Work in Progress: Mechatronics and Robotics Engineering Definitions among Students, Educators, and Industry Professionals

Dr. James A. Mynderse, Lawrence Technological University

James A. Mynderse is an Associate Professor in the A. Leon Linton Department of Mechanical, Robotics, and Industrial Engineering at Lawrence Technological University where he serves as director for the MS in Mechatronic Systems Engineering program. He received his BS, MS, and PhD in mechanical engineering from Purdue University. His research interests include mechatronics, dynamic systems, and control with applications to piezoelectric actuators, UAVs, and manufacturing. He serves as the faculty advisor for the LTU Baja SAE team.

Dr. Nima Lotfi, Southern Illinois University, Edwardsville

Nima Lotfi received his B.S. degree in electrical engineering from Sahand University of Technology, Tabriz, Iran, in 2006, his M.S. degree in electrical engineering from Sharif University of Technology, Tehran, Iran, in 2010, and his Ph.D. degree in mechanical engineering from Missouri University of Science and Technology, Rolla, MO, USA, in 2016. He is currently an Assistant Professor with the Mechanical Engineering Department at Southern Illinois University Edwardsville, Edwardsville, IL, USA. His current research interests include characterization and electrochemical modeling of Li-ion batteries, traditional and electrochemical model-based Li-ion battery management system design, and real-world applications of control and estimation theory especially in alternative and renewable energy systems, mechatronics, robotics, and electrified and autonomous transportation. Dr. Lotfi is a member of the IEEE Control Systems Society and ASME Dynamic Systems and Control Division.

Dr. Nikhil Bajaj, University of Pittsburgh

Dr. Bajaj earned his bachelor's, master's and PhD in mechanical engineering from Purdue University, and has held research assistant positions on several projects in the areas of nonlinear dynamics, control systems, sensing and machine learning, computational design, and heat transfer. He has held a summer research position with Alcatel-Lucent Bell Laboratories and has also served as a consulting mechatronics engineer with two startup technology companies, in the areas of force sensing in gaming devices and the control of multi-actuator haptics. His research interests include nonlinear dynamical and control systems, and the analysis and design of mechatronic systems, especially in the context of cyber-physical systems—in particular making them secure and resilient.

Dr. Vishesh Vikas, The University of Alabama

Vishesh Vikas is an assistant professor in the Department of Mechanical Engineering, University of Alabama, Tuscaloosa (UA) and the director of the Agile Robotics Lab at UA. His research interests are in the field of soft robotics, bioinspired robotics and tensegrity mechanisms. He received his MS (2008) and PhD (2011) in Mechanical Engineering from the Center of Intelligent Machines and Robotics, University of Florida, Gainesville. Thereafter, he was a postdoctoral researcher at the Neuromechanics and Biomimetics Devices, Tufts University (2012-2016). He has served as the Chair of Student Mechanisms and Robotics Design Competition at the ASME IDETC (2017-2019). Currently, he serves on the Electronic Editorial Board for the ASME Journal of Mechanisms and Robotics (JMR).

Prof. Michael A. Gennert, Worcester Polytechnic Institute

Michael A. Gennert is Professor of Robotics Engineering, CS, and ECE at Worcester Polytechnic Institute, where he leads the WPI Humanoid Robotics Laboratory and was Founding Director of the Robotics Engineering Program. He has worked at the University of Massachusetts Medical Center, the University of California Riverside, PAR Technology Corporation, and General Electric. He received the S.B. in CS, S.B. in EE, and S.M. in EECS in 1980 and the Sc.D. in EECS in 1987 from MIT. Dr. Gennert's research interests include robotics, computer vision, and image processing, with ongoing projects in humanoid robotics, robot navigation and guidance, biomedical image processing, and stereo and motion vision. He

led WPI teams in the DARPA Robotics Challenge and NASA Space Robotics Challenge and is author or co-author of over 100 papers. His research has been supported by DARPA, NASA, NIH, NSF, and industry. He is a member of Sigma Xi, and a senior member of IEEE and ACM.

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Abstract

Mechatronics and Robotics Engineering (MRE) is a growing engineering discipline focused on the creation of smart and autonomous systems and processes in an integrated and interdisciplinary fashion towards improving the quality of human lives. Despite the growing need for MRE professionals and increasing numbers of undergraduate and graduate degree programs, this field does not yet enjoy recognition as a distinct and identifiable discipline.

