

## **Work in Progress: A Preliminary Investigation of the Ways Engineering Students Experience Innovation**

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## **Introduction**

This work in progress presents an ongoing study investigating the distinct ways engineering students experience innovation in their engineering projects. Innovation has been a frequent objective of course and program reform in engineering education<sup>1</sup>. Engineering educators strive to improve students' abilities to contribute to innovative products, processes, and systems, but an increasing number of studies suggest that despite the growing number of initiatives to promote innovation among engineering students, students often do not demonstrate competencies and mindsets commonly associated with successful innovators<sup>2-4</sup>. Innovation is a complex phenomenon that spans a variety of disciplines and can be affected by a variety of context-dependent variables<sup>5</sup>. Thus, more work is needed to understand the variety of perspectives engineering students have regarding innovation, and how individual and environmental factors affect student development of innovative skills and mindsets.

This study employs a phenomenographic approach to explore variation in how engineering students experience innovation. Phenomenography is an established qualitative research method for identifying a limited number of distinct ways individuals interact with a particular phenomenon<sup>6,7</sup>. These distinct ways of experiencing the phenomenon are regarded as resulting from the interplay between the characteristics of the individual and the forum(s) through which the individual experienced the phenomenon. Several important phenomenographic studies have occurred in engineering education over the last few years, including investigations of the variation in ways engineering students and engineers experience human-centered design<sup>8</sup>, sustainable design<sup>9</sup>, and design<sup>10</sup>. This study aims to continue in that tradition to explore the unique and varied intersection between undergraduate engineering students and the complex phenomenon of innovation.

As a work in progress, this paper serves two purposes. First, it provides the authors with an opportunity to share and receive feedback on preliminary results, an important step in phenomenography<sup>11</sup>. Second, it provides an archival example of phenomenography in progress. Along these lines, we provide a detailed account of the research design and methods decisions, that might otherwise be obscured or limited by descriptions of purpose, findings, and implications on completed studies.

## **Literature Review**

Innovation has been described in a variety of ways in a variety of contexts by a variety of people<sup>12,13</sup>. Even the most cursory review of innovation can reveal a cornucopia of definitions of innovation focusing on innovative design solutions as well as characteristics of individuals, processes, and environments that support such solutions<sup>12-16</sup>. This breadth of conceptualizations of innovation does not necessarily represent widespread disjuncture on the concept of innovation, only that different situations call for different fragmentations of the overall phenomenon of innovation that may or may not be accessible across different project contexts.

For example, when studying tools that support variety and depth of idea generation, one might focus on the creative aspects<sup>17,18</sup>. However, one might focus on human-centered aspects during projects involving immersion with end-users.

Other studies have focused on innovators and the attitudes, processes, competencies, and motivations they bring to innovation projects<sup>19-21</sup>. While these studies suggest several similarities among innovators, key individual characteristics may differ among engineering students. For example different skill and process requirements have been observed in different types of student engineering projects<sup>22</sup>. Further, engineering students tend to characterize and approach innovation differently based on specific demographics, such as academic major<sup>23</sup>. This study seeks to characterize the intersections between these different project scenarios and individual characteristics of the student engineers who experienced those project scenarios.

## **Methods**

### *Methodological Overview*

This study employs a phenomenographic approach to understand the qualitatively different ways engineering students experience innovation during their engineering projects. Phenomenography is characterized by a nondualist ontology<sup>7</sup>. This stance, in contrast to social and individual constructivism, which differentiate the internal world of the individual from the external world in which individuals are situated, indicates a single world that is experienced by different people in different ways<sup>7,24</sup>. Experience and the resulting understanding of a phenomenon then is always partial<sup>7</sup>. An individual will attend to certain aspects of a phenomenon but not others as a result of his or her individual characteristics or the context in which he or she encounters the phenomenon<sup>7,24</sup>.

The overall goal of a phenomenographic study is to uncover the variation in the ways people experience a particular aspect of the world<sup>7</sup>. This variation is described by the outcome space, which contains two elements: categories of description and structural relationships between those categories. The categories of description are aligned with the ways that the phenomenon is experienced while the structural relationships describe the connections, differences, transitions, and ordering of the different categories. While many phenomenographic outcome spaces form a logical one- or two-dimensional hierarchical mapping (e.g.,<sup>8,10</sup>, respectively), a hierarchy is not a necessary condition<sup>7</sup>. The outcome space is dictated by the content of the data collected. The outcome space, thus, presents a comprehensive tapestry of the different ways the phenomenon has been experienced unique to participants in the sample and the phenomenon experienced.

### *Participants*

A total of 33 undergraduate engineering students from a single large public university in the Midwestern United States participated in this study. Achieving a diverse sample is critical for phenomenography as increased sample variety increases the potential for alternative experiences and individual characteristics present in the sample<sup>25</sup>. More specifically, it is critical to identify potential sources for individual variation and attempt to expand the sample along those lines. Here, the primary focus was on recruiting students who had experienced innovation across a

variety of project settings. Thus, students were primarily recruited through organizations and programs that offered unique design experiences. These included university-affiliated EPICS, Global Design, and Entrepreneurship & Innovation certificate programs. Students were also recruited through a wide selection of engineering or innovation related student organizations. In order to cast a wide net and account for innovation experiences not foreseen during study planning, recruitment posters were also posted in engineering buildings across campus.

Three secondary recruitment criteria were utilized to identify potential candidates among those recruited through various project experiences. These criteria were based on research that suggested differences either in characterizations or approaches to innovative engineering design and included academic major<sup>24</sup>, year in school<sup>26</sup>, and gender<sup>27</sup>. All 33 participants are listed in Table 1.

