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A Conceptual Qualitative Framework for Assessing Human Systems Engineering Education Outcomes and Opportunities

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Human systems engineering education seeks to infuse principles of applied psychology, cognitive science, human factors, and user-centered design into the engineering curriculum to help students understand the people they are engineering for (e.g., clients) and their own roles as engineers. This paper outlines a conceptual qualitative framework for formative assessment of students' incorporation of human systems engineering concepts in their projects and documentation. The framework examines potential conceptual dimensions along with applications, sources, and depth of such knowledge, which we argue can begin to evaluate students' work and inform iterative efforts to improve human-centered engineering education programs. Example applications of the framework based on several data sets are discussed.

INTRODUCTION

Multiple calls have been issued to integrate human-centered perspectives into engineering training (ABET, 2015; Hynes & Swenson, 2013; Kellam et al., 2007; Zoltowski, Oakes, & Cardella, 2012). Modern engineers are expected to be empathic (Hess, Beever, Strobel, & Brightman, 2017), socially-engaged (Litchfield & Javernick-Will, 2015), and ready to solve widespread human and man-made problems. Although traditional engineering training provides technical expertise for creating functional systems (Feland, Leifer, & Cockayne, 2004), we argue that an understanding of human needs and capabilities empowers engineers to produce systems that are also usable, resilient, safe, and satisfying for human users. Specifically, the field of *human systems engineering* seeks to infuse applied psychology, cognitive science, human factors, and user-centered design into the engineering curriculum, which is hypothesized to help students understand the people they are engineering for (e.g., users and clients) and their own roles as engineers (e.g., developers and teammates).

In this paper, we offer a conceptual qualitative framework for formative assessment of human systems engineering in students' projects and documentation. The overarching goal is to introduce an analytical tool that can reveal students' current knowledge about the role of human psychological principles in engineering and design, highlight areas for growth and instruction, and assess the effects of interventions and training. Importantly, human behavior encompasses cognitive, metacognitive, motivational, social, and cultural factors that are relevant to both potential end users and engineers themselves. Additionally, because students are learners, it is important to consider how and where they encounter critical concepts, and how meaningfully such concepts are applied in their work. Thus, the framework is multidimensional and examines students' conceptual knowledge as well as the applications, sources, and depth of such knowledge.

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Value of the Framework

The proposed framework is anticipated to support three interrelated aims for human systems engineering education.

First, the framework begins to *articulate specific themes and targets for instruction*. What do we want students to know with regard to how their users (or themselves) think, act, and feel? The multidimensional framework presented in this paper outlines broad categories of relevant conceptual knowledge (e.g., cognitive and cultural principles), describes potential applications and beneficiaries, and considers both the sources and depth of this knowledge. All of these concerns are relevant to human systems engineering educational aims.

Second, the framework enables *formative assessments of students' current application of human-centered principles* to engineering and design, thus revealing key knowledge gaps and opportunities for instruction. What do students already know (or not know) about human-centered engineering and design? Analyses may highlight potentially relevant concepts that were omitted, or might identify concepts that were cited correctly but superficially. In both cases, the formative assessment would indicate fruitful topics for future lessons.

Finally, the framework provides a *concrete means to assess and compare the effects of different curricula, assignments and interventions*. Assessments of students' work can be used to test whether a given lesson successfully communicated desired concepts. For example, do software engineering students who learn about "cognitive load" (Sweller, Ayres, & Kalyuga, 2011) actually apply these concepts to the design of new data visualization interfaces? Similarly, by assessing students' work within contrasting instructional contexts, we can reveal how those contexts elicit different kinds of conceptual knowledge and application. For instance, do either hands-on projects or reflection assignments better help students gain insight into their problem solving and teamwork processes?

FRAMEWORK OVERVIEW

The framework is organized around four dimensions that describe how students communicate a principled understanding of human-centered aspects of engineering and design.

Conceptual Dimension

Human thought, feeling, and action are almost infinitely complex, and thus there are myriad human-centered principles that students might invoke to guide their engineering or design work. Engineers benefit from knowing how these processes occur, their constraints, and environmental influences. The current framework includes five categories, but these are not intended to be definitive. Other researchers can and should refine the categories as needed.