A distinct and identifiable engineering discipline must address four questions: 1) What is the body of knowledge that practitioners must master? 2) What skills must practitioners demonstrate? 3) What are the ways of thinking that permeate the discipline? 4) How do practitioners define and distinguish the discipline? Within the MRE community, there is disagreement over how these questions are addressed, and hence, whether and how to define a unified "mechatronics and robotics engineering" discipline or to differentiate "mechatronics engineering" from "robotics engineering".

Four groups of stakeholders were identified: prospective students, current students, educators, and industry professionals. An online survey with common sections on definitions of "mechatronics engineering" and "robotics engineering" and stakeholder-specific questions about differentiators was distributed to stakeholders via email invitation. Quantitative data analysis was used to code and categorize responses. Preliminary data analysis results for categories and codes are presented.

Introduction

Mechatronics and Robotics Engineering (MRE) is a growing engineering discipline focused on the creation of smart and autonomous systems and processes in an integrated and interdisciplinary fashion towards improving the quality of human lives. Despite the growing need for MRE professionals and increasing numbers of undergraduate and graduate degree programs, this field does not yet enjoy recognition as a distinct and identifiable discipline.

Building on the 2016 Mechatronics Education Innovation Workshop [1], a team of MRE educators launched a series of four workshops on the Future of Mechatronics and Robotics Education (FoMRE) with the vision that "MRE will become one of the most impactful disciplines of engineering; attracting diverse and innovative students, graduating professional engineers who will design, develop, and implement transformative autonomous technologies, and improving health and welfare sectors while extending human reach to previously inaccessible realms large and small, near and far" [2].

The long-term goals of the team were to:

- Develop a diverse, inclusive community of MRE educators, students, and practitioners
- Define the MRE knowledgebase as a community
- Achieve recognition of MRE as a distinct engineering discipline
- Accelerate adoption of MRE courses and curricula [2]

During the course of planning, running, and documenting the workshops, the organizers had the opportunity for discussions about the nature of MRE and our individual perceptions of the field. Even within a small group that was focused on a common outcome, individual working definitions of "mechatronics engineering" and "robotics engineering" differed. Similarly, the degree programs represented by workshop participants and organizers included "Mechatronics Engineering", "Mechatronic Systems Engineering", "Mechatronics and Robotics Engineering", and "Robotics Engineering". Similar confusion was observed among industrial professionals who were consulted.

This confusion is certainly not new. In 1997, Fukuda and Arakawa compared intelligent systems from mechatronics and robotics perspectives and noted that "the difference between mechatronics and robotics is not clear", though they did identify both overlap and differences [3]. Bradley stated in 2004 that "it is still not certain that there is a clear and consistent understanding of what mechatronics is and how, and at what level, it should be taught" [4]. A 2008 International Federation of Automatic Control (IFAC) milestone report distinguishes between the applications of control on mechatronic systems and robotics without addressing overlap [5].

Based on the discrepancies among the literature, workshop organizers, educators, and other stakeholders, two research concerns arose. How do stakeholders (prospective students, current students, educators, and industry professionals) define "mechatronics engineering" and "robotics engineering"? Are the stakeholders in agreement? If the prospective students and educators are not aligned, then the field may suffer lower enrollment in degree programs, and hence fewer young engineers in the future. If educators and industry professionals are not aligned, it becomes more difficult for qualified graduates to find jobs. This concern likely seems trivial until graduates encounter recruiters or other human resources professionals that simply do not have a box to check for their degree program.

This work aims to address this lack of agreement by identifying trends in definitions of MRE among various stakeholders: faculty, industry professionals, current students, and prospective students (excluding minors). A set of surveys was developed and distributed to sample stakeholders. The survey asked participants to define "mechatronics engineering" and "robotics engineering" and identify skills associated with each degree. Survey results were analyzed for common themes and preliminary results are presented.

This work is hypothesis-generating research [6]. Instead of surveying the literature to identify a problem and developing a hypothesis to test, a survey was developed to elicit individual working definitions of "mechatronics engineering" and "robotics engineering" from stakeholders. Responses were necessarily qualitative. Similar work examined definitions of biomedical engineering written by undergraduate students [7]. Qualitative research is a growing trend within engineering research [8]. For references on interpreting qualitative data, see for instance [6, 9, 10].

Existing MRE Definitions

Many "official" definitions exist for "mechatronics engineering" and "robotics engineering". A representative sampling of these definitions is provided below. These lists are not meant to be exhaustive, but instead demonstrate the variety among existing definitions.