**Table 1.** Study Participants and Key Demographic Information

<b>Pseudonym</b>	<b>Engr. Major</b>	<b>Year in School</b>	<b>Gender</b>	<b>Project(s) described during interview</b>
<i>Dana</i>	<i>Aeronautical</i>	<i>Senior</i>	<i>Female</i>	<i>Senior design</i>
<i>Maria</i>	<i>Industrial</i>	<i>Junior</i>	<i>Female</i>	<i>FYE design project</i>
<i>Jessica</i>	<i>Biological</i>	<i>Sophomore</i>	<i>Female</i>	<i>FYE design project</i>
<i>Esteban</i>	<i>First-Year</i>	<i>First-year</i>	<i>Male</i>	<i>Personal project (3-D printed longboard)</i>
<i>Elon</i>	<i>Mechanical</i>	<i>Senior</i>	<i>Male</i>	<i>Personal project (lamp design); Internship</i>
<i>Ajay</i>	<i>First-Year</i>	<i>First-year</i>	<i>Male</i>	<i>Design competition</i>
<i>Marshall</i>	<i>Aeronautical</i>	<i>Senior</i>	<i>Male</i>	<i>Internship</i>
<i>Tony</i>	<i>Industrial</i>	<i>Senior</i>	<i>Male</i>	<i>Senior design</i>
<i>Michael</i>	<i>Biological</i>	<i>Senior</i>	<i>Male</i>	<i>Senior design</i>
<i>Maxine</i>	<i>Mechanical</i>	<i>Senior</i>	<i>Female</i>	<i>Senior design</i>
<i>Sharon</i>	<i>Biomedical</i>	<i>Junior</i>	<i>Female</i>	<i>Internship</i>
<i>Jerry</i>	<i>First-Year</i>	<i>First-year</i>	<i>Male</i>	<i>Design competition</i>
<i>Verdasco</i>	<i>Mechanical</i>	<i>Junior</i>	<i>Male</i>	<i>Global engineering project</i>
<i>Penelope</i>	<i>Biological</i>	<i>Senior</i>	<i>Female</i>	<i>Design competition</i>
<i>Matt</i>	<i>Mechanical</i>	<i>Senior</i>	<i>Male</i>	<i>ME Sophomore design project</i>
<i>Theresa</i>	<i>First-Year</i>	<i>First-year</i>	<i>Female</i>	<i>CS assignments and everyday problems</i>
<i>Ron</i>	<i>Mechanical</i>	<i>Sophomore</i>	<i>Male</i>	<i>FYE design project</i>
<i>Hannah</i>	<i>Chemical</i>	<i>Sophomore</i>	<i>Female</i>	<i>EPICS</i>
<i>Dante</i>	<i>Agricultural</i>	<i>Junior</i>	<i>Male</i>	<i>EPICS</i>
<i>Alex</i>	<i>Agricultural</i>	<i>Sophomore</i>	<i>Male</i>	<i>EPICS</i>
<i>Fred</i>	<i>Agricultural</i>	<i>Junior</i>	<i>Male</i>	<i>High school design project (2-week)</i>
<i>Ella</i>	<i>Industrial</i>	<i>Senior</i>	<i>Female</i>	<i>Internship</i>
<i>Caroline</i>	<i>Industrial</i>	<i>Senior</i>	<i>Female</i>	<i>Internship</i>
<i>Snow</i>	<i>Mechanical</i>	<i>Senior</i>	<i>Male</i>	<i>Internship</i>
<i>Vespasian</i>	<i>First-Year</i>	<i>First-year</i>	<i>Male</i>	<i>Personal project (glazes for father's business)</i>
<i>Dylan</i>	<i>Biomedical</i>	<i>Senior</i>	<i>Male</i>	<i>Senior design</i>
<i>Leon</i>	<i>Electrical</i>	<i>Sophomore</i>	<i>Male</i>	<i>Personal project; Student organization</i>
<i>John</i>	<i>Acoustical</i>	<i>Senior</i>	<i>Female</i>	<i>Internship; EPICS; FYE design project</i>
<i>Summer</i>	<i>Electrical</i>	<i>Junior</i>	<i>Female</i>	<i>FYE design project; EPICS; Internship</i>
<i>Taylor</i>	<i>Computer</i>	<i>Senior</i>	<i>Female</i>	<i>Lab course project</i>
<i>Chris</i>	<i>Nuclear</i>	<i>First-semester master's</i>	<i>Male</i>	<i>Long term business (involving significant technological R&amp;D)</i>
<i>Sarah</i>	<i>Chemical</i>	<i>Senior</i>	<i>Female</i>	<i>EPICS (multiple projects)</i>
<i>Socrates</i>	<i>Civil</i>	<i>Senior</i>	<i>Female</i>	<i>Personal project (fixing a wine-making machine)</i>