Cognition and reasoning. Cognition refers to foundational mental processes such as *perception*, *attention*, *memory* (e.g., working, short-term, and long-term), and *knowledge* (e.g., declarative and procedural), as well as higher order processes such as *relational reasoning*, *sense making*, *decision making*, and *problem solving*.

Human memory and attention are not infinite, and systems with high memory demands (Sweller et al., 2011) or multitasking (Adler & Benbunan-Fich, 2012) can induce overload and hinder performance. At a higher level, relational reasoning is the ability to recognize underlying similarities, analyze discrepant patterns, and reconcile opposing perspectives (Dumas, 2017; Dumas, Alexander, & Grossnickle, 2013). Students may benefit from applying these reasoning strategies to identify user needs, interpret user data, repurpose existing technologies, or invent original products.

Metacognition and self-regulation. Metacognition refers to evaluative processes applied to one's own thoughts, actions, or performance (e.g., *comprehension monitoring*, *judgments of knowing*, *predictions of learning*, *metamemory*). In addition, metacognition includes strategic actions to regulate or adapt performance, such as *planning* and *help seeking*.

Humans tend to overestimate their own knowledge and skills (Dunning, Heath, & Suls, 2004), and designs that require accurate self-monitoring and awareness (without support) may be more likely to fail. However, in some contexts, such as educational technologies, challenging users to engage in self-regulation can improve performance (Devolder, van Braak, & Tondeur, 2012; English & Kitsanas, 2013). Similarly, engineers must be wary of their own tendencies to misgauge their abilities, and should consider how iterative self-evaluation can be critical to design thinking (Dym, Agogino, Eris, Frey, & Leifer, 2005; Razzouk & Shute, 2012).

Motivation and affect. Motivation refers to human drives and emotions that influence how we think and act, and how we interpret behaviors and events. These factors include needs and desires (e.g., *intrinsic and extrinsic motivation*, *goals,* and *personal and situational interest*), self-beliefs (e.g., *self-efficacy* and *identity*), and affective experiences (e.g., *moods*, *emotions*, and *anxiety*).

Factors such as achievement goals (Duffy & Azevedo, 2015), self-efficacy (Bandura, 1993), and intrinsic motivation (Ryan & Deci, 2017) can have a profound effect on individuals' effort, persistence, reasoning, and decisions. Engineers and designers must consider how their products inspire positive or negative subjective experiences, and how product use is influenced by motivation. For example, self-efficacy beliefs can influence use of learning technologies (Holden & Rada, 2011) or assistive devices (Sakakibara, Miller, Routhier, Backman, & Eng, 2014) — devices that are intended to be "empowering" might be avoided due to fears about inability or embarrassment.

Motivational factors also promote or undermine engineering students' own engagement, persistence, and career goals (Jones, Paretti, Hein, & Knott, 2010), such as their self-efficacy (Hsieh, Sullivan, Sass, & Guerra, 2012) and personal identity (Matusovich, Streveler, & Miller, 2010). Helping students to regulate their own motivations and goals may have long-term benefits for retention and graduation.

Social and interpersonal interactions. Social factors describe ways that individuals interact with each other (e.g., *communication*, *negotiation*, *mentoring*, *conflict, cooperation* and *competition*) and interpersonal relationships (e.g., *trust, disclosure, social comparison*, *accountability*, and *authority*).

Engineers need to consider how their products are situated within users' social relationships, and must think about how they interact with their own teammates, clients, and investors. Building on the above example, assistive devices can be empowering, yet persons with disabilities may fear social stigma or involuntary disclosure by the device (Parette & Scherer, 2004). However, incorporating tools for social interaction can also increase user engagement and productivity (Hemmi, Bayne, & Land, 2009; Yu, Lin, & Liao, 2017).

Engineers must also learn to navigate interpersonal and professional relationships (Shuman, Besterfield-Sacre, & McGourty, 2005). For example, research on teams highlights the importance of knowledge sharing, adaptive training, and role awareness among successful teams (Cooke et al., 2013).

Culture and organizations. Organizational and cultural issues refer to broad, systemic factors that may influence the operations of whole institutions or societies (e.g., *racism*, *sexism*, *law*, *policy*, *ethics*, *inequality*, and *tradition*).

