Human-Centered and Psychological Concepts in Undergraduate Engineering Project Documentation

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The success of engineering and design is facilitated by a working understanding of human thoughts, feelings, and behaviors. In this study, we explored how undergraduate engineering students included such human-centered and psychological concepts in their project documentation. Although, we observed a range of concepts related to design processes, teams, cognition, and motivation, these concepts appeared infrequently and superficially. We discuss how this analysis and approach may help to identify topics that could be leveraged for future human-centered engineering instruction.

Introduction

The success of engineering and design is facilitated by a working understanding of human thoughts, feelings, and behaviors. For instance, well-intentioned engineers seek to design assistive devices that afford greater freedom and access to persons with disabilities. However, users' adoption and perception of these technologies could be undermined by cognitive and affective processes related to decision-making, self-efficacy, relationships, and stigma (Mortenson et al., 2012; Parette & Scherer, 2004; Sakakibara et al., 2014). To meaningfully empathize with these users—to anticipate, understand, and respond to their concerns and experiences in ways that inform robust design—engineers should have familiarity with underlying psychological concepts. Knowledge of psychology topics and terminology may also enable engineers to bridge engineering and psychology in multidisciplinary teams (Roscoe et al., 2019).

One goal for engineering education is thus to prepare future engineers to address the "human side" of their work (Hynes & Swenson, 2013; Kellam et al., 2007; Oehlberg et al., 2012; Zoltowski et al., 2012). Along with expertise in math and science, engineering students should develop appreciation of users' and clients' psychosocial needs (Hess et al., 2016, 2017) and engage with societal and humanitarian problem-solving (Bielefeldt & Canney, 2016; Litchfield & Javernick-Will, 2015, 2017; Muñoz & Mitcham, 2012). These aims align with conceptions of design thinking (Carlgren et al., 2016; Dym et al., 2005; Razzouk & Shute, 2012) and design processes (i.e., defining problems and ideating solutions) that are guided by empathizing with stakeholders.

As a starting point, it is worthwhile to investigate engineering students' existing knowledge and application of human-centered principles. We do not expect students to possess broad or deep understanding of psychology, but exploring their current knowledge can reveal (a) emerging conceptions to be elaborated via instruction or (b) knowledge gaps that represent opportunities for insight. For instance, if students possess nascent awareness of "user frustration," supplemental lessons could enrich their understanding both conceptually (e.g., causes and consequences of that emotion) and practically (e.g., strategies for detecting and reducing frustration) (DeFalco et al., 2018). Likewise, students might be unaware of how cognitive biases undermine design (e.g., confirmation bias; Calikli & Bener, 2015). Thus, instruction about biased reasoning might empower them to avoid common pitfalls and fallacies. As an analogy, this approach considers how we can plant or cultivate "seeds" of human-centered engineering and understanding.

In service to these goals, this paper explores the inclusion of human-centered and psychological concepts in engineering students' project documentation. Specifically, final project reports in an introductory engineering course are analyzed using a qualitative framework (Roscoe et al., 2018) to reveal the occurrence of human-centered concepts along with their focus (i.e., users or engineers), sources (i.e., instruction, research, or personal experience), and depth of discussion (i.e., definitions, examples, and explanations of effects).

Method

Participants

Anonymized project documents were obtained from undergraduates ($n = 222$) enrolled in *EGR 101: Foundations of Engineering Design* at Arizona State University in Fall or Spring 2016. These data were archival and no demographic data (e.g., gender and ethnicity) were available, although most students were first-year engineering majors.

Student teams were asked to "redesign the future of being a passenger" (see below), and were instructed to (a) identify users, (b) empathize with users, (c) define problems, (d) brainstorm solutions, (e) create prototypes, and (f) improve designs using feedback. Each student submitted a written report about their design activities.

> …your team will be tasked with improving one particular aspect of the transportation experience: being a passenger... The context of being a passenger can be defined for any mode of transportation (e.g., cars, trains, airplanes, subways, gondolas, etc.) and will be selected by each team. Furthermore, the specific passenger group your team chooses to design a solution for may be someone like you (e.g., another college student) or someone who's needs in the context of being a passenger may be quite different from you (e.g., an elderly person with mobility issues).