Mechatronics definitions:

- "The application of complex decision making to the operation of physical systems" [11].
- "… the synergistic combination of mechanical engineering, electronics, control systems, and computers" [12], exemplified by a diagram similar to Figure 1.

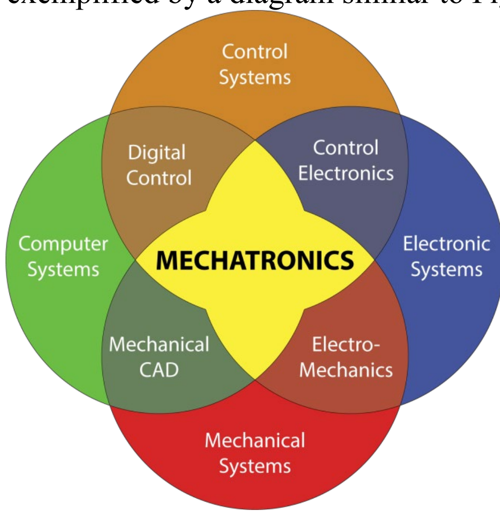

Figure 1. Graphical representation of mechatronics from Craig [12].

- Mechatronics "concerns the synergistic application of mechanics, electronics, control, and computer engineering in the development of electromechanical products and systems through an integrated design approach" [13].
- "Mechatronic Engineering combines the fundamentals of Mechanical, Electrical and Computer Science to develop autonomous systems. A Mechatronic Engineer designs smart machines and systems that are aware of their environment, and can processing information to make decisions" [14]

Robot and Robotics definitions:

- "A robot is a programmable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks" [15].
- "[A] robot is a physically embodied artificially intelligent agent that can take actions that have effects on the physical world" and "a physical machine that's usually programmable by a computer that can execute tasks autonomously or automatically by itself" [16].
- "A machine capable of automatically carrying out a complex series of movements, *esp*. one which is programmable" [17].

While educators and industry professionals may be familiar with one or more of the presented definitions, it is possible (or even likely) that prospective engineering students have more experience with robots through popular culture than academics. If a prospective student knows of C-3PO and Wall-E [18] but not Capek or Kuka, there are likely to be differences in understanding of robotics between the stakeholders.

Study Design

As a first step in understanding the stakeholder definitions, the authors selected an exploratory qualitative study design. Future work will use the exploratory study to identify important areas for later quantitative study. In this work, a survey was developed for each type of stakeholder: prospective engineering student, current engineering student, engineering educator, and industry professional. The survey was approved by the Lawrence Technological University Institutional Review Board (IRB).

The survey consists of three parts:

- The first section is common across stakeholders with demographic information. Respondents are also asked to define both "mechatronics engineering" and "robotics engineering".
- The second section is specific to the stakeholder category. Prospective engineering students are asked about enrolling in a mechatronics engineering or robotics engineering degree. Current engineering students are asked about selecting a mechatronics engineering or robotics engineering technical elective. Engineering educators are asked about launching a new mechatronics engineering or robotics engineering degree program. Industry professionals are asked about hiring a mechatronics engineering or robotics engineering graduate. In each case, a Likert scale question rates those options and free response questions address differences in skills.
- The third section is free response to address any differences between mechatronics engineering and robotics engineering that was not previously covered and additional open feedback on perceptions of MRE.

The complete survey is available in Appendix A.

Data Collection

An online survey using Google Forms was selected for ease of distribution across a wide geographical area. A single email invitation to participate was created in collaboration with other FoMRE participants who were developing other MRE-related surveys. The invitation email was sent to colleagues, collaborators, current students, members of university Industrial Advisory Boards, and distribution lists related to MRE.

After excluding responses from minors as a protected class, there were 132 responses remaining that met the criteria for inclusion. These were distributed among the stakeholder groups as shown in Table 1. Because there were only two responses from prospective engineering students, these will be considered only as a part of the aggregate response. Respondents were overwhelmingly male and white as shown in Table 2 and Table 3. Current engineering students were mostly traditional students enrolled as upperclassmen (juniors and seniors) or graduate students as shown in Table 4 and Table 5. Engineering educators and industry professionals were more widely distributed in age and experience as shown in Table 4 and Table 6.

Table 1. Distribution of responses among stakeholder groups.

	N
Prospective engineering student	2
Current engineering student	76
Engineering educator	30
Industry professional	24
Overall	132

Table 2. Distribution of gender identity among stakeholder groups.

