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Do I need to know this?: A comparison of mechatronics program offerings to industry expectations for necessary on-the-job skillsets.

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Educational programs in mechatronics engineering are tasked with providing well-rounded curricula for their students that balance fundamental conceptual knowledge with additional relevant technical skills. However, it is unclear how well educational programs match industry expectations in terms of maintaining this balance and preparing future mechatronic professionals. As part of a larger NSF-funded project, educational opportunities across the United States were compared to surveyed industry expectations for six categories of mechatronic skills. A comparison of the distribution of skills instructed across categories showed that educational institutions cover a significantly *wider* range of skills than what most industry professionals believe are important for a career working in mechatronics. For example, while most educational programs prioritize engineering fundamentals, industry professionals instead indicated that knowledge of electrical hardware systems were equally (if not more) important. These results suggest that there does exist an opportunity to refine engineering educational programs, such that they might more effectively match industry expectations and "on-the-job" duties. Increasing this match between industry expectations and educational programs seems especially important for enabling existing workers to achieve rapid upskilling through micro-credentialing or certification; both are becoming increasingly popular and necessary alternatives to full-degree programs in order to maintain a robust and prepared workforce . Information from this study should provide an initial catalyst to frame the improvement and streamlining of curricular programs, and thus more effectively balance academic offerings with required industrial skillsets.

Introduction

Mechatronics is a multi-disciplinary field combining mechanical and electrical/electronic engineering with information technology to design electromechanical systems that reduce human physical and mental strain [1,2]. Individuals who are trained in the field are employed as electromechanical technicians, robotics engineers, and automation engineers, amongst other positions, all of which require a well-rounded education and training opportunities in both theoretical and applied aspects of engineering [3]. Whether this balanced training in both theoretical and applied skills is currently provided by current U.S. engineering programs, however, is an open question.

For example, there is broad criticism that the U.S. educational system does not equip graduates with the necessary skills to support the manufacturing industry and that there is a disconnect between academic offerings and industry expectations [4,5,6]. This might be especially exaggerated in multi-disciplinary areas like mechatronics. While most mechatronics programs provide students training in mechanical engineering, electrical engineering, and computer science, one program's conceptualization of a robust mechatronics education may markedly differ from another's. While one program may incorporate more courses that train students in mechanical engineering, another may provide a greater number of courses in electrical engineering, and yet another might instead focus on computer science knowledge and programming [7]. Some have even suggested that academic mechatronics programs should be longer than the standard engineering degree and require more credits, given the need to cover basic engineering concepts *plus* information technology and robotics [7]. These divergences in curricular composition are further exacerbated by a potential shortage of faculty members with experience in actual systems (versus theoretical modeling), which can result in a lack of hands-on training for students [8]. Thus, even *within* a given curriculum there is potential variance in how and what material is being instructed to students.

These factors taken together produce a significant potential risk that students and professionals wanting to train for a mechatronics career may emerge from programs under- or mis-prepared for actual positions in the field. To mitigate this risk, it is important that students receive educational opportunities that are largely consistent with industry standards/expectations (i.e., covering the variety of skills needed for a mechatronics career), as this will enable these learners to better realize their own career goals while simultaneously also more effectively bolstering the mechatronics workforce. However, it is not clear what these expectations might be, as to date there has been little work focusing on industry expectations of mechatronics professionals. As part of a larger National Science Foundation (NSF) – funded project to create a modular, online mechatronics certificate program, educational programs were compared to industry expectations to determine what overlaps and gaps exist between industry expectations and current mechatronics programs in universities and/or community colleges.

First, industry professionals were surveyed about which mechatronics-relevant skills they believe are essential to have for a successful career within the field. We then conducted a meta-analytic evaluation of mechatronics programs across the U.S. to determine what skills are currently instructed within current mechatronics programs, at both two-year and four-year programs. Finally, these educational and industry perspectives were compared to discover what (if any) differences or knowledge gaps exist. This final step is critical to help programs highlight areas for improvement or restructuring to better prepare their students for success in the field.

Methods

As a part of an NSF-funded project [9] to develop and distribute an online mechatronics program, we investigated the similarities and differences between skills that are expected of a mechatronics graduate by industry professionals, and those that are taught in mechatronics engineering programs. This effort proceeded in 3 distinct phases.