Framework

The framework comprises four dimensions—*Conceptual*, *Application*, *Source*, and *Depth*—and is collaboratively implemented by researchers who review student artifacts for evidence of the dimensions.

Conceptual Dimension. Human behavior is complex, which gives rise to a wealth of psychological concepts that might influence engineering. The framework includes (but is not limited to) five broad categories. *Cognitive* concepts refer to foundational mental processes (e.g., attention and memory) and higher-order reasoning (e.g., decision-making and problem-solving). *Metacognitive* concepts refer to reflective and evaluative processes applied to the thoughts and performance of oneself. *Motivational* concepts refer to human goals and feelings that influence our behavior (e.g., interests, goals, and anxiety). *Social* concepts refer to ways that individuals and groups interact with each other (e.g., communication and teamwork) and aspects of interpersonal relationships (e.g., accountability and trust). *Cultural* concepts refer to systemic or situational factors that might influence entire institutions or communities (e.g., policy, ethics, racism, and sexism). All categories have relevance to engineering outcomes, such as cognitive overload induced by faulty designs (Sweller et al., 2011) or optimizing team performance via strategic interaction (Cooke et al., 2013).

Application Dimension. Psychological concepts can be *applied to users* to describe their needs, capabilities, goals, and limitations. Similarly, these principles can also be *applied to engineers*. Engineers must also be aware of their own thoughts, feelings, beliefs, and biases, and how such factors influence their decisions or learning.

Source Dimension. Concepts may be learned via *personal experience*, such observations of the world or trial-and-error. Concepts can be acquired through *research*, wherein students review the literature or conduct experiments and interviews. For many students, concepts may be acquired through *instruction*, such as lessons, tutorials, and textbooks.

Depth Dimension. An important indicator of students' understanding is whether they *define* the concept, explain the *effect* of that concept on engineering outcomes, or offer *examples* of the concept in action. If a concept is explained in students' documentation, we can infer that they possess meaningful working knowledge.

Implementation: Four Steps

Analysts first reviewed student documents to extract concepts that appeared within the data. These reviews were mindful that students lacked technical terminology. Annotations were then iteratively debated and refined to finalize a list of concepts, operational definitions, and examples (Table 1), which were applied to identify concepts in the documents.

Second, analysts assessed whether identified concepts were applied to users (e.g., "users," "passengers") or engineers (e.g., "my team"). Third, analysts inspected whether any source (i.e., personal experience, instruction, or research) was cited for the concept (e.g., "as we learned in class"). Fourth, analysts examined whether students defined the concept, explained how it affected engineering, or gave an example.

Implementation was situated within qualitative or mixed-method approaches such as verbal data analysis and grounded theory (e.g., Chi, 1997; Strauss & Corbin, 1994). The process provided a window into general trends about the frequency or relative distributions of concepts. Numerical data are provided to help readers characterize these trends (Tables 1-2) but should not be interpreted as a strict quantification of the patterns.

Results

Human-centered Concepts

Approximately 15 concepts occurred with sufficient clarity to be labeled (Tables 1-2). Five concepts related to design processes taught in the course: *empathy*, *problem-solving*, *brainstorming*, *selection*, and *evaluation*. Another four concepts pertained to teams: *consensus*, *delegation*, *leadership*, and *teamwork*. Finally, six concepts related to psychological aspects of cognition (*attention*, *learning*, and *planning*) or motivation/affect *(anxiety*, *frustration*, and *interest*).

Table 1. Percentage of Documents that Referenced a Concept

Concept	Percentage
Design Thinking	
Empathy	1.8
Problem-solving	3.5
Ideate	8.8
Selection	6.6
Evaluation	2.2
Teams	
Consensus	4.9
Delegation	2.2
Leadership	1.8
Teamwork	5.3
Thoughts and Feelings	
Anxiety	5.8
Attention	0.9
Frustration	4.0
Interest	0.9
Learning	1.3
Planning	0.4

All concepts occurred with low frequency. Given that design concepts (e.g., empathizing, and ideation) were explicit in the assignment, we expected these concepts to be better represented. However, fewer than 10% of students mentioned these topics. Similarly, although students worked in teams, only a handful of documents discussed teamwork. A few students stated that their teams made decisions via consensus or described how they delegated roles and tasks to team members. Students primarily focused on describing their materials and manufacturing methods.