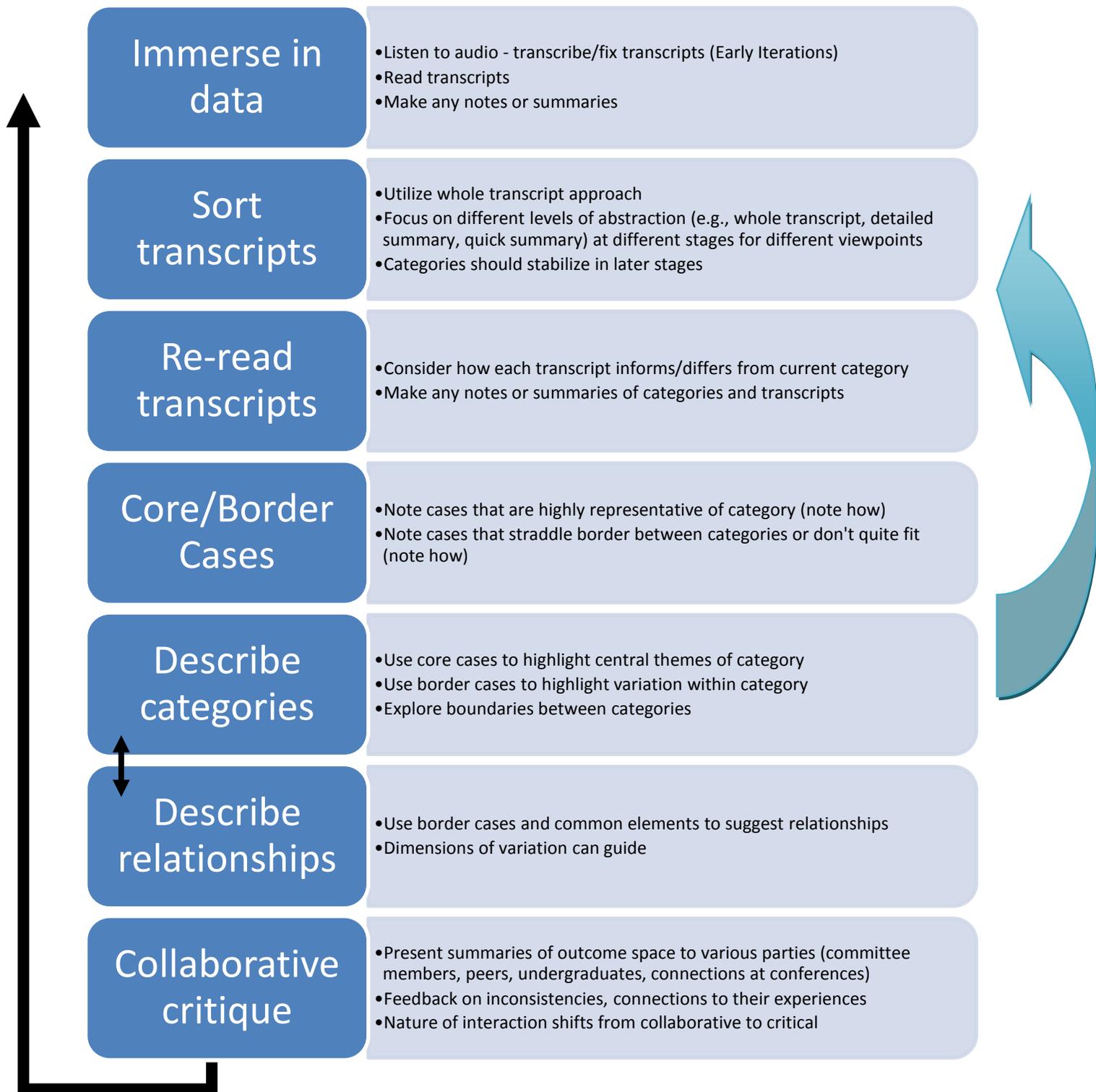
For this preliminary investigation, we focused on the 18 participants italicized in Table 1. It is common to utilize a portion of the participant sample during early analysis to mitigate the challenge of addressing the larger data set<sup>11</sup>. Later iterations will utilize the full sample.

### *Data Collection*

The primary data source for this study was semi-structured phenomenographic interviews<sup>7,11</sup>. The purpose of these interviews was to elicit students' perspectives and experiences with innovation. These interviews featured a limited number of open-ended questions and the interviewer followed up with more directed questions to probe meaning, elicit additional details, and explore connections and contradictions between previous responses. The interview protocol is included as Appendix A. These interviews began by focusing on participants' descriptions of experiences with the phenomenon before moving towards questions more directly targeted at the phenomenon under investigation. The interviews all lasted between one and two hours, ending when the interviewer (the first author) believed he had exhausted salient follow-up questions and the participants' experience and understanding of innovation in engineering projects<sup>11</sup>. This is a critical stage in the phenomenographic process as comprehensive exploration of participant experiences and conceptualizations allows more thorough and nuanced understanding of ways of experiencing the phenomenon uncovered during analysis.

### *Data Analysis*

This study is informed by the iterative, inductive data analysis procedures outlined in previous exemplary phenomenographic studies<sup>8-10,25</sup>. While data analysis in this study is not a linear process, it may be best understood as a series of stages with unique activities and purposes. These stages and their general order are described in Figure 1. Analysis begins with *immersing oneself in the data*. This involves, at various stages of analysis, listening to original audio recordings, reading entire transcripts, and reading key excerpts, notes, and summaries identified throughout analysis. The next stage, *sorting transcripts*, involves sorting participants (based on the entirety of their responses, i.e., transcripts) into categories that represent distinct ways of experiencing innovation. These categories need not be entirely distinct and elaborated throughout analysis, but are refined throughout the study. After the participants are sorted, the analyst *re-reads the transcripts* with the current categorization in mind. This involves identifying each participant's fit within the category and serves to better identify the core elements of the category. From there, the analyst *identifies core and border cases*, i.e., participants who strongly fit within current categories and those who may straddle the borders between categories. Using these cases, the analyst *describes the categories* as currently constructed, and during later stages, also *describes the relationships between the categories*. Core and border cases are particularly important here for identifying unique elements of each category and aspects of overlap. A final stage includes *collaborative critique*, in which the categories and relationships are presented to external parties for close scrutiny. When the results hold up under scrutiny from a variety of viewpoints salient to the phenomenon and participants (e.g., engineering instructors, undergraduate engineering students, engineering education researchers, and innovation researchers in this study), they can be finalized.



