Bridging Psychology and Engineering: Undergraduate Conceptions of Human Systems Engineering

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Instruction and coursework that link engineering and psychology may enable future engineers to better understand the people they are engineering *for* (e.g., users and clients) and themselves *as* engineers (e.g., teammates). In addition, human-centered engineering education may empower engineering students to better solve problems at the intersection of technology and people. In this study, we surveyed students' conceptions and attitudes toward human systems engineering. We aggregate responses across three survey iterations to discuss students' knowledge and beliefs, and to consider instructional opportunities for introductory courses.

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Introduction

ABET student outcomes include the "ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability" (ABET, 2017). These goals are fundamental to *human-centered engineering* (Feland et al., 2004; Hynes & Swenson, 2013; Oehlberg et al., 2012; Zoltowski et al., 2012). Engineering preparation that emphasizes math, science, and technical design can support proficiency in building functional systems (Feland et al., 2004), but well-rounded engineers area also empathic (Hess et al., 2016; 2017), humanitarian (Bielefeldt & Canney, 2016; Muñoz & Mitcham, 2012; Smith et al., 2019), and socially-engaged (Litchfield & Javernick-Will, 2015, 2017).

Instruction that links engineering and psychology—how people think, feel, and behave—may enable engineering students to better understand the people they are engineering *for* (e.g., users and clients) and themselves *as* engineers (e.g., teammates and entrepreneurs). Human-centered engineering education may also empower students to solve problems at the intersection of technology and people (Roscoe et al., 2018, 2019a, 2019b), including many of the National Academy of Engineering Grand Challenges (NAE, 2017).

To support this goal, Arizona State University offers degrees in human systems engineering (HSE) that bridge psychology and engineering (Roscoe et al., 2019). HSE courses incorporate psychology, cognitive science, human systems integration, human factors, and user-centered design in engineering work. Students who choose HSE as their field of study typically seek careers in human factors and user experience. HSE is also available as a secondary field to students pursuing degrees in engineering. Importantly, all engineering undergraduates have access to *HSE 101: Introduction to Human Systems Engineering* to fulfill a "social-behavioral" requirement. Such courses address "methods of inquiry and empirical knowledge about human behavior, within society and individually" related to "cultural, economic, geographic, historical, linguistic, political, psychological or social" topics. Engineering students have historically met this requirement via *PSY 101: Introduction to Psychology*, but that course is not aligned to engineering. In contrast, the relevance of HSE 101 is evidenced by the course description:

> Introduces basic principles, methods, and theories of psychology, and applications to engineering programs relevant to human systems. Gives particular attention to the intersection of psychology and engineering. Students learn brain anatomy and physiology, sensation and perception, cognition, social systems, and research methods so that they are able to design systems consistent with human capabilities and limitations.

A core purpose (and design challenge) for HSE 101 is to leverage engineering students' interests and prepare them to consider human concerns. To inform HSE 101 curricula, we surveyed students' conceptions of HSE and attitudes toward psychology, engineering, course topics, and skills. In this paper, we aggregate responses across three survey iterations to discuss students' HSE knowledge and beliefs. Findings can suggest instructional opportunities for HSE 101 and similar courses.

Method

Survey

The Human Systems Engineering Attitudes Survey (HSEAS) was informed by prior engineering education instruments (Besterfield-Sacre et al., 1997a, 1997b; Hilpert et al., 2008, 2010; Olson et al., 2013). The survey was developed and deployed over three iterations with varying questions.

This paper presents findings for select items that were shared across all versions. One focus was three open-ended questions on the nature of HSE, relevant methods, and values:

- In your own words, describe the field of human systems engineering. What does "human systems engineering" mean to you?
- How would a skilled engineer use human systems engineering to improve the quality of their designs? What are some of the methods or techniques they might use?
- In your opinion, is learning about human systems engineering useful to engineering students? Why do you feel this way?

The HSEAS also included items on engineering (e.g., "I understand what engineers do" and "engineering contributes to improving society") and psychology (e.g., "I understand what psychologists do" and "psychology contributes to improving society"). A few items linked engineering and psychology (e.g., "engineers benefit from learning about psychology" and "psychologists benefit from learning about engineering"). Participants responded using a 10-point scale from "1" (Strongly Disagree) to "10" (Strongly Agree).

Participants

In Fall 2017, participants were recruited from HSE 101 and completed the survey via paper-and-pencil (n = 44). In Spring 2018, participants were recruited from HSE 101 (n = 27) and *EGR 101: Foundations of Engineering Design* courses (n = 48), primarily via paper-and-pencil. In Fall 2018, participants were recruited from a general university 101 course as we tested an online survey (n = 38). Across all three administrations, 157 undergraduate students provided usable responses.