	Male	Female	No response
Prospective engineering student	2	0	0
Current engineering student	59	13	4
Engineering educator	25	2	3
Industry professional	20	3	1
Overall	106	18	8

Table 3. Distribution of race/ethnicity among stakeholder groups. Some respondents selected more than one option.

	White	Black	Latin(x)	Asian	No response
Prospective engineering student	1	0	1	0	0
Current engineering student	60	5	4	9	1
Engineering educator	23	0	2	4	2
Industry professional	18	1	1	4	1
Overall	102	6	8	17	4

Table 4. Distribution of age among stakeholder groups.

	18-25	25-30	30-35	35-40	40-50	50-60	≥60
Prospective engineering student	2	0	0	0	0	0	0
Current engineering student	60	6	6	1	0	0	1
Engineering educator	0	4	4	3	3	6	8
Industry professional	1	6	7	3	2	3	2
Overall	63	16	17	7	5	9	11

Table 5. Distribution of class among current engineering students.

Freshman	Sophomore	Junior	Senior	Graduate student	No response
5	6	14	30	20	1

Table 6. Distribution of years of experience among engineering educators and industry professionals.

	<5	5-10	≥10
Engineering educator	9	8	13
Industry professional	3	9	12

Results

Responses to the common qualitative questions "How do you define Mechatronics Engineering?", "How do you define Robotics Engineering?", "What differences exist between Mechatronics Engineering and Robotics Engineering that were not captured in your previous responses?", and "Is there anything else that you would like us to know about your perceptions of Mechatronics Engineering and Robotics Engineering?" were coded using simultaneous descriptive codes [9]. Due to the use of simultaneous descriptive codes, some response may fit more than one code. Thus, not all results shown sum to 100%. The resulting codes and categories with descriptions are provided in Appendix B.

The first two categories were selected as mechatronics engineering definition and robotics engineering definition. Codes within the definition categories were usually unique. For instance, a respondent might define mechatronics as being only the combination of mechanical engineering and electronics (electro-mechanical code) or might use something similar to Craig's definition including computer systems and control systems (interdisciplinary code). In contrast, robotics engineering definitions made mention of the combination of mechanical, electronic, computer, and control systems (subdomains code) or alternatively described the sense-think-act paradigm (function code). A number of respondents defined robotics engineering as being related to robots without further explanation. It was unclear if these participants lacked a clear definition or adopted the "I know it when I see it" approach.

The third category was robotics engineering differentiators. These codes were not unique. Many respondents elaborated on the topic of robotics engineering with additional differentiators compared to mechatronics engineering. These included the need for additional computer science, artificial intelligence, or machine learning (CS/AI code), the assumption of autonomy (autonomy code), labeling of robots as smart (smart code), or a focus on the robot as specific to a goal or task (task code).

Finally, respondents compared mechatronics and robotics and these ideas were captured in the mechatronics vs. robotics category. Opinions described included that mechatronics engineering and robotics engineering were very similar or the same (same code), that mechatronics engineering was broader or that robotics engineering was a subset of mechatronics engineering (mechatronics broader code), or that robotics engineering was broader or that mechatronics engineering was a subset of robotics engineering (robotics broader code). These codes were almost completely unique.

The results of the qualitative data analysis (coding) are shown in the following figures. Figure 2 and Figure 3 present the results for the "Mechatronics Engineering definition" and "Robotics

Engineering definition" categories. For mechatronics engineering, results are consistent across stakeholder groups that almost all respondents define mechatronics by the subdomains, favoring an interdisciplinary definition similar to that of Craig [12]. Robotics engineering definitions are more evenly split among the three types of definitions: subdomains, function, and robots. The high support for a circular definition of robotics engineering as having to do with robots was surprising. As noted above, it was unclear if this definition indicated a lack of clear working definition for respondents or a sense of obviousness. This is an area for future study.

