Paper ID #36371

First Year Engineering Student Definitions of Systems Engineering: A Comparison Between Two Institutions

Mrs. Katrina L Carlson, Michigan Technological University

Katrina Carlson is currently working with a team of researchers at Michigan Technological University as a PhD student in Applied Cognitive Sciences and Human Factors.

Dr. Akua B. Oppong-Anane, Montana Technological University

Akua Oppong-Anane is an Assistant Professor of Freshman Engineering at Montana Technological University. She holds a bachelor's degree in Chemical Engineering, a master's degree in Chemistry and a doctoral degree in Environmental Engineering Sciences. Her research areas are in groundwater contamination at landfill sites, advising and retention of first year engineering students.

Dr. Michelle E Jarvie-Eggart P.E., Michigan Technological University

Dr. Jarvie-Eggart is a registered professional engineer with over a decade of experience as an environmental engineer. She is an Assistant Professor in the Engineering Fundamentals department at Michigan Technological University. Her research interests include online learning, CS/programming education, and service learning.

Miss Amanda Marie Singer, Michigan Technological University

Amanda Singer is a PhD student in the Department of Engineering Education at the Ohio State University. Prior to attending OSU, she received a B.S. and M.S. in Environmental Engineering from Michigan Technological University. Her current research interests include understanding engineering identity and motivation in first-generation college students, online learning pedagogy, and service learning projects.

First Year Engineering Student Definitions of Systems Engineering: A Comparison Between Two Institutions

Abstract

This full research paper builds on previous work investigating first-year engineering (FYE) students' understanding of Systems Engineering and suggests methods to increase students' knowledge of the major. Systems Engineering has recently been acknowledged as a discipline in its own right by the Accreditation Board for Engineering and Technology (ABET), which began accrediting Systems Engineering programs during the 2017-2018 school year. In 2021, ABET approved and accepted an updated Systems Engineering Program Criteria, cooperatively revised with INCOSE (International Council on Systems Engineering). This study seeks to understand how first year engineering students define Systems Engineering and whether their understanding of the discipline is influenced by the availability of a Systems Engineering program at their university. To accomplish this, a survey asking students to define Systems Engineering was administered to students at two universities, Michigan Technological University (Michigan Tech) and Montana Technological University (Montana Tech). Systems Engineering is not available at Montana Tech, and it is currently offered as a minor and pathway of study under the Bachelor of Science in Engineering (BSE) degree at Michigan Tech. Student responses to this open-ended survey question were analyzed using deductive and inductive coding techniques to identify common terms and emergent themes. When viewing the collective results, student definitions of Systems Engineering most commonly referenced the following terms and themes: systems, modeling and design, project and systems management, and Systems Engineering applications.

Background

Due to its relative newness as an ABET [1] accredited discipline, engineering students across the country may not be as aware of Systems Engineering. In fact, the literature shows a general lack of student understanding of engineering, and student knowledge of Systems Engineering is likely lower. FYE students' perceptions have been shown to be low for engineering knowledge and skill base, along with engineering application and ability. Their perception is high for professionalism and personal attributes of engineers, but there is a demonstrated lack of awareness about the technical skills and knowledge required of all engineers in general [2]. Studies of middle school and high school students found that most students, even teachers, at the K-12 level could not describe the work of an engineer accurately without experiences and instruction aimed at increasing knowledge and understanding [3, 4]. The lack of awareness of engineering in general indicates that students may not have good mental models of specific disciplines before they enter college. This may be especially true for Systems Engineering, due to its comparative infancy in the ABET accreditation realm.

Students' Definitions of Engineering

Although little work has addressed students' understanding of Systems Engineering programs, there have been studies which address students' definitions of engineering in general. Arbrow et al. [5] studied a new course developed to provide students with an understanding of the cross-disciplinary aspects of modern engineering work, finding that open-ended projects helped students to form better mental models of each engineering discipline. Students are not likely to choose a major without a mental model and a clear picture of possible job opportunities.