On average, participants were 20.9 years old (SD = 3.9), with 24.8% self-identifying as female, 74.5% as male, and 0.6% providing no response. Participants primarily self-identified as Caucasian (49.7%) or Hispanic (19.7%), although the sample included African (0.6%), African-American (3.2%), Asian (10.2%), Middle Eastern (7.0%), Native American (1.3%), and Multiracial (8.3%) individuals. Most participants spoke and wrote only English (63.7%) but 36.3% spoke and wrote English and at least one other language. Most students classified as freshmen (61.8%), but the sample included sophomores (14.6%), juniors (14.0%), and seniors (9.6%). A mix of majors were reported, including engineering fields (e.g., electrical and manufacturing) (49.0%), computing and IT (17.2%), flight and/or air traffic control (13.4%), HSE or psychology (8.9%), business (5.7%), and other (5.7%).

Open-Ended Responses

Open-ended questions invited students to *define HSE*, describe *HSE methods*, and discuss the *value of HSE* for engineering. We identified codeable concepts using deductive and inductive approaches. Based on program descriptors (Roscoe et al., 2019), core themes were specified (e.g., “multidisciplinary” and “experimental”). Participants’ responses were then reviewed to refine the categories. This process generated operational definitions and examples to guide the coding process (Table 1).

Concepts could appear in answer to *any* of the three questions. For instance, although one question focused on “methods,” participants might also describe a value. Thus, responses to all questions were pooled—participants could receive credit for a concept wherever it occurred. Concepts were coded as “present” or “absent.” Two raters independently coded a subset of answers with good reliability (i.e., kappas from .64 to .87). A single rater coded the remaining responses.

Analyses

We grouped participants with respect to their reported engineering background and exposure to HSE: *non-engineers with no HSE courses* (n = 12), *engineers with no HSE courses* (n = 63), *non-engineers with one or more HSE courses* (n = 26), *engineers with one or more HSE courses* (n = 46), and *HSE majors* (n = 10). Except for majors, most participants’ exposure to HSE was *only* HSE 101. These informal groups were compared with respect to attitude ratings and concepts expressed in open-ended responses. Our focus was to identify qualitative patterns. Statistical tests (e.g., ANOVA and chi-square) were cautiously conducted only to further explore patterns. Due to unbalanced sample sizes and variances, these tests were not intended to inform strong inferences.

Table 1. Coded Concepts and Example Responses

Definition of HSE	**Brief Operational Definition**
Human-centered	HSE focuses on human needs, goals, abilities, and limitations. Includes “users,” “clients,” “engineers,” and “designers”
“…the study of human behavior, limitations, and abilities to create safer, efficient, cost-effective products while also putting and emphasis on the experience of all users”	
Engineering-focused	HSE interacts with engineering and design, such as improving engineering of devices, products, or other technologies
“…any engineering that is designed for human direct use or aid such as like analyzing health or something and using engineering to improve it”	
Applied Social Science	HSE involves the study and application of concepts from psychology, sociology, anthropology and related social sciences
“…the psychology behind engineering. Why people do things the way they do and how engineering needs to take that into account”	
Research-based	HSE is empirical and uses research, data, methods, and scientific practices to understand issues and solve problems
“…for researchers who would like to discover the requirement from human being which make provide scientists original issue to think about how to solve.”	
Multidisciplinary	HSE is the blending or combination of two or more fields of study, either separate disciplines or subfields within a discipline
“…a blend of Cognitive Psychology and Engineering, and probably includes Artificial Intelligence and Robotics”	
Methods of HSE	**Operational Definition**
Qualitative Methods	HSE elicits responses from people (e.g., users, and clients) by probing their knowledge and attitudes, or by observing their actions and interactions
“Matching it to maybe what humans who are going to use it want. Talking with the community or maybe doing a survey”	
Experimental Methods	HSE uses experimental methods in which groups are compared across manipulated variables and tasks (e.g., control groups)
“…to conduct experiments… and test the limitations of the human mind and body and how to fix or improve on them”	

Table 1, Continued

Methods of HSE	Operational Definition
Design Methods	HSE uses prototyping and design methods in which researchers develop and evaluate systems with or without end-user input
"…prototyping, testing, cognitive walkthroughs etc."	
Data Analysis Methods	HSE uses valid techniques for analyzing and visualizing data, including qualitative, quantitative, and statistical methods
"…using qualitative and quantitative information about humans' physical structure and psychological responses/thought process."	
Value of HSE	**Operational Definitions**
User Experience	HSE improves users' or clients' subjective feelings or satisfaction toward a task, product, or system (e.g., enjoyment)
"…good to understand how others think and what they enjoy doing to be able to create something enjoyable for everyone"	
Productivity	HSE improves, streamlines, or otherwise makes a system or process operate more effectively; improves human performance
"…a product that is not only advanced and efficient for its use but also has a high success rate because of the ease of operation"	
Understanding	HSE improves understanding or insight related to an issue, such as understanding human needs and design principles
"a design can only be useful if the human's cognitive and bodily capacities are understood, recognized, and accounted for"	
Safety and Ergonomics	HSE improves the safety or comfort of a task or device, or reduces risk in task performance or related processes
"as a pilot and aviator HSE is very important to us because we have not just our lives at stake but hundreds of others"	