Engineers must remain aware of how their technologies may be received or perceived in context. For instance, humanitarian engineering projects often bring together individuals from multiple societies or cultures to solve critical problems, but cultural differences can influence how participants evaluate or even conceptualize key problems and potential solutions (Amadei, Sandekian, & Thomas, 2009; Campbell, 2013). More locally, numerous studies have explored the effects of diversity, discrimination, (under)representation, and institutional climate on engineers' and students' decisions to remain in engineering fields (Geisinger & Raman, 2013; Marra, Rodgers, Shen, & Bogue, 2012). Thus, engineering students are also affected by the environments in which they learn and work.

Application Dimension

Psychological principles may be applied to engineering and design in two broad ways: (a) to understand, evaluate, or design for *potential users*, and (b) to understand, evaluate, or improve *engineering practice*. The framework focuses on students' causal attributions about successful engineering based on these concepts. How do students define "good" or "bad" engineering with respect to the psychology of users or engineers?

Psychology of the user. User-centric applications focus on the needs, capabilities, goals, and limitations of the user or audience for the system, device, or design. If students reference factors such as users' memory, knowledge, self-perceptions, social networks, or cultures, we can assess how students define the value of these principles for creating functional, usable, or desirable products. We can also capture instances where students fail to articulate such value.

Psychology of the engineer. Engineer-centric applications focus on the needs and processes of engineers when engaging in engineering or design activities. As humans, engineers are of course beholden to various thoughts, beliefs, and feelings that influence behavior. What do engineering students believe about their own prior knowledge, strategic reasoning, self-evaluation, or motivations? How do students reference such factors to account for their (or their team's) success or failure?

Source Dimension

Students' knowledge of human-centered principles may be acquired from a variety of overlapping sources, including their own experiences, coursework, or research. In addition to capturing conceptual knowledge, the framework assesses how and whether students credit their sources of learning.

Instruction and coursework. Sources of knowledge are lectures, discussions, textbooks, or other direct instruction. Students can and do learn fundamental principles by being taught, and such instruction is often essential for novices (see Clark, Kirschner, & Sweller, 2012).

Personal experience and insight. Another source of information can be inquiry, insight, observation, and personal experience (English & Kitsanas, 2013). Through engaging in engineering projects or design activities, students may come to realize certain concepts or "lessons learned," such as discovering that cluttered interfaces are confusing and exhausting for users (i.e., cognitive overload).

Research and scholarship. A third source of principled knowledge is independent investigation and research. Students can conduct literature reviews, needs analyses, market analyses, or experimental studies to learn or establish human-centered principles for engineering. Rather than depending on a mentor or a lucky discovery, students could ideally explore relevant scholarship about the "human side" of their products and users from the earliest stages of design.

Depth Dimension

Finally, the framework considers how students define the concept, articulate a mechanism by which the principle affects engineering outcomes (e.g., functionality, usability, and team cohesion), or illustrate the principle via examples.

Definition. Students may describe the nature of the concept (i.e., who, what, where, and when) but not articulate how the principle affects other concepts or engineering outcomes.

Effect. Students may explain a causal mechanism through which the principle influences other variables or engineering outcomes (i.e., how and why).

Exemplification. Students may provide hypothetical or real-world examples that demonstrate the principle "in action" or illustration applications and outcomes.

IMPLEMENTATION

To implement the framework, researchers and educators examine student engineers' and designers' written project documentation, images, artifacts, or reflections for references to human-centered principles and practices. This proceeds as a multi-step process that sequentially assesses each dimension. In broad terms, this implementation is situated within qualitative or mixed-method approaches such as grounded theory, content analysis, and verbal data analysis (e.g., Chi, 1997; Strauss & Corbin, 1994). The results of this process are profiles of students' knowledge along each dimension, which may be used to assess students individually or collectively (e.g., patterns across a whole class), identify distinct student clusters, and link these patterns to other variables.

Step 1: Identify conceptual categories. The research team collaboratively and holistically reviews individual data entries for references to cognitive, metacognitive, motivational, social, and cultural categories. Because the list of possible principles is infinite, a complete list of concepts cannot be generated a priori. Analysts should initially adopt an inclusive perspective and be mindful that students often lack technical terminology for important concepts (e.g., referring to "low confidence" rather than "low self-efficacy"). Finally, the subjectivity of this task benefits from recruiting multiple reviewers who debate data entries to establish a set of categories for subsequent coding—the initial set of observed concepts is reduced through collaborative analysis. The output of this stage is a list of human-centered principles represented in each data entry.