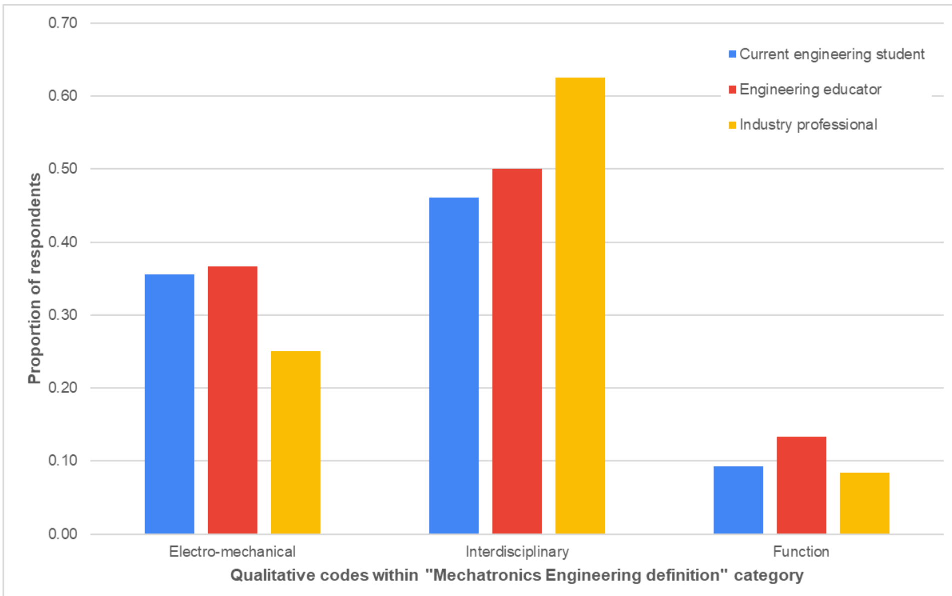

Figure 2. Results of qualitative data analysis within "Mechatronics Engineering definition" category for three stakeholder groups.

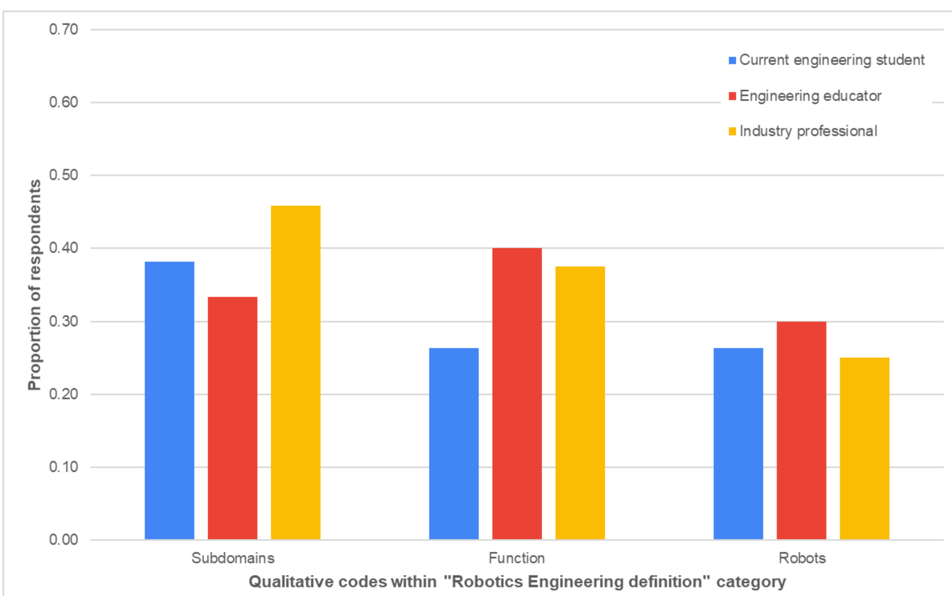

Figure 3. Results of qualitative data analysis within "Robotics Engineering definition" category for three stakeholder groups.

Figure 4 shows the qualitative data analysis results for the “Robotics Engineering differentiators” category. This category showed more variety as respondents chose to elaborate (or not) on the differentiators that marked robotics engineering. A computer science or artificial intelligence component was frequently described by current engineering students but less frequently by engineering educators and industry professionals. Autonomy was noted by current engineering students and engineering educators but less frequently by industry professionals. Instead, industry professionals more commonly described robotics in terms of completing a task.