Phase 1. Survey of Industry Professionals

In the first phase, a panel of engineering educators with expertise in both electrical and mechanical engineering compiled a list of 32 possible mechatronics-relevant skills (e.g., *electric circuits*, *microcontrollers*). A group of industry professionals (*N* = 11) was then surveyed and asked to confirm the relevancy of these skills to normal job-duties within the mechatronics field. All industry participants were initially identified via nominations from the advisory board for the NSF project, and were then sent an email soliciting their participation in this survey. Of the 11 surveyed professionals, six respondents were from companies employing more than 200 people, and the remaining five were from companies employing less than 50. These individuals were also employed in various mechatronics domains (i.e., medical (*n* = 1), aerospace (*n* = 3), automotive (*n* = 2), precision machine manufacturing (*n* = 1), product development (*n* = 2), and educational (*n* = 2)), and have been employed anywhere from 3 to 40 years in their respective positions or area (e.g., operations manager, production director, technical lead engineer, and robotics researcher). Thus, a diverse industry perspective of mechatronics skills is likely captured in this survey.

Respondents rated each of the 32 skills as either *very relevant, somewhat relevant, not relevant*, or *unsure.* These ratings were completed two times for every skill – once for individuals who would complete a "*Career Pathway*" certificate and once for individuals who would complete a "*Professional*" certificate. Career Pathway certificates were operationalized as a certificate offered through community colleges at the associate degree level, while Professional pathway certificates were operationalized as those offered at the university level to individuals who either already have (or are currently working toward) a bachelor's degree in another engineering area, and/or pursuing additional specialized certification in mechatronics or mechatronics engineering. Respondents were also asked to suggest any required skills not already listed, and these were added to the list of skills. Thus, following the survey, 37 skills were listed as important (i.e., rated on average as *somewhat relevant* or higher) for Career Pathway certificate-holders and 36 skills for Professional certificate-holders. These lists were then combined and sorted into six overarching categories: engineering fundamentals (e.g., analysis/design, digital, electrical, mechanical, and safety/material properties), mechanical hardware systems (e.g., fluid mechanics, pneumatics/hydraulics, and thermal), electrical hardware systems, software systems (e.g., programming and robotics), systems integration, and applications (see Table 1).

Table 1

Categorization of relevant content skills as identified by industry professionals for Career Pathway and Professional certificates, sorted across general content categories.

Engineering Fundamentals	Mechanical Hardware Systems	Electrical Hardware Systems	Software Systems	Systems Integration	Applications
Actuator motor modeling	[CP] **Electro-pneumatics**	AC/DC conversion, circuits, and motors	ANN coding	Digital implementation of control laws	Image sampling and pre-processing
Cantilever beam modeling	[CP] **Pneumatics and hydraulics (e.g., properties, power sources, reservoirs, pumps, compressors, lines, valves)**	A/D and D/A conversion	Arduino and C/C++ programming basics	Digital implementation of feedback control	Motor dynamics identification
Feedback control (performance analysis)		Actuators and basic control	Control algorithm design		
Fourier transformation and FFT		Actuator and motor selection/design	Data sampling		
Image signal processing basics		Analog AC/DC circuits	Digital filtering		
[P] **LCD vs. LED**		Breadboard circuit design	Feedback control design (P/PD/PID controllers for robots)		
Laplace domain transformation		DC to DC buck/boost converters	FFT/STFT coding		

Measurement (e.g., oscilloscopes, bread boards)	Digital circuits (gates and flip-flops)	
Neural network basics	I/O operation	Stability of feedback control systems
Numerical methods (e.g., binary number system, Boolean algebra)	Microcontroller input/output ports	
[P] **Types of battery storage**	Microcontroller memory/clock/interrupt	
Vibration measurement	Preamplifier for sensors	
	Sensor principles and applications	

Note. Content skills in **bold** are unique to either Professional or Career Pathway certifications.
[P]: Relevant content skills unique to Professional certificate-holders.
[CP]: Relevant content skills unique to Career Pathway certificate-holders.

Phase 2. Survey of Mechatronics Degree Programs in the U.S.