**Figure 1.** Data Analysis Overview

The order of these stages does not describe a temporal order, per se, as this process is iterative and at any one time the analyst can jump from one stage to any previous or former stage. The order does describe a general path of increased understanding of the current outcome space

during each full iteration (stages 1–7). In other words, an iteration would progress from reading all transcripts to dive into the data and end with a critique of the description of the way of experiencing in and relationship between the categories, while allowing for steps forward and backward within that progression.

It is also important to note that individual stages take on slightly different forms as analysis builds towards later iterations and the categories of description crystallize. For example, in the study's current preliminary stage, it is inappropriate to discuss the structural relationships between categories because the categories themselves are likely to change substantially throughout the analysis process. However, in later phases of analysis, the core/border cases stage may be particularly useful in distinguishing the structural relationships between categories.

### *Key Analysis Decisions*

Marton & Booth<sup>7</sup> argue that there is no set way to perform phenomenographic analysis, but this is often an iterative and comparative process. Akerlind<sup>28</sup> identified four dimensions along which phenomenographic studies commonly vary, and thus dimensions that must be addressed individually with each study. These variations include: amount of each transcript considered, emphasis on collaboration between data analysts, ways of managing data, and ways of constituting structure.

In this study, the unit of analysis is selected as the entire interview transcript<sup>25</sup>, as compared to decontextualized quotes or excerpts as suggested in other interpretations of phenomenography<sup>7</sup>. The rationale for this decision is that transcripts represent a set of interrelated meanings<sup>28</sup>. Thus, even if participants may make certain statements that can be represented by different categories of description, these statements are understood within the larger context of the individual. Further, the slight variation within individual transcripts can highlight critical border cases that aid in differentiating between categories of description and determining structure. Finally, more nuanced views of the categories of description can be developed when whole transcripts are considered over even contextualized quotes. For example, Akerlind<sup>25</sup> identifies multiple themes of expanding awareness within each category of description that otherwise might not have been uncovered with a less holistic approach.

Akerlind<sup>28</sup>, notes that while an individual researcher may make substantial headway in identifying the outcome space, collaborative effort is likely to present a more complex and complete picture of the phenomenon due to the different perspectives of the researchers involved. Due to the constraints of this study (a doctoral dissertation), it would be improper to suggest truly collaborative analysis during this study. However, this study utilizes several opportunities for collaborative critique of tentative categories of description and structural relationships (e.g., this paper represents the attempt at collaborative critique with peers at this conference). This approach allows multiple perspectives to shape the outcome space, but also meets the requirements of doctoral study.

Data management techniques are necessary to consider each piece of data within the vastness of the data set<sup>28</sup>. The primary means of data management is to attend to a single aspect of the data at a time. For example, at any one time, the analysis will focus on border cases or, conversely, core

cases of a particular category. This data management is also supported by utilizing a limited set of transcripts during early analysis<sup>11</sup>, when the analyst is not as familiar with the details and scope of the entire data set.

The co-construction of the categories of description and the structural relationships between those categories is another unique element of this process compared to other developmental phenomenography. Similar to Akerlind<sup>11</sup>, this study will allow structural relationships to form before categories of description are finalized. The first few iterations focus on developing the categories of description, and then we will alternate focus on categories of description and their structural relationships with each subsequent iteration. Akerlind argues for the process of co-construction in order to highlight critical aspects of variation during analysis, and thus move beyond simple descriptions in order to present results that are meaningful and applicable in educational settings. We would also argue that elements of structural relationships naturally become evident to the researcher when transcripts are placed into categories. When one selects a category for a transcript, he or she is not only saying it is similar to transcripts in that category, but different in some critical way from transcripts in other categories.

### *Quality and Rigor*

Quality in phenomenographic work is typically established through rigorous development and execution of data collection and analysis methods<sup>11,24,25,29-31</sup>. In data collection, quality is ensuring that the interview attains as comprehensive and accurate account of the participant's understanding and experience of the phenomenon as possible, without introducing any element of the interviewer's own views related to the phenomenon. This is accomplished through bracketing the interviewer's perspective<sup>11,24,31</sup>, empathic engagement with the participant<sup>25,32</sup>, and detailed planning related to interview structure and questions<sup>11,24,31</sup>. In data analysis, quality is ensuring that findings derive solely from and accurately represent the data, and that results are applicable and meaningful. This is accomplished through interpretive awareness, situating analysis in participant terminology, and incorporating multiple perspectives during collaborative critique<sup>11,24</sup>.

In line with previous attempts to align quality in phenomenographic studies with quality in qualitative research<sup>29,30</sup>—and, in order to aid in understanding of rigor among those familiar with other qualitative traditions—this study maps techniques used during the research process to an existing quality framework<sup>33,34</sup>. This framework seeks to incorporate elements of quality throughout the process, including making and handling data, rather than simply providing an evaluation of quality after completion. To ensure quality and rigor in this work, this study is designed to incorporate appropriate qualitative validation methods wherever possible. While communicative and pragmatic validity are typically emphasized in phenomenographic work<sup>8,28</sup>, the additional elements of theoretical, procedural, and ethical validation, and process reliability from Walther and colleagues' framework will also improve the quality of this work. Table 2, adapted from Walther and colleagues<sup>33,34</sup>, outlines these concepts and specific procedures used.