Although rare, an intriguing finding is that students did occasionally refer to psychological concepts. For example, students mentioned that passengers in planes or cars might feel "worried" about safety (anxiety), feel "irritated" by delays (frustration) or "enjoy" certain features (interest). A few projects mentioned that drivers may be "distracted" by certain designs (attention). Finally, several students described organizing their own engineering tasks "in advance" (planning) or gaining new skills to complete the project (learning).

Table 2. Percentage of Project Documents that Described an Application, Source, or Depth

Concept	Percentage
Application	
Users	9.7
Engineers	27.4
Source	
Instruction	0.0
Research	0.0
Experience	0.0
Depth	
Definition	0.0
Effect	0.0
Example	2.7

Applications

About one-fourth of students applied concepts to engineering design processes or teams. Concepts such as "problem-solving" or "delegation" were almost always discussed in terms of the engineers' own work. A few students also described their own efforts to "learn" or acquire a new skill (e.g., how to use a 3D printer) or "planning" their project. In rare cases, students reported their own anxieties or frustrations (e.g., worry about a failed prototype).

Fewer than 10% of projects mentioned applied concepts to users or clients. Typically, these references superficially mentioned users' imagined anxieties, interests, or frustration. For a user-centered engineering assignment, attention to user considerations was surprisingly rare.

Sources

No students indicated that any concept was learned via course instruction (e.g., design processes taught in class) or was derived from either personal experience or research.

Depth

No students defined or explained any concept. However, a few projects did include examples. Examples typically described a technique used to brainstorm (e.g., writing ideas down on sticky notes) or evaluate prototypes (e.g., assessing material cost).

Discussion

Human-centered engineers should possess working knowledge of human thought, feeling, and behavior—both in terms of users and clients (i.e., who they are engineering *for*) and themselves *as* engineers. An understanding of psychological concepts offers engineers the terminology and mental models to appreciate human experience and consider these issues during design. Likewise, such knowledge might be applied to oneself to improve performance and avoid pitfalls (e.g., biases). In this study, introductory engineering students' work suggested (or perhaps confirmed) that knowledge of human-centered and psychological concepts was minimal.

Design thinking concepts discussed in class and assignment materials should have been better represented. Students were asked to document their design processes, which they appeared to narrowly (mis)interpret as manufacturing procedures. More explicit document guidelines might remedy this oversight. A complementary approach is to enrich students' understanding of design by elaborating on the psychological roots—for instance, bridging the psychology and engineering of "empathy" (Cuff et al., 2016; Strobel et al., 2013; Walther et al., 2017) or "creativity" (Daly et al., 2014; Sternberg & Kaufman, 2018). As a hypothesis, further instruction may make these principles more salient or accessible, thus improving students' "uptake" and application of the ideas.

Importantly, the catalog of human-centered concepts is infinite—engineering students cannot be expected to include them all. However, by identifying concepts that students adopt spontaneously, we might leverage their existing curiosity. Several students incorporated cognitive and affective psychological concepts such as frustration and interest. These examples perhaps reveal "seeds" of emerging psychology knowledge that could be nurtured. For example, engineering students might be interested to learn how perceptions of "enjoyment" or "frustration" influence technology use (e.g., technology acceptance models; Holden & Karsh, 2010; Marangunić & Granić, 2015). Such instruction could deepen students' understanding of the concepts and empower them to apply these issues in practice.

