in product development.
Josh	Mechanical engineering major; 3 semesters of experience in EPICS.	Early-career design engineer at large corporation.
Julia	Team leader; 3 semesters of experience in EPICS.	Secondary math educator and curriculum developer.
Kate	Team leader; electrical and computer engineer; over 4 semesters in EPICS	Project engineer for aerospace corporation.
Kelsey	Team leader; industrial engineering major; 3 semesters in EPICS.	Early-career industrial engineer for aerospace corporation
Kyle	Team leader; computer science major; 2 semesters in EPICS	Software engineer for large corporation.
Libby	Civil engineering major; 2 semesters in EPICS	Design reviewer for government agency; prior experience in consulting.
Marcus	Computer-science major; 1 semester in EPICS	Software engineer for start-up company
Mindy	Industrial engineering major; 2 semesters in EPICS.	Business executive for healthcare company; prior experience as industrial engineer in another healthcare company.
Nicole	Biology major; 1 semester in EPICS	Scientist in an environmental engineering firm.
Philip	Team leader; civil engineering major; 2 semesters in EPICS	Field engineer for sanitation engineering company.
Rajesh	Electrical and computer engineer; over 4 semesters of experience in EPICS.	Electrical engineer for computing corporation.
Rita	Health and human sciences major; 1 semester in EPICS.	Environmental engineering student; industry experience in chemical manufacturing.
Robert	Team leader; Computer engineering major; 4 semesters in EPICS	Computer engineer at computer engineering corporation. Master's degree in product development.
Todd	Computer engineering major; 3 semesters in EPICS	Software engineer at large corporation. Previous experience in aerospace industry.
Tony	Team leader; mechanical engineering major; over 4 semesters in EPICS	Design engineer at large protective clothing corporation; previous experience in automotive industry.
Vijay	Technology major; 4 semesters in EPICS	Early-career professional in software engineering consulting company.
Will	Electrical engineering major; 2 semesters in EPICS.	IT project manager; previous experience in software sales.

Table 2: Participants and their Design Experiences

Analysis:

We approached this study with a systematic thematic analysis that involved multiple angles and iterations of studying the participants' interview transcripts[29]. Our analysis framework was inspired by thematic analysis described by Braun & Clarke[29], who describe *thematic analysis* as "a method for identifying, analyzing and reporting patterns (themes) within data" (p. 79). This method of analysis is distinguished from other types of similar qualitative methods, such as discourse analysis, in that "thematic analysis is not wedded to any pre-existing theoretical framework and therefore it can be used within different theoretical frameworks" (p. 81)[29]. Additionally, they note distinction from grounded theory in that "[thematic analysis] researchers need not subscribe to the implicit theoretical commitments of grounded theory if they do not wish to produce a fully worked-up grounded theory analysis" (p. 81)[29].

The research team began by validating the transcriptions through reading a transcript and listening to its corresponding audio recording. We then studied each transcript one-at-a-time, actively engaging the text through memo-ing, highlighting sections, and then generating 1-3 page summaries about each participant. After completing this phase and applying open coding to three transcripts, we agreed upon a list of 23 codes with corresponding definitions. Three more codes were added during further analysis. Using NVivo software, we coded sections of text in the transcript that aligned with the descriptions of the code as well as the surrounding context. In this process, we regarded our codes as filters to the large amounts of textual data in that they organized sections of text around a common description [30]. Once the codes were applied to all of the transcripts, we re-organized the codes into themes. While four other themes were organized as a complex interconnection of codes, the themes presented in this paper emanated from of a text associated with accounts related to design.

We observed these themes related to design to be quite pervasive throughout the participants' accounts. We re-read and analyzed text associated with the "design code" in order to articulate a thematic description of the participants' articulation of design. The design code was described as any reference to design *qua* design as well as skills associated with design. Particularly, we noted when they discussed (1) integrating disparate features of a problem into a coherent solution as well as (2) problem-solving. The alumni communicate transference of their design experiences in EPICS to their current practice, albeit to varying degrees and in nuanced ways.