*Step 2: Coding application***.** Coders assess whether labeled principles address the psychology of the user, the engineer, or both (i.e., not mutually exclusive). To establish reliability, two raters independently code each data point, or a subset, and calculate a metric of agreement (e.g., kappa). Disagreements are resolved via discussion, and iterative rounds of additional coding should proceed until a desired criterion is attained.

*Step 3: Coding source***.** Coders assess whether students cite the origins of their knowledge, such as instruction, experience, and/or research (not mutually exclusive). Agreement between independent coders should be established as above.

*Step 4: Coding depth***.** Finally, coders assess whether the concepts are defined, explained, and/or supported by examples (not mutually exclusive). Agreement between independent coders should be established as above.

*Optional: Quantification***.** One question is whether to use the above coding to assign "scores" to student work, such that higher scores might indicate "better" or "deeper" conceptual knowledge and applications. We do not currently specify any method or rubric for such scoring as part of the framework. Instead, we argue that quantification should proceed based on researchers' specific needs or questions.

For instance, one might weight ideas learned via independent research more heavily than information "regurgitated" from lecture notes. Similarly, if researchers are interested in "depth of knowledge" as a measure of student performance, perhaps definitions, explanations, and examples might be assigned values based on researchers' theory or pedagogy. Further theoretical distinctions (e.g., *content* of definitions or *types* of examples) might be added for more precise scoring.

THE FRAMEWORK IN PRACTICE

Our purpose is to introduce an assessment framework rather than to report a full analysis using the framework. Nonetheless, to consider the potential utility and validity, it is worthwhile to demonstrate how it might be put into practice.

Example data were obtained from an undergraduate course, *Foundations of Engineering Design* (EGR 101), in which students prototyped devices to improve high school settings. The instructor explicitly taught about *empathy* with users (interpersonal: engineers) and *brainstorming* (cognitive: engineers). The excerpts below were extracted from students' prototype documentation; technical details about materials, costs, and manufacturing processes were omitted.

Many students referenced target concepts of empathy and brainstorming, yet differed how deeply the principles were discussed. For example, excerpt A includes an example of brainstorming and loosely explains how optimal ideas were selected. Empathy is mentioned in passing but is not defined, explained, or exemplified. In contrast, excerpt B describes a process of empathizing but brainstorming remains vague.

> [A] *Our product was created to make returning and charging laptops easier in the classroom. First step was empathize and to do that we interviewed a high school student. For brainstorming we wrote down ideas and sketches on sticky notes then picked the most viable options evaluating them based on practicality, usability, cost, and manufacturing.*

> [B] *The device will allow use of public fountains without meeting the germs and filth that tends to collect on these fountains. The first step was to empathize with the student in high school. This was accomplished by doing an interview during class hours. We discussed what issues they had experienced and speculated at ideas on how we could improve the standard. Next, we had a brainstorming session with our group in class to discuss solutions for water quality in public high school.*

Other students did not refer to empathy or brainstorming at all—they listed product features without reference to either the psychology of users or engineers (excerpts C and D).

> [C] *The device was a customizable organization box that is placed in a backpack. The device is a sturdy structure that has removable compartments and pieces in order to change the amount of compartments desired.*

> [D] *For our redesigned project we decided to improve the modern high school desk. Our desk is meant to provide a more comfortable learning experience for all kinds of students with different body types.*

In addition to capturing whether students applied concepts from the curriculum, we can also inspect students' inclusion of concepts *not* taught by the instructor. For instance, excerpt E cites helping users "focus" (cognition: users) and "remember" (cognition: users). However, no sources were credited for these claims about attention and memory, and neither concept was defined, explained, nor exemplified.

> [E] *The purpose for our project was to have a chair that would aid in keeping a student awake during class and also help them focus and remember material.*

Finally, students on the same team did not always articulate the same ideas—their documentation referenced different concepts or discussed them in distinct ways (perhaps a sign of poor team cognition, Cooke et al., 2013). Excerpt F emerged from the same team as excerpt D. In addition to discussing empathy and brainstorming, this student also briefly addressed engagement (motivation: users) and provided examples of how discomfort or pain could hinder participation.