Should all engineering students be required to take multiple psychology courses or double-major in engineering and psychology? Should psychology be required in already tight engineering curricula? Certainly not! However, at Arizona State University, degrees in human systems engineering (HSE) promote human-centered engineering education by bridging psychology and engineering (Roscoe et al., 2019). Students can enroll in HSE courses—as a primary or secondary field of study, to fulfill generation requirements, or out of curiosity—to learn about engineering from a variety of social science perspectives (e.g., cognitive science, human factors, ergonomics, and human-computer interaction). Students also have access to an introductory course—*HSE 101: Introduction to Human Systems Engineering*—that is design to help students recognize the relevance of psychology in engineering. In future research, the methods employed in this research (i.e., analyses of project documentation) can be used to assess the effects or benefits of HSE-based instruction and interventions.

Acknowledgements

This research was supported in part by the National Science Foundation (#1712328). Opinions, findings, conclusions, or recommendations expressed in this work are those of the authors and do not necessarily reflect the reviews of NSF. The authors are grateful for the efforts of Micah Lande and Ashley Clark in the collection and analysis of data.

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Appendix: Coded Concepts, Operational Definitions, and Examples

Concept	Brief Operational Definition	Relevant Terminology	Example Excerpts
Design			
Empathy	Understanding the needs of others, often through processes of active listening and observing their experiences	"empathizing," "understand the users," "thinking about how the user would feel"	"We then empathized with the user by deciding what would be the most comfortable and accessible place…"
Define the Problem	Determining the problem to be solved or the problem space to be explored	"define the problem," "determining the problem," "identifying the obstacles"	"… decided to actually solve the problem our user was struggling with. Thus, we clearly defined the problem to be…"
Ideate	Generating ideas (e.g., problems, strategies, and solutions)	"brainstorm," "ideate," "pitching ideas," "thinking of ways to solve problems"	"Before designing the prototype, we had all brainstormed together and ideated what we wanted to implement in our project"
Selection	Choosing or deciding upon an idea, solution, or course of action	"decided," "chose," "opted to," "narrowed it down to"	"After a bit of group thinking we decided to change our idea to the current prototype"
Evaluation	Judging or assessing ideas to determine value, feasibility, or other qualities	"worst idea," "most practical plan," "feasibility," "silly"	"although we came up with 30+ ideas, the idea of this door system stuck with us the most"
Teams			
Consensus	Discussing or debating ideas to support team-based agreement or decision-making	"we agreed," "came to consensus," "pooling of ideas," "incorporating our ideas"	"To start we came to an agreement…"
Delegation	Assigning roles and tasks to team members	"delegated," "split up the work," "assigned jobs"	"each group member began to work on a part of the tray in which they specialize in said skill"
Leadership	Taking responsibility for assigning roles and tasks, evaluating others' work, making and choosing plans for team action	"director," "directed," "took the lead," "oversee"	"I took lead of managing our resources: buying supplies and making sure we had materials to build with"
Teamwork	Working together as a collaborative or cooperative group to achieve a shared goal	"team effort," "all contributed," "helping each other"	"When it came to building the prototype everyone played an active role in building the model"
Psychological			
Anxiety	Feelings of worry or fear about a task, event, or outcome	"worry," "anxious," "fear," "feeling pressure," "being judged," "feeling awkward"	"waking up late was embarrassing because it would always cause them to be late"
Attention	Focusing mental resources on a task or stimulus, and to avoid focusing on distracting or irrelevant stimuli	"pay attention," "distracted," "concentration," "focus"	"Can turn in their phone to be charged and remove the distraction of always checking their phone"
Frustration	Feeling of irritation, annoyance, or discomfort about a task or outcome, particularly toward obstacles	"frustration" "discomfort," "being blocked or prevented," "difficulty"	"was frustrated with on how long it took
Interest	Feeling of engagement, liking, or enjoyment of a task or event (or feelings of boredom and dislike)	"fun," "happy," "enticing," "bored," "lack enthusiasm"	the idea entices children to use the device because it is designed to look like a character from a children's movie"
Learning	Acquiring new information and skills; demonstrating skills and performance in assignments	"learn," "performance," "misunderstand," "gaining knowledge"	"I got certified to use the 3d printer and just uploaded my model to the printer and printed it"
Planning	Establishing strategies, courses of action, resources, and evaluation criteria in advance	"plan," "timing," "schedule," "organizing our resources"	"Personally, I planned out our meeting dates as well as the plan for the day"