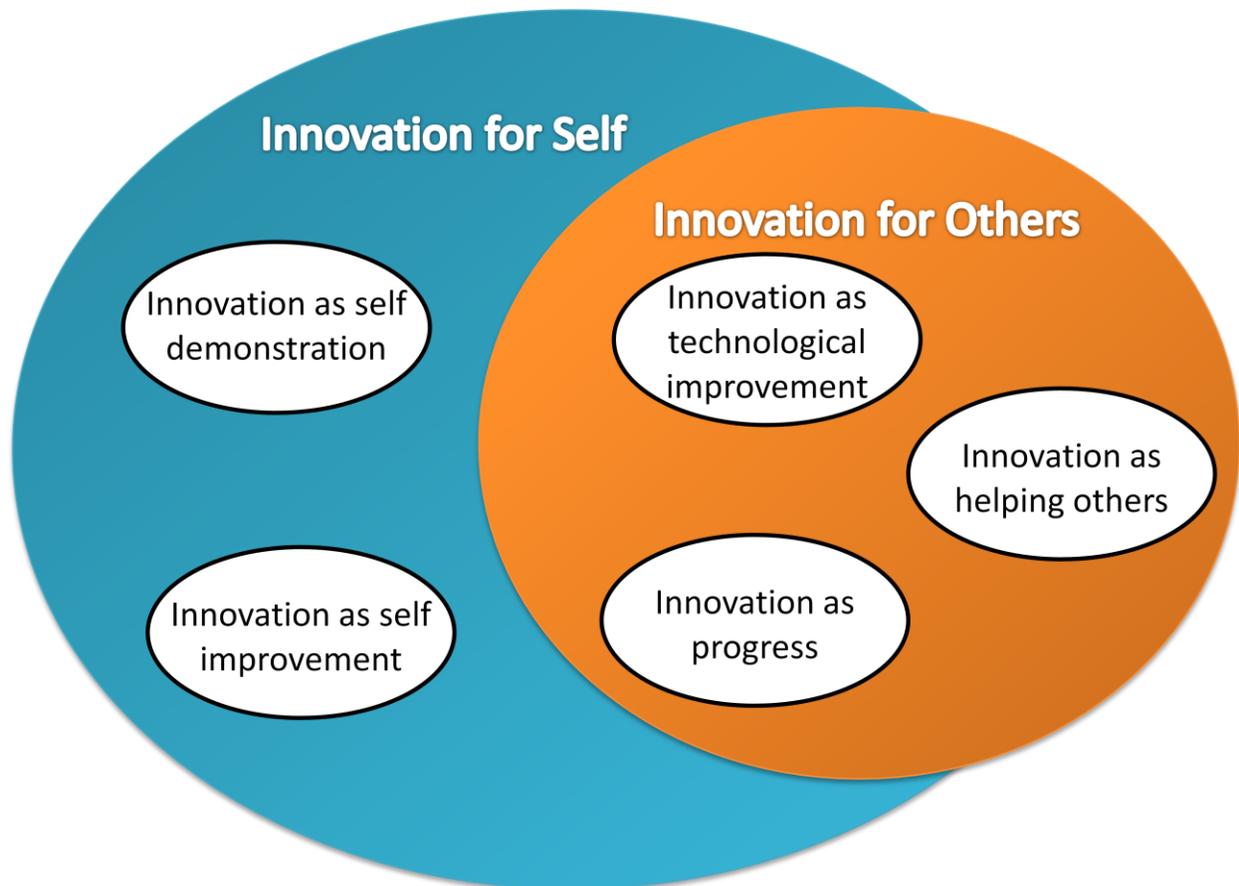
This paper itself, and the resulting conference presentation, represent one critical step in ensuring the quality and rigor of the work. In particular, by presenting this work, in an intermediate stage, to a variety of individuals, we receive feedback to support communicative validity<sup>8,11</sup>.

**Table 2.** Considerations of Quality in Current Study, Suggested by Walther and colleagues<sup>33,34</sup>

<b>Quality Aspect</b>	<b>Focus in Making Data</b>	<b>Strategies Used in Making Data</b>	<b>Focus in Handling Data</b>	<b>Strategies Used in Handling Data</b>
<b>Theoretical Validation – “Do the concepts and relationships of the theory appropriately correspond to the social reality under investigation?”</b>	Capture the breadth of ways the phenomenon is experienced	Maximum variation sampling across critical factors	Accurately represent variation in the participant sample	Situate analysis in participant terminology
<b>Procedural Validation – “Which features of the research design improve the fit between reality and the theory generated?”</b>	Comprehensively capture participant experience during interview	Open-ended and non-leading questions Clarity of interview purpose Pilot interviews to improve questions and interviewer approach	Situate analysis in participant context	Interpretive awareness Reflexivity/transparency of researcher’s own perspectives
<b>Communicative Validation – “Is the knowledge socially constructed within the relevant communication community?”</b>	Knowledge aligns with participants’ second-order perspectives	Transparency with participants during interview Empathy for participants during interviews	Knowledge situated in participant accounts and resonates in research and participant communities	Discuss and defend results with members of research community and representatives of sample during and after analysis
<b>Pragmatic Validation – “Do the concepts and knowledge claims withstand exposure to the reality investigated?”</b>	“Concepts underlying research design... compatible with reality in the field”	Transparency Empathy Open-ended and non-leading questions	“Knowledge produced... meaningful in the social context under investigation”	Present results to design educators and researchers and discuss applications and utility
<b>Ethical Validation – “Aspects of integrity and responsibility throughout the research process”</b>	Interview conducted in responsible and individually sensitive manner	Relaxed and conversational interview environment	Study results reflect and benefit participant group	Potential better understanding of student variation More appropriate assessment and instruction
<b>Process Reliability – “How can the research process be made as independent as possible from random influences?”</b>	“Data... collected and recorded in a dependable way”	Well-defined data collection procedure	“Procedures for generating and representing knowledge... established and documented”	Transparency of method Consistency with previous methods used studying similar topics Checking interpretations and supporting with data

## Results

The results we present here represent the categories of description after a single round of analysis. Phenomenography often requires several such rounds of analysis<sup>24</sup>, thus these results should be viewed as temporary, mile marker #1 on a transcontinental highway. Still, these results offer value as a starting point for further analysis and critique, as well as an opportunity to identify potentially salient features of the phenomenon (innovation) among the participant population.