Summary of Results:

The participants expressed how they understood design in a variety of ways, despite their common experience of designing in EPICS. While we somewhat explore the multiplicity of articulating design here, we focus primarily on the overarching common language that ties together these various articulations. We observed three prominent ways of articulating design throughout the alumni transcripts. First, some describe explicit *boundaries of design*, articulating what design *is*…and what it is not. Second, participants recognized that design (and artifacts that are designed) have a *lifecycle*, in which they, as designers, participate to various extents. Finally, participants subtly recognized that design requires *knowledge situated* across a variety of actors.

Boundaries of Design:

While the interview participants did share a common experience of participating in an EPICS design project, they now seem to occupy a variety of positions with regard to design. Furthermore, in several cases, how they currently engage in design seems related to their experience in EPICS. For both Tony and Josh, their individual experiences in the program reinforced their career aspirations to be design engineer. As Tony said, "[B]ased on what I did at [EPICS], that's sort of what led me to what I always wanted to be, which is a design engineer." Julia, while not an engineer, also identified as one who designs, reflecting how in her job, "there are so many parallels to designing". She elaborates how she recognized these parallels through her experience in EPICS.

Yet other alums with similar experiences in EPICS responded to this experience quite differently in relation to design. For example, Will's time in EPICS drew him to pursue sales of software products. In his own words, "[Upon graduation], I was certainly not going to be a good electrical engineer…and do design and do theory and those kinds of things. But I was certainly able to understand what was going on in the classroom, to some extent, and be able to translate that to…what a common person was going through at the time." He credited EPICS for helping him realize how he did *not* have to "do design." Instead, he could translate technical knowledge through sales. Doug provides a similar account, as he "knew [he] didn't want to do design...[but instead] wanted to do something around project management." He also elaborated on how EPICS prepared him to be a competent project manager in a manufacturing plant. However, when asked how EPICS helped him develop competency as a project manager, he responded:

> "…just the chance of … working in a group and *solving…real-life problems* that somebody has, and just *trying to find/use different resources*, whether it's the Internet or other people at the university, to *help come up with solutions*, or different vendors or different people to help *develop solutions and implement those solutions and bring them to light*" (*emphasis* ours).

While Doug did not explicitly employ the term "design" in his reason for EPICS, he certainly illustrated a "design" experience that prepared him for "project management." Yet Doug himself did not seem to make this connection, placing himself as a project manager *outside* the boundaries of "design." Kate, similarly, made the statement, "[C]ertainly, you can go your whole life just *working in a closet* and just *doing your design*. But what I've found is that you have to be able to interface between the different teams, and you have to able to coordinate" (*emphasis* ours). In these perspectives, design seems to exist apart from any social world, and be purely focused on technical problem solving. And even in the cases of alums that enthusiastically resonate with design, such as Tony, this separation of design from a social world is not necessarily refuted.

But when we closely and systematically examined *all* of the participant accounts, we saw a more nuanced perspective, which we unpack in the following two themes. While some particular interview participants expressed especially lucid viewpoints on how they connected their design experiences in EPICS to their careers, we found that most of the participants did not have such profound and blatant articulations of design. Indeed, most of our participants fell somewhere in between the above cases with regard to how they currently engage design and how this engagement connects to their experiences in EPICS. They (1) recognized design as a lifecycle and (2) subtly recognized design as knowledge situated (i.e., distributed) across many stakeholders. This first theme illustrates how most alums explicitly articulated design and the latter depicts how they might *actually* view design, supported by quotes regarding the *activities* of designing in the workplace. In other words, a participant might *explicitly articulate* design as separate from a social world, but when describing the actual design experience, the experience clearly is recognized as a social activity situated across many actors.

Design as Lifecycle:

"[N]obody just takes something, just writes something and builds then sells…because things happen in cycles, things happen in stages and phases, and that is a basic fundamental concept of how *ideas materialize*…" (*emphasis* ours). This statement, made by Rajesh, articulated a salient theme that we found to pervade the transcripts. The alums tended to construe design as engaging an artifact or system through its entire lifecycle. Consequently, they seemed to perceive design as a *process*, albeit a complex process that consists of multiple activities. Some alums felt that they participated in much of this lifecycle during their time in EPICS, especially if they participated for multiple semesters. For example, Tony noted that "I went through that whole [design] process during my time in [EPICS]…Not one bit of it is boring, nothing is stagnant." And Kate described staying in EPICS for the entire design of a device intended to teach science concepts to elementary children, which included re-designing her initial prototype and delivering the product the project partner.