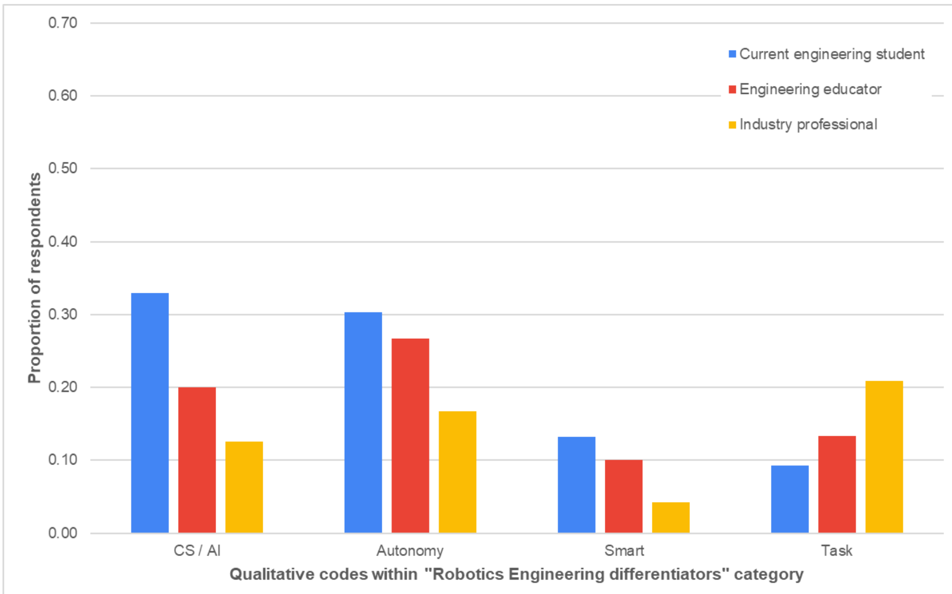

Figure 4. Results of qualitative data analysis within “Robotics differentiators definition” category for three stakeholder groups.

Figure 5 shows the results of qualitative data analysis for the “Mechatronics vs. Robotics” category. This category of codes did not explicitly correspond to survey questions and was not addressed by all respondents. However, many respondents did provide comments on distinguishing between mechatronics and robotics. Again, responses from industry professionals differed from current engineering students and engineering educators as industry professionals were much more likely to view mechatronics and robotics as being the same. Support across all stakeholder groups for mechatronics being a broader field was stronger than that for robotics being a broader field. This is consistent with the results in Figure 3 showing support for mechatronics engineering as an interdisciplinary discipline that is larger than only electro-mechanical devices. Under this definition, robotics engineering with the associated differentiators from Figure 4 would fit as a subset of mechatronics engineering.

Finally, the only quantitative survey question asked respondents to select between mechatronics engineering and robotics engineering as a degree program, technical elective, new program to launch, or graduate to hire. While these are different results, they required the respondents to apply a value to select between the domains. The results are shown in Figure 6.

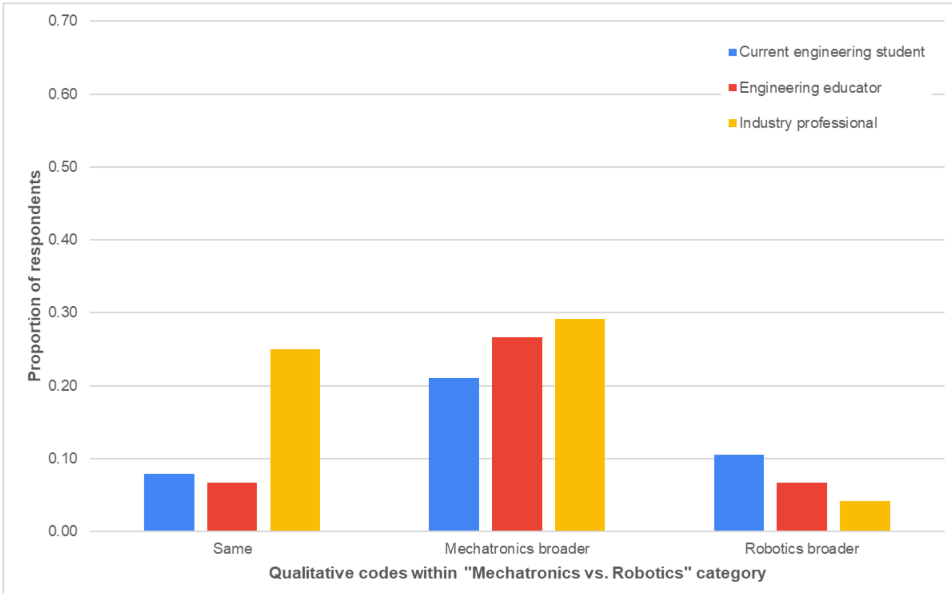

Figure 5. Results of qualitative data analysis within "Mechatronics vs. Robotics" category for three stakeholder groups.