**Figure 2.** Initial Categorization of Ways Engineering Students Experienced Innovation

The initial sorting revealed five categories which each center on the function that an innovation project served according to the student. These categories are tentatively separated into two groups (see Figure 2). In the first group, two categories focus on innovation as a student-centered experience. These categories (innovation as self demonstration and innovation as self improvement) portray the innovation experience as self serving. Student seek and participate in innovation projects as means toward their own egoistic or developmental imperatives. In the second group, three categories focus on innovation as beyond oneself. Students still experience, to varying degrees, self demonstration and development (as evidenced by the overlap between *Innovation for Self* and *Innovation for Others* in Figure 2), but the focus more heavily lies on the project's purpose within a larger ecosystem. Each of the three categories (innovation as technological development, innovation as helping others, and innovation as progress) center on

the primary aspect of the larger ecosystem that the activity of innovation supports. Below, we describe each tentative category in greater depth and provide example excerpts from the students who comprise the categories.

#### *Innovation as Self Demonstration – Ajay, John, and Michael*

This category presents innovation as an exercise in self demonstration. Students in this category frequently referred to innovation as providing them the opportunity to “set themselves apart” from others by displaying technical and/or creative capabilities. This need for demonstration can be internal or external; students noted satisfaction at both accomplishing their own goals and receiving praise from instructors, supervisors, and judges. For these students, innovation is marked by observable productivity and tangible outcomes. As Michael described:

*I suppose actually I guess my favorite part would be the solution, when I get there. That’s the most satisfying part, you know, is just getting to a solution when given a difficult problem. Knowing how much went into the process, and then once you finally get to a solution and you’re confident in it, then that feels pretty good.*

In order to provide adequate opportunities for self-demonstration, students sought a variety of challenging projects. Thus, challenge becomes a key feature of an innovation project. This characteristic allowed students to constantly push themselves, and as Ajay noted:

*Any kind of innovation that you do sets you apart from other people who design or who work on mundane projects. So I guess that’s why it’s important... Facing a new challenge every day. That is one of the reasons I want to work on innovative projects.*

#### *Innovation as Self-Improvement – Jerry, Leon, and Marshall*

Students in this category also sought innovation projects as personal challenges. Their focus, however, was on the challenge as an opportunity for learning and development. More specifically, these students sought to expand their knowledge and abilities in real-world contexts, thus innovation projects were distinctly external to course projects. Jerry experienced innovation in an extracurricular design competition team. Leon described a variety of experiences on personal projects and engineering-related clubs. Marshall discussed an innovation project during his internship.

Through these real-world innovation projects, students saw the opportunity to contextualize their technical knowledge and develop new competencies. As a result, the focus here was less about the projects’ outcomes and more about personal outcomes. As Leon described, innovation was not necessarily about producing radically new artifacts, but learning and doing things you did not already know how to do.

*I think innovation for yourself is when you’re learning something new and then you’re figuring out something you don’t know based off of that and sure every other person on the planet could know it, but now you do, and you figured it out for yourself so it was innovation for you.*

Still, students acknowledged that the learning they accomplished on innovation projects could lead to what would traditionally be considered innovative solutions at a later date. Jerry, for example, discussed the insights he developed during his design competition innovation project as supporting team performance the following year(s).

*First try we gave it the old college try and it could've been better. But we learned so much. It helped. And we'll try again next year. Yeah. Is basically the way I took away from it. I learned so much. I can teach what I know to other people. I've learned it to that extent now. And I would say regardless of its outcome in terms of how we performed at the competition, the outcome for me I just took so much away from it that I can now learn how to do this on my own. I can think critically about what needs to be done in order for me to call it a success.*

#### *Innovation as Technological Development – Esteban, Summer, Dana, and Taylor*

Compared to the previous two categories, students in this category focused their attention on the process of innovation more so than how participating in innovation benefited themselves. They may still have experienced positive external and internal appraisals, and grown as a result of completing innovation projects, but the focus was on innovation as a process of technological development. Here, students shaped design problems based on client/instructor requirements and considerations of the problem context (e.g., user needs). These structured problems allowed for clear product performance goals and a focus on technical problem solving. As Summer noted:

*I mean in order to innovate something new I feel like you have to have some type of goal in mind, I mean there has to be a purpose to everything to meet at least. Otherwise it's not like a solution to anything, and I think that engineers try to solve problems usually. And if you don't have a goal in mind why are you doing the project, you know?... And then also to see if it's an actual possible thing we can do. I mean I think goals pretty much go hand in hand with innovation.*

While these students more thoroughly experienced the process of innovation, and to a lesser extent other-oriented elements of innovation, there were still personal elements to their experience. They perceived great importance for personal motivation and engagement in innovation. Often these personal motivations aligned with the technology, i.e., students were excited to pursue technological developments that interested them or they viewed as critical. Taylor, potentially a border case, described greater affinity for the particular use of the innovative solution.