> [F] *Our team created an adjustable desk for students while they attend high school. The problem that we would be addressing would be one of importance to student participation and engagement. This specific problem was lack of comfort while sitting at uncomfortable desks. Due to different body shapes and sizes of students, generic desks were not designed with specific students in mind. As a result, many high school students proceed with their days in pain, and as a result, not participating in class as much as they could and or deserved to.*

In sum, these excerpts begin to show that the framework has the potential to capture nuanced differences in how students reference human-centered psychological principles for design and engineering. Students vary in whether they address the psychology of the user or engineer, and whether they draw upon course instruction or other knowledge. Similarly, students vary in how deeply they define, explain, or make use of the concepts. In conjunction with other data (e.g., grades, observations, and demographics), we can begin to explain these variations and develop targeted instruction to improve student outcomes.

CONCLUSION

Effective engineering requires more than just technical skill or knowledge of mechanical, physical, chemical, biological, or computing systems. The *human system* must also be considered, referring to the complex thoughts, feelings, actions, and interactions that humans (both users and engineers) bring to any endeavor. An important goal for educating future engineers and designers is to nurture an understanding of the psychology of their users, clients, teammates, and selves.

To support formative assessment of these educational efforts, we introduced a preliminary qualitative framework comprising multiple dimensions of conceptual knowledge, application, sources, and depth. This framework could be used to analyze students' current knowledge, the impact or effectiveness of instruction, and potential learning goals and opportunities.

Importantly, this framework is extensible to further aspects of human-centered engineering. For example, future iterations could assess knowledge of user-centered design practices (e.g., *participatory design*, Simonsen & Robertson, 2001) or students' epistemic stance toward engineering and innovation (e.g., *entrepreneurial mindset*, Kriewall & Mekemson, 2010). Thus, the framework can be aligned to other researchers' questions, and can evolve alongside our growing understanding of effective human systems engineering education.

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REFERENCES

ABET (2015). *2016-2017 Criteria for Accrediting Engineering Programs*. Baltimore, MD: ABET. Retrieved online from http://www.abet.org

Adler, R. F., Benbunan-Fich, R. (2012). Juggling on a high wire: Multitasking effects on performance. *International Journal of Human-Computer Studies*, *70*(2), 156-168.

Amadei, B., Sandekian, R., & Thomas, E. (2009). A model for sustainable humanitarian engineering projects. *Sustainability*, *1*(4), 1087-1105.

Bandura, A. (1993). Perceived self-efficacy in cognitive development and functioning. *Educational Psychologist*, *28*(2), 117-148.

Campbell, R. C. (2013). Caring in engineering: How can engineering students learn to care? How can engineering faculty teach to care? In J. Lucena (Ed.), *Engineering education for social justice: Critical explorations and opportunities*. *Philosophy of Engineering and Technology, Vol. 10* (pp. 111-131). Dordrecht, Netherlands: Springer.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, *6*(3), 271-315.

Clark, R. E., Kirschner, P. A., & Sweller, J. (2012). Putting students on the path to learning: The case for fully guided instruction. *American Educator*, *36*(1), 6-11.

Cooke, N. J., Gorman, J. C., Myers, C. W., & Duran, J. L. (2013). Interactive team cognition. *Cognitive Science*, *37*, 255-285.

Devolder, A., van Braak, J., & Tondeur, J. (2012). Supporting self-regulated learning in computer-based learning environments: Systematic review of effects of scaffolding in the domain of science education. *Journal of Computer Assisted Learning*, *28*(6), 557-573.

Duffy, M. C., & Azevedo, R. (2015). Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system. *Computers in Human Behavior*, *52*, 338-348.

Dumas, D. (2017). Relational reasoning in science, medicine, and engineering. *Educational Psychology Review*, *29*, 73-95.

Dumas, D., Alexander, P. A., & Grossnickle, E. M. (2013). Relational reasoning and its manifestations in the educational context: A systematic review of the literature. *Educational Psychology Review*, *25*, 391-427.

Dunning, D., Heath, C., & Suls, J. M. (2004). Flawed self-assessment: Implications for health, education, and the workplace. *Psychological Science in the Public Interest*, *5*, 69-106.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, *94*, 103-120.

English, M. C., & Kitsantas, A. (2013). Supporting student self-regulated learning in problem- and project-based learning. *Interdisciplinary Journal of Problem-based Learning*, *7*. Available at: http://dx.doi.org/10.7771/1541-5015.1339

Feland, J., Leifer, L. J., & Cockayne, W. (2004). Comprehensive design engineering: designers taking responsibility. *International Journal of Engineering Education* 20, 416–423.