Open-ended projects, accompanied by mentoring from professors and other students who have completed a major, appear to be proven methods to help FYE students choose a major [6]. Thus, it is recommended that universities with Systems Engineering programs leverage their faculty and alumni as mentors and speakers about Systems Engineering.

In a study of FYE students by Mena, et. al, [7] student responses to the definition of engineering, among other research questions, were compared to definitions from The Engineer of 2020 report: Visions of Engineering for the Next Century attributes [8]. These students defined engineering as improving the world, using math, science, and technology, and solving problems with the application of knowledge, whereas the Engineer of 2020 report defines an engineer as a good communicator who is creative and ethical with the skills to work in global and multidisciplinary teams. It goes on to discuss creativity as invention, innovation, and thinking outside the box. While communication skills to work in teams is paramount in importance, the report also mentions the need to master the principles of business and management, along with the principles of leadership. Because of rapid changes in technology and the global market the Engineer of 2020 will require dynamism, agility, resilience, and flexibility. And lastly, the Engineer of today and tomorrow must commit to being a lifelong learner to adjust to changes, not only in technology but also in the changing ways that Engineers will collaborate with other disciplines across the globe while working on new challenges.

Meadows, et al. [9] found that FYE projects that were designed by both engineering faculty (designed the project) and technical communication faculty (designed the "deliverables' to industry) increased interest and investment of faculty. The authors found the excitement and interest of faculty to be a factor in student satisfaction with the class and student retention in the program overall. Students at the university studied are able to choose a FYE section based on the type of project that is the focus of the class, such as an environmental focus, system design, alternative energy, humanitarian design, engineering and the arts, and entrepreneurship, and it was found that students were very motivated in the class with the focus they chose. The authors report that 81% of the students had a better understanding of what an engineer does as a result of taking the class, according to the end of semester survey. As FYE students become more knowledgeable about engineering, all of the various branches and disciplines of engineering, and the skills necessary to be successful, they will be better able to match their interests and skills to the area that is a best fit for them. A best fit for the student increases the chances of a graduating engineering student who is prepared for the demands of the discipline and the workforce in today's ever-changing societies.

Definitions of Systems Engineering

The INCOSE definition of Systems Engineering is "a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods" [10]. According to Michigan Tech's Systems Engineering program description, "Systems engineers apply low-fidelity modeling to understand, design, and manage complex systems over their life cycles. As management leaders, systems engineers utilize systems thinking and interdisciplinary skills from across all areas of engineering and management" [11]. The definition and description of Systems Engineering is complicated, multifaceted, and abstract. The systems referred to in the definition vary across settings and purposes. In fact, a paper by Keating et al. [12] identified 16 different representative definitions of Systems Engineering.

Although studies have been conducted to examine FYE students' perceptions of engineering disciplines and majors [2, 5], little work has been done on student perceptions of Systems Engineering. Previous work by Singer & Jarvie-Eggart (2020) examined FYE student definitions of engineering at Michigan Tech [16]. Student survey responses indicated an understanding of the importance of designing diverse systems, as well as systems management. However, none of the students surveyed indicated an understanding of the "retirement" of system components or life cycle concept, which is a key component discussed in definitions of Systems Engineering. The existence of the Systems Engineering focus and minor at Michigan Tech may have influenced the results. Thus, the current study compares student definitions of Systems Engineering from Michigan Tech, which has a Systems Engineering focus and minor, with Montana Tech, which does not offer Systems Engineering either as a major or minor.

Results presented in this paper were part of a larger survey of the participants. FYE students were asked about their major choice, factors influencing it, and their understanding of the definitions of various engineering majors. As Systems Engineering is a relatively new discipline that is not as widely offered as other engineering majors, we wondered whether FYE students could accurately describe the discipline. This paper specifically focuses on the questions of: How do FYE students define Systems Engineering? Are students' understanding of Systems Engineering influenced by the presence of a Systems Engineering program at their university?