*I want to have ownership in it, I mean I don't want to make something that I wouldn't use myself. I don't know. And it keeps me engaged like if I—like a tool that helps teach or a tool that helps athletes or something, that's going to catch my attention a lot more than something that's targeted toward like dancers or biology majors or something, you know what I mean. I'll still be involved in it but I have to see that aspect of it where I fit in... You know if you're coming from the ground up and adding and creating something new then you have full reign to say, 'oh actually I think it would be cool if we did something that was related to teaching and athletics and computers and ta-da,' and then I'll be*

*really proud and excited to talk about my project because I have a lot of enthusiasm for this thing.*

#### *Innovation as Helping Others – Sarah, Sharon, Verdasco, and Jessica*

The previous category saw innovation as partially driven by user needs, but mostly a process of technological development. Here, the focus is switched. Technological development is part of innovation, but the focus is on identifying and meeting user needs. Innovation involves coming to understand users and developing something specific to their context in order to improve their lives. In many cases, as Sarah described below, one must sacrifice technological improvement in service to user needs.

*The traditional thought for how a lot of students, especially on our team where we have a lot ECE students and things that are very technically-focused, they think of innovation as, "We can make this bigger, better, faster, stronger," and have all these capabilities. To me, it's important to think about innovating on the side of what makes it better for the user and what makes it more effective than what makes something exciting to an engineer. That's different than what makes something exciting for your user.*

Like the previous group, this group discussed the importance of individual motivation and engagement with the project. Here, oftentimes the motivation came from a desire to help others (as Sarah described above), rather than from particular interest in the topic area. This motivation can be stifled by project circumstances, such as an individual sacrificing his or her own topical interests to better assist users. Due to the importance of the diverse perspectives on an innovation team and the contributions each individual can make to help others, the participants in this group saw the importance of supporting their teammates' motivation rather than just their own. Below Sharon noted the effectiveness of diversity of perspectives and knowledge in a user-oriented innovation setting:

*I think you just need as much knowledge as possible, because if you don't have it I don't know how it could succeed because it's too narrow, like you don't have a broad enough scope. In order for something to actually work and to be used, you have to have a market, it has to actually work. Like there are a lot of things that go into it and if you don't have the knowledge and the people with skills to do all of that, it's never going to happen or be at all.*

#### *Innovation as Progress – Dylan, Maxine, Penelope, and Tony*

This final category focused on innovation as a means toward societal progress. In this way, the participants took a long term view of innovation (i.e., their projects were just small contributions on an extended pathway). The focus here was on the intersection of technological advancement and meeting user needs. In the quote below, Verdasco discussed making technological advances as a means of empowering people.

*I would say it's actually contributing to society. Because even though you might contribute a small part of the innovation before your time is up, every small portion or*

*part counts towards the end goal... I would maybe, looking at the bigger picture probably, even if you helped design a small component of a car, like a suspension system, they could mass produce it. And that might actually in some way save lives. Like a suspension system working in their favor. Or a braking system. You might not actually see the rewards of it, but knowing that you did your part.*

In taking this long view of innovation, students noted the importance of working within themselves and setting small, manageable goals. As with the previous category, diverse team skills and knowledge were critical, but in this category, team diversity expands the technological development potential of the team. As Dylan described, you need to effectively utilize the expertise in your team to support innovation.

*So using the strengths of all the people in your group to work on that innovative idea I think that's where the final products going to come from. While I don't necessarily know the heart inside and out, I do know how to make a device that can work within the heart, and I do have a basic knowledge of the heart where I know what I make won't hurt it, whereas someone who has a high level of cardiovascular knowledge can say, 'ok this is what we have to consider, this is what we have to consider, this is reasons that this,' and they can say this is what we have to create in the end. Whereas someone who knows fluid flow really well can say, 'oh ok if you incorporate this device here then the pressure will move this way, so then this is going to move this way, and this is how it would affect the body.' And I think having a bunch of different minded people with a likeminded outcome, or desire for outcome, that's where that group can really go to work on that deliverable.*

### *Connections Between the Categories*

It would be inappropriate at this early stage in analysis to begin to suggest the structural relationships between these categories. We offer one key distinction, innovation for oneself versus innovation for others, but this may or may not prove important for the final outcome space. We provide this limited notion of structure to better articulate current results and to offer an archive of our current thought surrounding the categories (a snapshot we can later explore to identify potential sources of bias or differences not covered in the final outcome space). We would also note several similarities between themes throughout the previous sections that may represent non-critical variation, or may suggest later refinements to the categories.

### **Closing Remarks**

This paper has presented a preliminary description of the qualitatively different ways undergraduate engineering students experience innovation in their engineering projects. These results are by no means complete, and thus it would be inappropriate to discuss potential implications or draw conclusions at this point. Eventual results of the complete study, however, may have key implications for how we educate engineering students to innovate and may contribute to broader understanding of the phenomenon of innovation. More specifically, this study has the potential to lead to three key benefits to practice in engineering education, which can be strengthened through presenting this paper. First, the results may suggest pedagogical activities that are beneficial in learning innovation. At a minimum results can help engineering

students and instructors expand their awareness of student perspectives related to innovation and reflect on their own perspectives. Second, results may indicate learning progressions, and thus suggest course sequences or ways innovation-related pedagogy can be integrated into a variety of engineering courses. Finally, the results can provide a knowledgebase to aid the development of improved assessments or activities on the topic of innovation in engineering.

This paper represents a critical step in the analysis process for the overall study. Presenting these results to a diverse group of educators and researchers, especially those outside the educational context in which the study took place, can elicit critical feedback that may inform new ways of interpreting the data and results. We thank the reviewers for their helpful comments and look forward to interacting with a variety of colleagues at the conference.