The participants certainly did not all participate in the entire lifecycle of their project in EPICS, but by engaging in a part of the lifecycle, they tended to recognize how their participation in the project connected to design that had preceded them and design that would follow them. Some described how they wish they had participated earlier in the lifecycle, while others articulate their desire to have seen their project mature. They differentiated the experience of participating in a lifecycle from other curricular experiences, where the design focus was either simulated or constrained to one year. Typically, when the participants described design as a lifecycle, they did not articulate how this lifecycle occurred as situated across a variety of actors. One exception to this was an observation made by Todd:

> "When you've been through the whole product lifecycle, you have an appreciation for what came before and what comes after, to know that you're not one little independent [piece] or one little self-contained piece; you're part of a bigger working system…I really do believe [this understanding] gives me an advantage being able to *help out people* essentially *in front of you* and *behind you* in a development cycle; and then,… it lets you switch between these roles a lot better" (*emphasis* ours).

While Todd made the social nature of the design lifecycle apparent, noting that multiple actors engage a lifecycle, other alums were more subtle in this observation. In many accounts, the social nature of their design experience became clear when they expounded upon their coupled experiences in EPICS and industry.

Design as Situated Knowledge:

The interview participants recognized that prior knowledge was crucial for design, but they also discussed how this knowledge was not simply learned in a set of discipline-based courses. Rather, the knowledge influencing the design was distributed, or *situated*, across customers (i.e., project partners), past and present teammates, and a number of stakeholders. Borrowing from Hutchins, these participants recognized the knowledge of design as "socially distributed cognition" (p. 223)[32] rather than a straightforward application of science concepts.

When Josh described his multiple design experiences, including EPICS, he described them by saying that "knowledge was flowing." This sentiment aligns well with many of the participants. When they were asked how their participation in EPICS differed from coursework, they generally offered responses similar to Julia: "[I]t was the coursework…that really gave me the content, the guts, that actually goes into that design." However, by many accounts, their individual knowledge only provided the platform for a certain role for the design. In reality, according to many participants, the "guts" of the design was actually situated across a number of different actors, some of which included their team members. For example, Marcus reflected on his experience in EPICS, "I liked the collaboration…coming together to try and make an idea work and then splitting up to do our own separate pieces…I think it aids…in the creative process, just because you're *not limited* to…what's essentially narrow-minded at that point, because there are *so many other thoughts* that come in." This recognition by Marcus describes his teammates as conduits for other forms of knowledge to "flow" into the design. Amber's and Libby's accounts also aligned with this concept, but both reflected on the role of their teammates (and now, colleagues) in their own learning. As put by Amber, the design experience created an occasion for teammates to "pass down the knowledge," which, according to both of them, is how they have learned relevant knowledge and skills in industry.

Beyond the design team itself, participants also ubiquitously recognized that a customer and/or users had knowledge essential for design. For example, when describing her project in EPICS, a children's museum exhibit, Brooke noted that "parents were going to interact with it, children were going to interact with it,…[the design team members] were *making the design*, but [they] didn't necessarily have the *expertise* to know what the parents or children…would want" (*emphasis* ours). While not all participants recognized customers as "experts" of a part of the design, in either their EPICS or industry experience, they did recognize that their role was not trivial. As put by Todd:

> "[T]he customer *isn't this static thing* that just sits out there and gives you something, "Go implement it," and you come back and do it…[T]hese customers,…you were interacting with them, and the value of the customer was…[being] the *ultimate goal or reason you're doing what you're doing*" (*emphasis* ours).

Although participants did articulate various levels of affinity toward customers, their experience in EPICS seemed to recognize that the customer, beyond providing the *occasion for the design*, played a significant role with regard to their knowledge that was capable of *affecting the design*.