Methods

Positionality

We acknowledge the impact that our individual perspectives and experiences may have on the design, data collection, analysis, and interpretation of results [13]. Thus, we provide information on our own unique positionalities. Katrina Carlson is a PhD student in the Cognitive and Learning Sciences Department at Michigan Tech who joined the project after data collection to help with the data analysis and interpretation phases. Amanda Singer was a teaching assistant in the First-year engineering program at Michigan Tech during this study's development and data collection. Akua Oppong-Anane is an associate teaching professor and academic advisor within the first-year engineering program at Montana Tech, who also taught the FYE courses that students were surveyed from. Michelle Jarvie-Eggart is an assistant professor within the Department of Engineering Fundamentals at Michigan Tech, who taught two offerings of the FYE courses that students were surveyed from.

Study Context and Participants

Participants in this study included students enrolled in introductory FYE classes at Michigan Tech and Montana Tech during the fall 2020 semester. At each of these universities, students enrolled in their first year of engineering study are required to complete a common set of core classes, which include an introductory engineering course. These introductory engineering courses are designed to develop foundational engineering skills and promote student exploration of the various engineering majors available at each university. At Michigan Tech, Systems Engineering became a possible pathway of study for students under the Bachelor of Science in

Engineering (BSE) degree in 2017 and as a degree minor in 2019 [11]. The BSE Systems Engineering focus “emphasizes (a) systems thinking (b) low fidelity systems modeling, and developing competencies in (c) communication, (d) problem solving in a collaborative team, (e) professional leadership, and (f) a selection of courses to fulfill college and university requirements that cover a system” [14, pg. 1]. Systems Engineering is not currently offered as a major or minor at Montana Tech.

An extra credit survey was offered to 216 students (91 from Michigan Tech and 125 from Montana Tech; with 94 students completing the survey with informed consent (43.5% completion rate). Respondents at both universities were composed of majority male populations. Among the 58 respondents at Michigan Tech, 39 (67.2%) identified as male, 18 identified as female (31.0%), and 1 (1.8%) refrained from reporting their gender. Within Montana Tech respondents, 26 (72.2%) identified as male, 10 students (28.8%) identified as female. At both Universities, no other gender identities except those discussed above were reported. The respondent populations were even less diverse when it came to race/ethnic backgrounds.The Michigan Tech population identified as 91.4% white, 3.4% Asian/Pacific Islander, and 1.7% Hispanic/Latino students. Student respondents from Montana Tech identified only as white.

Data Collection and Analysis

To investigate the identified research questions, student participants were asked to provide their definition of Systems Engineering through an open-ended, short answer survey question. Student responses to this prompt were collected as a part of a larger study investigating student knowledge of the different engineering majors. Student definitions collected as a part of this study were coded for common themes by multiple researchers using deductive and inductive coding techniques [15]. Initial codes were developed based on prior work conducted by the authors [16] and the INCOSE definition of Systems Engineering [10]. During the coding process, new codes were identified and developed as necessary. After each coding cycle, researchers met to discuss and resolve coding differences, adjusting code definitions as necessary.

Limitations

The results of this study reflect those of two midwestern rural populations that are predominantly white and male. Additionally, students had access to the internet while completing these surveys and may have searched for the term “Systems Engineering.” Future work should consider methods for reducing or preventing student internet searches, and expand the diversity of participant populations.

Results & Discussion

Results obtained from the inductive and deductive coding cycles are summarized in Table 1. Overall, the most prevalent concepts reported within student definitions included the following: systems, modeling and design, applications, and project management / systems operation. At Michigan Tech, which possesses the Systems Engineering focus and minor, the five most commonly mentioned concepts were those of systems, followed by modeling & design, then areas where Systems Engineering might be applied (computers, software, hardware, electrical, electricity, assembly lines), project/operations/systems management skills, and finally efficiency & improvement. In contrast, at Montana Tech, where there is no Systems Engineering offering, the five most commonly mentioned concepts included areas where Systems Engineering might be applied, followed by students indicating they had no idea what systems engineering was, then Systems, modeling & design, and finally complex systems. The presence of a Systems Engineering program seems to affect students' ability to define Systems Engineering. Overall, 10.3% of the respondents from Michigan Tech and 33.3% from Montana Tech did not provide a definition for Systems Engineering. When asked to explain Systems Engineering, the responses of students at a university without a Systems Engineering offering most often addressed areas where Systems Engineering might be applied. These students could more readily identify where systems engineers might be needed than the work they perform. In contrast, students at the university with a Systems Engineering minor, were better able to identify the work of a systems engineer (modeling & design, efficiency & improvement).