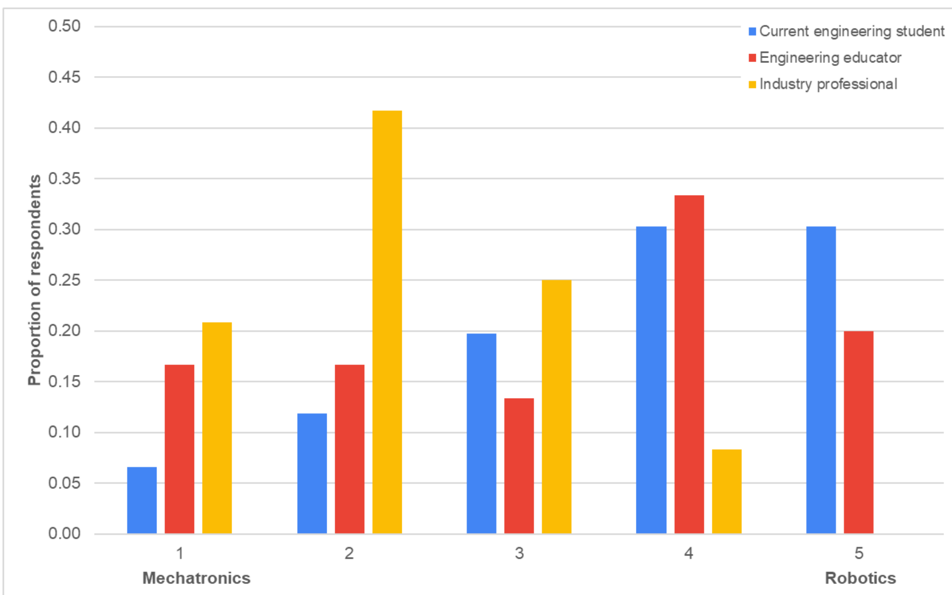

Figure 6. Results of quantitative data analysis for question about selecting between mechatronics engineering and robotics engineering.

Most interesting from Figure 6 was the differences between stakeholders. The majority of current engineering students and engineering educators preferred robotics engineering while the majority of industry professionals preferred mechatronics engineering. Given the limited number of respondents in this preliminary study, it is possible that these results are skewed by underrepresented groups. However, if this result holds in a larger sample it indicates that there is a clear disconnect between academia and industry. This trend should be considered for future study.

Conclusions and Future Work

Mechatronics and Robotics Engineering are growing fields, but they lack agreed upon definitions, due to (and perhaps causing) confusion amongst stakeholders, from prospective students, to current students, to educators, to potential employers (industry professionals). In order to assess more clearly the current state of the perceptions of the fields amongst stakeholders, a survey was developed and distributed, targeting prospective students, current students, educators, and industry professionals. This survey was analyzed qualitatively using a set of simultaneous descriptive codes, which were then classified into categories. The preliminary results indicate a good start in qualitative analysis and towards understanding the perceptions of the field; however, the number of responses is currently relatively low, and so caution should be used in generalizing results. In future work, the authors plan to continue to solicit additional survey responses from all classes of stakeholders, but in particular prospective engineering students. It will be important to connect the students' perspectives and responses to faculty understanding. There are also additional, more puzzling results to explore—for example, respondents often defined robotics engineering as being defined by robots—whereas mechatronics was not circularly defined in this way.

This work represents the first application, to the authors' knowledge, of a hypothesis-generating approach to compare and contrast mechatronics engineering and robotics engineering. Thus, although it was not possible to compare the current survey responses against the literature, this work may serve as a baseline against which mechatronics engineering and robotics engineering may be compared as they evolve.

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Appendix A – MRE Definitions Survey Questions

Common Section

1. Please type your name in the box below to indicate agreement to participate in this study.
2. What is your gender identity?
3. What is your race/ethnic identity? Please check all that apply.
    - White
    - Black
    - Latin(x)
    - Asian
    - Other: ____________________
4. What is your age?
5. Are you a:
    - Prospective engineering student
    - Parent or guardian of a prospective engineering student
    - Current engineering student
    - Engineering educator (e.g. faculty member)
    - Industry professional
6. How do you define Mechatronics Engineering
7. How do you define Robotics Engineering?