Discussion:

This analysis attempts to make sense of how the interview participants articulated design. Their views on design, however, seem to be connected to how they *enact* design (via activities and strategies). EPICS had a significant effect on some alums, spurring them into or confirming their interest in a career focused on design. To a few other alums, the experience moved them away from design and opened doors careers that coordinate people within a company. At a first glance, this may appear that alums view design as separate from the social processes of engineering work. However, upon closer examination, we can see that the opposite is true. Essentially, we believe that the alumni recognize design to be, in the words of Bucciarelli, a "social process" [30]. While design may be explicitly articulated as a lifecycle process, with little reference to the social nature of this process, the alums seemed to exhibit a profound understanding that the actual activities of the process are quite social and that many people affect the design.

To illustrate how the participants' views of design affects how they *do* design, we refer to the Informed Design Teaching and Learning Matrix by Crismond & Adams[14.] Participants seem to enact, or at least highly value, the practice of "idea fluency" in design (p. 748). Many of the participants engaged in an early phase of the design in EPICS where they were generating ideas regarding a certain artifact or system. As Marcus earlier articulated, these participants discuss the value of generating multiple ideas in this experience (or dealing with the detrimental consequences of fixating on one idea).

Additionally, through their experience in EPICS, they seem to have enacted another pattern of informed designers: "iterative designing" (p. 749)[14]. They discuss how through the occasion of designing in EPICS, their design received multiple voices of feedback to consider, such as users, project partners (i.e., customers), faculty advisors, industry reviewers, student teammates, and students (on the same project) from previous semesters. Through these occasions of receiving feedback, they recognize how ideas and beliefs held in the design may be improved through being challenged.

In both of these patterns, alums view the role of other stakeholders as particularly salient, and they express this viewpoint. They recognize that ideas are best generated fluently when multiple and diverse people are generating them, including customers and/or users. They also recognize how the feedback of multiple stakeholders improves ideas surrounding the design.

In some regard, we recognize how the participants' perspectives on design align with traditional views of design. For example, some articulations of design as a lifecycle may resonate with holding to a rigid, linear process. Moreover, the participants were typically ready to identify how knowledge gained in courses *flowed* into their design. These concepts of design align with the limited perspectives of design earlier discussed. However, we suggest perspectives are only limiting when they are *exclusively* held. For example, if a student perceives design as *only* an application of engineering sciences, then s/he might be blinded to navigating ambiguity within the design. Is it possible for someone view design as a lifecycle, *both* progressing through steps in a linear matter *and* iterating on feedback? Can one see design as exercising *both* knowledge from engineering science coursework *and* knowledge from other sources, such as customers, users, and/or teammates? Such perspectives of design certainly seem incommensurable with one another. But through the perspectives of these alums, we maintain that such perspectives of design *can* synergistically align with each other.

Implications:

This study suggests significant implications for deans of engineering programs, senior design professors, and others who develop engineering curriculum. First, we encourage consideration on how to infuse *authentic* design experiences into the four-year curriculum. As we have discussed, the participants often articulated how the complex negotiations and relationships that accompanied their design in EPICS were significant for their professional preparation. Design problems may certainly (and perhaps appropriately) be contrived for the purpose of teaching in the classroom. But we do not believe the authentic social network of stakeholders, and the complexity that this network brings to a design problem, can similarly be contrived. And the alums recognized this. One of the alumni participants, Kelsey, stated such recognition when she discussed the design of a made-up project in another course as compared to EPICS: "There's no real follow-up, there's no real timeframe, there's nothing. You know, we get to make up our own budget… So it kinda takes reality out of it. …[I]t's almost like you're playing Monopoly with a design project."

Additionally, we encourage those who develop engineering curricula to consider how students might engage in a multi-semester design project. Such engagement might be realized through students themselves participating in a common design project for multiple semesters. Alternatively, if such extended participation is not possible, then we suggest at least considering how design problems might extend multiple years and semesters, allowing many students to participate in the lifecycle of the problem. Even interview participants that participated in EPICS for just one semester expressed how, by participating in a multi-semester design problem, they came to recognize the activities of design as occurring through the entire lifecycle of the designed product, system, or process. They further expressed how this *lifecycle* perspective of design prepared them for how they experience design in the workplace. We do not believe that this same view of design can readily be instilled in students when their design problems are created and retired in the course of a single capstone or cornerstone design experience.

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