Although complex systems only appeared in the top 5 responses of students at Montana Tech, there was only a 1.2% difference in the responses of the students at the two universities with regards to this concept. Complex systems or products, like cars, require engineers from many disciplines to design the parts of the car, with the Systems engineer putting it all together to produce a final product that is marketable and profitable [17]. Complex systems are different from systems of systems (SoS). Comparatively, SoS is "the design, deployment, operation, and transformation of metasystems that must function as an integrated complex system to produce desirable results" [12, p. 41]. SoS is about finding solutions that work in extremely complicated scenarios versus finding the optimum and most efficient solution, which is a focus of systems engineers. It should be noted that the responses of students at neither university indicated an awareness of SoS. Consistent with prior work [16], none of the students from either university cited the life cycle or "retirement" of components of the System.

Table 1. Systems Engineering Coding Results

Code	Code Description	Michigan Tech	Montana Tech	Total	Example Student Quotes
S	Systems	46.6%	27.8%	39.4%	"Working to improve whatever systems they are working with."
CD	Modeling & Design	44.9%	19.5%	33.3%	"Design and prototype computing systems."
M	Project/operations/systems management skills	17.3%	41.7%	25.9%	"Someone who acts as an overseer to a project."
A	Applications: Computers/ software/ hardware/ electrical/ assembly lines	27.6%	13.9%	21.2%	"Works with electrical to create efficient systems. More related to computer engineering."
N	No Idea	10.3%	33.3%	18.7%	"...honestly, I still feel that I don't know enough about Systems Engineering."
CS	Complex Systems	15.5%	16.7%	16.0%	"Systems engineers help make sure anything that requires a complex system won't break and runs the way it should."

E	Efficiency & Improvement	20.7%	5.6%	14.0%	"Designing a process to make things make things better"
W	Work Across Disciplines	15.5%	8.3%	12.8%	"Systems engineers oversee all aspects of a project or system in a variety of fields, such as software, transportation, product development and manufacturing."
PS	Problem Solve	8.6%	2.8%	6.0%	"They solve problems in a production system."

Student responses were compared to descriptors of Systems Engineering within the INCOSE definition, including the terms/concepts of: transdisciplinarity; life cycles of engineered systems; and usage of scientific, technological, and management methods [10]. Just over half of the student respondents at Montana Tech provided definitions which included no INCOSE descriptors of Systems Engineering, compared to about a quarter of students at Michigan Tech. The majority of students at Michigan Tech provided one or more INCOSE descriptor of Systems Engineering. Thus, the presence of a Systems Engineering focus and minor seemed to indicate a better understanding of Systems Engineering as defined by INCOSE. However, this may only be a surface level understanding, as students at Michigan Tech were primarily capable of providing only one or two INCOSE descriptors (65.5% of respondents.)

Table 2: Presence of INCOSE Descriptors in Student Responses

University	None/blank	1-2	3+
Michigan Tech (n=58)	14 (24%)	38 (65.5%)	6 (10.3%)
Montana Tech (n=36)	18 (51.4%)	13 (37%)	4 (11.4%)

Conclusions

Systems Engineering is a relatively new accredited option within engineering programs. Students at Michigan Tech seem to possess a better understanding of Systems Engineering, but their depth of knowledge may be superficial. It may simply be that they are more likely to have heard of the discipline. Results of this study may help emerging Systems Engineering programs understand points of confusion about the discipline and better guide the development of educational materials and dissemination of information about their major. Students at both universities lacked an expressed awareness of SoS, as well as life cycle considerations, or end of life considerations for components of the system. Efforts to promote the discipline among students should focus on providing a deeper understanding of the discipline. Additionally, aspects of engineering such as the impacts on society, career opportunities, along with the need for strong communication and creativity skills, have been shown to be important to students entering the field of engineering [18].