Prospective Engineering Student or Parent/Guardian

1. What is your planned degree program?
2. What industries most need a combination of electrical & computer engineering, mechanical engineering, and computer science?
3. Assume that you (or your child or ward) are selecting between two degree programs at a prestigious university. Both programs are accredited and have excellent faculty and lab facilities. Which has better job prospects? (five point Likert scale)
    - Mechatronics Engineering
    -
    -
    -
    - Robotics Engineering
4. What skills do graduates from Mechatronics Engineering have?
5. What skills do graduates from Mechatronics Engineering NOT have?
6. What skills do graduates from Robotics Engineering have?
7. What skills do graduates from Robotics Engineering NOT have?

Current Engineering Student

1. What is your current degree program?
2. What year are you?
   - Freshman
   - Sophomore
   - Junior
   - Senior
   - Graduate student
   - Other: ____________________
3. What industries most need a combination of electrical & computer engineering, mechanical
4. engineering, and computer science?
5. Assume that you are selecting between two technical electives that both count towards your current degree program. Both courses are hands-on and have excellent faculty and lab facilities. Which course is more useful to you? (five point Likert scale)
   - Mechatronics Engineering
   -
   -
   -
   - Robotics Engineering
6. What skills will you learn from Mechatronics Engineering?
7. What skills will you NOT learn from Mechatronics Engineering?
8. What skills will you learn from Robotics Engineering?
9. What skills will you NOT learn from Robotics Engineering?

Engineering Educator

1. At which University/College/School do you teach?
2. What are your current teaching responsibilities? (level, area)
3. How many years of teaching experience do you have?
4. What industries most need a combination of electrical & computer engineering, mechanical engineering, and computer science?

10. Assume that you selecting between two new degree programs to launch at your current university. Both programs are supported by the University administration with available faculty lines and funding for lab facilities. Which program is more likely to be successful? (five point Likert scale)
    - Mechatronics Engineering
    -
    -
    -
    - Robotics Engineering

5. What skills will graduates from Mechatronics Engineering have?
6. What skills will graduates from Mechatronics Engineering NOT have?
7. What skills will graduates from Robotics Engineering have?
8. What skills will graduates from Robotics Engineering NOT have?

Industry Professional

1. In which industry do you work?
2. What is your current role within your company?
3. How many years of experience do you have?
4. What industries most need a combination of electrical & computer engineering, mechanical engineering, and computer science?
5. What area within your company most uses a combination of electrical & computer engineering, mechanical engineering, and computer science?
11. Assumed that you are hiring to fill one position in that area. You have two highly qualified applicants with different undergraduate degrees. Which degree is better suited for your available position? (five point Likert scale)
    - Mechatronics Engineering
    -
    -
    -
    - Robotics Engineering
6. What skills do graduates from Mechatronics Engineering bring to the position?
7. What skills do graduates from Mechatronics Engineering lack for the position?
8. What skills do graduates from Robotics Engineering bring to the position?
9. What skills do graduates from Robotics Engineering lack for the position?

Free Response

1. What differences exist between Mechatronics Engineering and Robotics Engineering that were not captured in your previous responses?
2. Is there anything else that you would like us to know about your perceptions of Mechatronics Engineering and Robotics Engineering?

Appendix B - Codes and Categories from Common Qualitative Survey Questions

Category	Code	Description
Mechatronics Engineering definition	Electro-mechanical	Definition of mechatronics engineering focuses only on electro-mechanical components.
	Interdisciplinary	Definition of mechatronics engineering expands beyond electro-mechanical to include other domains.
	Function	Definition of mechatronics engineering focuses on product or system function.
Robotics Engineering definition	Subdomains	Definition of robotics engineering focuses on domains (e.g. mechanics, electronics, etc.)
	Function	Definition of robotics engineering focuses on system function
	Robots	Definition of robotics engineering uses "robots" without significant explanation.
Robotics Engineering differentiators	CS / AI	Respondent highlights includes of computer science or artificial intelligence in robotics.
	Autonomy	Respondent highlights autonomy of robots.
	Smart	Respondent highlights robots as "smart" systems.
	Task	Respondent highlights robots as addressing a goal or task.
Mechatronics vs. Robotics	Same	Response clearly implies that terms are roughly equivalent.
	Mechatronics broader	Response clearly implies that mechatronics engineering is a broader field or that robotics engineering is a subset of mechatronics engineering.
	Robotics broader	Response clearly implies that robotics engineering is a broader field or that mechatronics engineering is a subset of robotics engineering.