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## Appendix A: Interview Protocol

NOTE: This protocol is meant to provide a general interview structure and offer potential question phrasings and follow-up items. Phrasing, question order, question addition, question omission were left to the interviewer's discretion on an interview-to-interview basis.

### Introduction

Hello, my name is Nick Fila. I am a Ph.D. candidate in engineering education here at Purdue. I am currently conducting these interviews to understand the different ways engineering students like you experience innovation during their engineering projects. Results of this study will be used to improve the way engineering students are educated as well as furthering understanding of the phenomenon of innovation.

I am going to be asking you some questions over the hour or two with the goal of understanding your unique experiences and perspectives related to innovation. There are no right or wrong answers to these questions, no right or wrong perspectives. I simply want to understand what *you* think.

Some of these questions may be difficult to answer immediately. If you wish to not answer a particular question, that's fine. We can always come back to it at a later time, or skip it entirely. Further, in an attempt to understand your perspectives as accurately as possible, I may ask what seems like a dumb question. Please forgive this as it's part of the interview process for this type of study. I will begin asking you about your background as an engineering student. Then we will discuss some experiences you have had related to innovation. Finally, we will discuss some of your general perspectives related to innovation. Your participation is completely voluntary, and you can stop at any time.

Do you have any questions before we begin? *[If participant asks what is innovation, jump to the final question of the background section]*

### General Follow-Up Questions

- Feelings/experience
  - What was that like for you?
  - How did you feel about that?
- Intention
  - Why did you do that?
  - Why did you do it that way?
- Connections
  - How does that connect to your conception of innovation?
  - How does that connect to \_\_\_\_?
- Clarifications/expansion
  - Would you explain what you mean by \_\_\_\_?
  - Could you tell me more about \_\_\_\_?
- Big Picture
  - What did that experience mean for you in terms of how you view innovation?

## Background

1. Before we start, can you tell me a little about yourself?
  - a. What are your hobbies/interests outside of school?
  - b. What prompted you to participate in this study?
2. Please tell me a little about your experience as an engineering student.
  - a. What is your major?
    - i. What do you like about it?
    - ii. What do you not like about it?
    - iii. Why did you choose that major?
  - b. What other majors, if any, have you studied?
    - i. What prompted the switch?
  - c. What is your year in school?
    - i. What are you most looking forward to between now and graduation?
  - d. What types of courses have you taken?
    - i. What was your favorite? Why?
3. What are your plans after graduation?
4. During the rest of this interview, we will be discussing your experiences and perspectives related to innovation. While I may have a particular conception of innovation, it is critical that we focus on your conception of innovation throughout the interview. In order to get started with that, would you please describe the things that come to mind when you think about “innovation”?

## Experiential

1. Please describe an engineering project you’ve worked on in which you experienced innovation in some way.
  - a. Descriptions
    - i. What was the project goal?
    - ii. What motivated you to become involved in the project?
    - iii. What was your role on the project?
    - iv. Who else was involved in the project? What were their roles?
    - v. Where did the project take place?
    - vi. Who were you designing for?
    - vii. How far did you get in the project?
      1. How did you feel about this outcome?
      2. What would you have done differently?
  - b. Please walk me through your approach to the project.
    - i. Why did you do that?
    - ii. How did you accomplish that?
    - iii. Could you explain that a little further?
    - iv. Did your approach change throughout the project? Why?
  - c. What about the project is linked to innovation?
  - d. What about the project was not innovative?
    - i. How do these compare to innovative elements?
  - e. What did you do that was particularly innovative?
    - i. Why did you do it that way?

- ii. What did you hope to accomplish?
  - f. What was your favorite part about the project?
  - g. Did the project change your perspective at all?
    - i. What did you learn during the project?
    - ii. Did you learn anything about innovation during the project?
- 2. Please describe an engineering project you've worked on in which you did not experience innovation.
  - a. Same follow-ups as previous question
  - b. How do you think this project is different from the experience we talked about earlier?
  - c. How did your approach compare to your innovative project?
    - i. What were some of the reasons for that difference?
  - d. Are your approaches to engineering projects that involve innovation different than those that do not involve innovation?
    - i. What is different about innovation projects?

### Conceptual

- 1. We've been discussing some engineering projects during which you did and did not experience innovation. With those experiences in mind, what does innovation mean to you?
  - a. Has your view of innovation changed over time?
  - b. What caused your view to change?
  - c. What experiences have been most important?
- 2. What is innovating or *doing innovation* to you?
  - a. What are some important things you must consider when innovating?
- 3. Earlier you talked about \_\_\_\_\_. How does that relate to innovation?
- 4. What role does innovation play in your life?
- 5. What are the biggest challenges you have faced related to innovation?
  - a. What would you change to make innovation easier?

### Process Mapping

- 6. As a final inquiry, I would like you to draw an innovation process. This is meant to represent a process you would use to develop an innovative solution in the context of an engineering project. This does not necessarily have to be a process you have used before. Nor does it need to be tied to any specific innovative solution. Please detail and label any steps, phases, or elements of your process. This is a verbal and written task, so please describe what you're thinking as you write. And please feel free to ask me any questions you have.
  - a. Most important step?
  - b. Favorite step for you personally?
  - c. Walk through the process map one step at a time.

### Wrap-Up

- 1. Thank you for participating in the interview. Before we conclude, would you like to comment on or add to any of your previous responses?

2. Your responses in this study may be used in publications and conference presentations. During those, we will always use a pseudonym. At this point, would you like to choose the pseudonym I would use for you? If not, I'll just choose one at random.
3. Do you have any questions for me?