References

[1] Accreditation Board for Engineering and Technology. 2020. *Criteria For Accrediting Engineering Programs, 2017 – 2018 | ABET*. [online] Available at: <https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2017-2018/> [Accessed 6 May 2020].

[2] Bennett, D., Kapoor, K., Rajinder, K., & Maynard, N. (2015) "First Year Engineering students: Perceptions of Engineers, Engineering Work Amongst Domestic and International Students." *The International Journal of the First Year in Higher Education.* ISSN: 1838-2959, vol. 6, Issue 1, pp. 89-105.

[3] Compeau, S. "The Calling of an Engineer: High School Students' Perceptions of Engineering," thesis, A thesis submitted to the Department of Mechanical Engineering. Queen's University Kingston, Ontario, Canada, 2015.

[4] English, L., Dawes, L., & Hudson, P. (2011) "Middle school students' perceptions of engineering" In Lee, K T, King, D, Hudson, P, & Chandra, V (Eds.) Proceedings of the 1st International Conference of STEM in Education 2010. Science, Technology, Engineering and Mathematics in Education, Queensland University of Technology, Australia, pp. 1-11.

[5] Arbrow, B., Louie, B., Knight, D., Canny, N., Brown, S. (2011). Introduction to Engineering: Preparing First Year Students for an Informed Major Choice. ASEE Annual Conference, Vancouver, BC, Canada, June 26-29, 2011.

[6] VanDeGrift, T. & Liao, S. (2017) Helping First Year Engineering Students Select a Major. ASEE Annual Conference, Columbus, OH, June 24-28, 2017. Paper ID 18109.

[7] Mena, I., Zappe, S. Litzinger, T.A. (2013). Examining the Experiences and Perceptions of First-Year Engineering Students. 120th ASEE Annual Conference & Exposition.

[8] Attributes of Engineers in 2020: Ch. 4 of *The Engineer of 2020*. Washington, D.C.: National Academies Press, 2004. doi: 10.17226/10999. [Accessed May 2022].

[9] Meadows, L., Fowler, R. Hildinger, E. (2012). Empowering Students with Choice in the First Year. ASEE Annual Conference, San Antonio, TX, June 10-13, 2012.

[10] International Council on Systems Engineering, "Systems Engineering Definition," *Systems Engineering*.https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition [Accessed May, 2022].

[11] Engineering Fundamentals, Bachelor of Science in Engineering, Advising, BSE Advising | Engineering Fundamentals | Michigan Tech (mtu.edu), [Accessed May, 2022].

[12] Keating, C., Rogers, R., Unal, R., Dryer, D., Souza-Poza, R.S., Peterson, W., and Rabadi, G. (2003). *System of Systems Engineering. Engineering Management Journal*, 15(3), 36-45.

[13] J. Walther, N. W. Sochacka, and N. N. Kellam, "Quality in Interpretive Engineering Education Research: Reflections on an Example Study," *Journal of Engineering Education*, vol. 102, no. 4, pp. 626–659, Oct. 2013, doi: 10.1002/jee.20029.

[14] Sticklen, J. & Green, N. (2021). Establishing a Non-traditional Systems Engineering Program in *2021 ASEE Annual Conference & Exposition, 2021: American Society for Engineering Education*, Paper ID 34712.

[15] Saldaña, J. (2016). *The Coding Manual for Qualitative Researchers*, 3rd Ed. Sage, London, pp. 339. ISBN 978-1-4739-0249-7

[16] Singer & Jarvie-Eggart (2020). Family Influence on First-year Engineering Major Choice. 2020 ASEE Virtual Annual Conference, June 22-26, 2021.

[17] Bradley, Tom. (Professor) (Fall 2021)"*What is Systems Engineering*?" [video] Department Seminar Series - Systems Engineering (colostate.edu) [Retrieved May 2022].

[18] Polozolo, P.J., Ivey, S., & Camp, C.V. (2010). Freshman Engineering Student Perceptions of Engineering Discipline. 2010 ASEE Southeast Section Conference.