Results

Psychology and Engineering Attitudes

Participants reported a good understanding of engineering and the belief that engineering solves real-world problems to improve society (Table 2). There were minimal subgroup differences. Psychology attitudes were slightly less positive, which may reflect a perception that engineering outcomes (e.g., new devices) are more tangible or salient than psychology outcomes (e.g., measuring behaviors). Engineering majors reported lower knowledge of psychology.

Participants were weakly positive toward engineers and psychologists learning about their respective fields. With respect to bridging psychology and engineering, participants seemed open-minded but unsure. Unsurprisingly, HSE majors most strongly endorsed cross-disciplinary learning. These students' experiences in HSE may have inspired their appreciation, and/or students may be attracted to the HSE program *because* of the opportunity to link multiple fields.

Conceptions of Human Systems Engineering

Participants' open-ended responses (Table 3) suggested that they lacked rich knowledge of the nature, methods, or values of HSE. However, HSE 101 helped to introduce basic concepts.

Definition. Many participants recognized that HSE is "human-centered engineering," but that definition could be inferred from the program name itself. However, trends suggested that engineering students who participated in HSE 101 were more likely to articulate this basic definition than engineering students without HSE 101. HSE coursework was also associated with describing "applied social science." Only 25% to 33% of participants defined HSE as "research-based," and few students characterized it as "multidisciplinary. Again, HSE 101 seemed to help participants conceptualize the field.

Methods. Methodology represented a clear gap in participants' HSE conceptions. Few participants described HSE in terms of "experiments," "design," or "analysis." Participants were somewhat more likely to recognize that HSE employs "qualitative" methods such as interviews and observation, but overall these concepts were still infrequent. In sum, many students did not associate HSE with clear procedures for enacting human-centered engineering.

Value. Participants described several ways in which HSE is worthwhile (e.g., improved user experience, productivity, or understanding). Students who participated HSE 101 seemed more likely to articulate a positive impact of HSE than students with no HSE coursework. Very few students recognized that HSE contributes to improved safety and ergonomics, but these topics may be somewhat specialized to advanced courses.

Conceptual Knowledge. We did not expect all participants to express every concept. However, participants who articulated more total concepts had arguably stronger conceptions. We thus calculated "scores" by summing the number of concepts articulated within each dimension (i.e., up to 5 points for definitions, 4 points for methods, and 4 points for values). Participants with HSE coursework (primarily HSE 101) overall expressed more definition concepts (2-3 concepts) than participants with no HSE coursework (1-2 concepts), $F(4,152) = 6.12$, $p < .001$. Participants with HSE courses also expressed more values (1-2 concepts) than participants without (0-1 concepts), $F(4,152) = 4.44$, $p = .002$ Methods concepts were infrequent and did not differ across groups, $F(4,152) = 1.80$, $p = .131$. Overall, HSE 101 appeared to help students begin to understand HSE and human-centered engineering.

Discussion

Human-centered engineering education prepares students to be more empathic, humanitarian, and social-engaged engineers, and human systems engineering (HSE) seeks to contribute to this mission by fusing psychology and engineering. To examine students' existing conceptions of human systems engineering (HSE), and attitudes toward bridging psychology and engineering, a survey was iteratively developed and administered over three time periods with a variety of students.

Table 2. Mean (and Standard Deviation) Ratings of General Attitudes toward Psychology and Engineering