Geisinger, B. N., & Raman, D. R. (2013). Why they leave: Understanding student attrition from engineering majors. *International Journal of Engineering Education*, *29*(4), 914-925.

Hemmi, A., Bayne, S., & Land, R. (2009). The appropriation and repurposing of social technologies in higher education. *Journal of Computer Assisted Learning*, *25*, 19-30.

Hess, J. L., Beever, J., Strobel, J., & Brightman, A. O. (2017). Empathic perspective-taking and ethical decision-making in engineering ethics education. In D. Michelfelder, B. Newberry, & Q. Zhu (Eds.), *Philosophy and engineering* (pp. 163-179). Springer International Publishing.

Holden, H., & Rada, R. (2011). Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. *Journal of Research on Technology in Education*, *43*, 343-367.

Hsieh, P., Sullivan, J. R., Sass, D. A., & Guerra, N. S. (2012). Undergraduate engineering students' beliefs, coping strategies, and academic performance: An evaluation of theoretical models. *Journal of Experimental Education*, *80*, 196–218.

Hynes, M. M., & Swenson, J. (2013). The humanistic side of engineering: considering social science and humanities dimensions of engineering education and research. *Journal of Pre-college Engineering Education Research*, *3*, 31-42.

Jones, B. D., & Paretti, M. C., Hein, S. F., & Knott, T. W. (2010). An analysis of motivation constructs with first-year engineering students: Relationships among expectancies, values, achievement, and career plans. *Journal of Engineering Education*, *99*, 319-336.

Kellam, N., Maher, M., Russell, J., Addison, V., & Peters, W. (2007). Benchmarking the integration of complex systems study in mechanical engineering programs in the southeastern United States. *International Journal of Mechanical Engineering Education*, *35*, 256-270.

Kriewall, T. J., & Mekemson, K. (2010). Instilling the entrepreneurial mindset into engineering undergraduates. *Journal of Engineering Entrepreneurship*, *1*, 5-19.

Litchfield, K., & Javernick-Will, A. (2015). "I am an engineer AND": A mixed methods study of socially engaged engineers. *Journal of Engineering Education*, *104*, 393-416.

Marra, R. M., Rodgers, K. A., Shen, D., & Bogue, B. (2012). Leaving engineering: A multi-year single institution study. *Journal of Engineering Education*, *101*(1), 6-27.

Matusovich, H. M., Streveler, R. A., & Miller, R. L. (2010). Why do students choose engineering? A qualitative, longitudinal investigation of students' motivational values. *Journal of Engineering Education*, *99*, 289-303.

Parette, P., & Scherer, M. (2004). Assistive technology use and stigma. *Education and Training in Development Disabilities*, *39*, 217-226.

Razzouk, R., & Shute, V. J. (2012). What is design thinking and why is it important? *Review of Educational Research*, *82*(3), 330-348.

Ryan, R. M., & Deci, E. L. (2017). *Self-Determination Theory: Basic psychological needs in motivation, development and wellness*. New York, NY: Guilford Press.

Sakakibara, B. M., Miller, W. C., Routhier, F., Backman, C. L., & Eng, J. J. (2014). Association between self-efficacy and participation in community-dwelling manual wheelchair users aged 50 years or old. *Physical Therapy*, *94*(5), 664-674.

Shuman, L. J., Besterfield-Sacre, M., & McGourty, J. (2005). The ABET "Professional Skills"—Can they be taught? Can they be assessed? *Journal of Engineering Education*, *94*, 41-55.

Simonsen, J., & Robertson, T. (Eds.) (2012). *Routledge international handbook of participatory design*. New York: NY: Routledge.

Strauss, A., & Corbin, J. (1994). Grounded theory methodology. *Handbook of Qualitative Research*, *17*, 273-285.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. New York, NY: Springer.

Yu, T-K., Lin, M-L, & Liao, Y-K (2017). Understanding factors influencing information communication technology adoption behavior: The moderators of information literacy and digital skills. *Computers in Human Behavior*, *71*, 196-208.

Zoltowski, C. B., Oakes, W. C., & Cardella, M. E. (2012). Students' ways of experiencing human-centered design. *Journal of Engineering Education*, *101*, 28-59.