	No HSE Courses		One or More HSE Courses				
Attitudes	**Non-Engr** (n = 12)	**Engr** (n = 63)	**Non-Engr** (n = 26)	**Engr** (n = 46)	**HSE** (n = 10)	F	p
About Engineering							
… understand what engineering is	8.0 (2.4)	8.6 (1.5)	8.2 (1.8)	8.7 (1.6)	8.4 (1.8)	< 1.00	.563
… understand what engineers do	8.5 (2.5)	8.5 (1.6)	7.8 (1.6)	8.6 (1.7)	7.5 (2.5)	1.55	.191
… solves real-world problems	9.4 (1.1)	9.5 (0.9)	9.2 (1.2)	9.4 (1.1)	8.8 (1.3)	1.11	.354
… improves society	9.0 (1.5)	9.2 (1.3)	9.2 (1.2)	9.2 (1.4)	8.9 (0.9)	< 1.00	.958
About Psychology							
… understand what psychology is	8.5 (2.0)	7.5 (2.1)	8.2 (1.8)	7.3 (1.8)	8.8 (1.7)	2.63	.037
… understand what psychologists do	8.3 (1.9)	7.0 (2.1)	8.2 (1.8)	7.1 (1.9)	9.1 (1.1)	4.36	.002
… solves real-world problems	6.7 (2.3)	8.6 (2.0)	8.0 (1.9)	7.7 (2.0)	8.8 (1.4)	3.25	.014
… improves society	8.2 (1.7)	8.0 (2.2)	8.6 (1.7)	8.1 (1.8)	8.8 (0.9)	< 1.00	.496
Bridging Psychology and Engineering							
… engineers benefit from psychology	6.8 (2.3)	7.0 (2.4)	6.7 (2.2)	7.6 (1.9)	9.6 (0.5)	3.94	.004
… psychologists benefit from engineering	6.1 (2.4)	6.1 (2.8)	6.2 (2.4)	6.8 (2.3)	8.5 (2.2)	2.15	.078

Note. The abbreviation "Non-Engr" refers to "non-engineering" students whose primary field of study was not an engineering discipline or HSE. "Engr" refers to engineering students.

Table 3. Percentage of Participant Responses that Included HSE Concepts

	No HSE Courses		One or More HSE Courses				
Characteristic	**Non-Engr** (n = 12)	**Engr** (n = 63)	**Non-Engr** (n = 26)	**Engr** (n = 46)	**HSE** (n = 10)	$X^2(4)$	p
Definition of HSE							
human-centered	50.0	57.1	53.8	71.7	70.0	4.14	.388
engineering	58.3	69.8	69.2	82.6	80.0	4.24	.375
social science	16.7	23.8	73.1	71.7	60.0	37.01	< .001
research-based	33.3	20.6	26.9	34.8	50.0	5.22	.265
multidisciplinary	8.3	7.9	23.1	28.3	20.0	9.10	.059
Methods of HSE							
qualitative	16.7	12.7	26.9	26.1	10.0	4.73	.316
experimental	0.0	1.6	7.7	4.3	0.0	3.16	.531
design	0.0	3.2	3.8	4.3	10.0	1.62	.805
analysis	0.0	1.6	0.0	6.5	0.0	4.42	.353
Value of HSE							
user experience	16.7	14.3	23.1	26.1	50.0	7.49	.112
productivity	8.3	33.3	42.3	37.0	60.0	7.17	.127
understanding	33.3	17.5	50.0	30.4	50.0	11.65	.020
safety/ergonomics	0.0	6.3	3.8	4.3	20.0	4.88	.300

Note. The abbreviation "Non-Engr" refers to "non-engineering" students whose primary field of study was not an engineering discipline or HSE. "Engr" refers to engineering students.

One limitation is that questions were framed in terms of "human systems engineering," which may be less familiar than "human factors" or related fields. More recent studies have included synonymous terms to further elicit students' conceptions. Current findings also represent a single survey administration per participant, which does not enable exploration of attitude change after completing an HSE 101 course. Recent studies have thus implemented a quasi-longitudinal format in which participants complete the survey at the beginning and end of the course. The sample size was also modest and our informally-defined subgroups were unbalanced. Future work could employ stratified sampling to recruit more diverse participants.

Despite limitations, findings suggest that undergraduates had (a) only superficial understanding of human-centered engineering and its value, and (b) very little knowledge of relevant methodologies. However, *introductory coursework in HSE—particularly a freshman-level 101 course—seemed to be a promising entry point for human-centered engineering*. Students who were exposed to HSE coursework appeared to possess a better understanding of the field. We also observed that *students were receptive to the bridging of psychology and engineering*. Attitudes toward the two fields and their combination were positive.

Several recommendations emerge for the design of "HSE 101" and courses with similar aims. These courses must introduce the "what" of human-centered engineering (e.g., terminology and goals). However, it may be crucial to tightly integrate and emphasize the "how" (e.g., methods and practices) and "why" (e.g., outcomes and contributions). That is, *students should learn that a mix of qualitative, experimental, design, and analytical methods is essential for attaining human-centered engineering outcomes* (e.g., improved performance and user experience). For example, when students are introduced to "human-centered" engineering, instruction might discuss how interviews and walkthroughs enable deeper empathizing with users. Likewise, when creating enjoyable products that can be operated without error, the curriculum might stress the roles of collecting and analyzing data using valid and reliable procedures. These methods and outcomes will be strengthened by connections to psychology principles that explain user, client, and team behaviors.

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