The second phase was designed to better understand mechatronic degree offerings in the U.S. and involved two steps. First, relevant degree programs were identified using internet search engines and professionally-oriented development websites (e.g., Burning Glass Technologies). To be included in the subsequent analysis, degree programs were required to meet all of the following criteria: (1) contain "*mechatronics*" in the name, (2) culminate in a certificate/credential, or more formal degree (i.e., Bachelor's degree), (3) offered through a college, university, or accredited online education institution, and (4) consisted of multiple courses (i.e., not just one mechatronics course offered within a degree in another field). Graduate programs were excluded to ensure results would be comparable to the Phase 1 survey of industry professionals.

This search identified 29 mechatronics-related programs across the U.S. (see Table 3). Once this list of programs was aggregated, skills taught in the required and elective courses of each of the respective programs were identified and compiled based on program websites and associated syllabi. The same panel of engineering educators with expertise in both electrical and mechanical engineering from Phase 1 then reviewed this inventory of academic skills and removed/grouped redundant or similar skills to create a final list of 53 discrete skills. These skills were then categorized into the same overarching 6 categories used in Phase 1 (e.g., engineering fundamentals and mechanical hardware systems; see Table 2).

Table 2

Categorization of instructed content skills in identified mechatronics programs, sorted across general content categories.

Engineering Fundamentals	Mechanical Hardware Systems	Electrical Hardware Systems	Software Systems	Systems Integration	Applications
Analysis (e.g., of systems, machines, designs, materials)	Fluid mechanics/power systems (e.g., fluid statics, flow)	AC/DC conversion, circuits, and motors	Arduino and C/C++ programming basics	Mechatronic system design	Manufacturing processes
Bode design/plots	Machine/system statics	A/D and D/A conversion	CAD (i.e., graphics)	Mechatronic system build	Industrial robotics
Design fundamentals (e.g., reliability, safety, energy, ethics, liability)	Mechanical systems (e.g., functions, properties, materials)	Actuators	Computer simulation	Robotics (basics)	Specialty topics - robotics
Feedback control (performance analysis)	Pneumatics/hydraulics (e.g., properties, power sources, reservoirs, pumps, compressors, lines, valves)	Digital systems/circuits (SSI, LSI, VLSI)	Control algorithm design	Robotics (build)	Welding and soldering
Fourier transformation and FFT	Thermal systems	Electric circuits	Control systems (e.g., modeling, control loops)	Testing and troubleshooting	

Karnaugh mapping		Electrical power systems	Feedback control design (PD/PID controllers for robots)	Work cell design
Laplace domain transformation		I/O operation	PLC1: functions, testing, applications	
Machine/system dynamics		Microcomputers	PLC2: applications, timers, counters, subroutines, event/time-driven sequences	
Manufacturing (e.g., safety and ergonomics)		Microcontrollers (e.g., Arduino, propeller)	Programming (MATLAB)	
Materials (e.g., stress & strain, torsion, buckling, failure criteria)		Microprocessors		
Mathematics (e.g., algebra, calculus, computations)		Sensor principles and applications		

Measurement (e.g., oscilloscopes, bread boards)	Transformers
Numerical methods (e.g., binary number system, Boolean algebra)	
Physical and mathematical modeling	
Thermodynamics	
Vibrations (e.g., oscillatory motion, patterns)	
Z-transformation	

Phase 3. Comparison of Industry expectations to Academic Curriculum.

In this final phase, the results of Phase 1 and Phase 2 were compared and contrasted to identify any differences in content coverage or importance. To facilitate comparisons between the industry and academic perspectives, proportion scores for each of the 6 conceptual categories were computed for industry expectations and academic programs (further split by certificate and 2- and 4-year programs) to identify the prominence of each category in either expectation/program. These proportions were calculated as following: the number of skills contained under each distinct category was divided by the total number of skills for each corresponding group (industry versus academic certificate versus 2-year academic versus 4-year academic). For example, in a hypothetical academic program which instructed 36 total skills summed across the entire curriculum, if 12 Engineering Fundamental skills are included in this program the proportion calculation would indicate that 1/3 of instruction in this program focuses on Engineering Fundamentals. (i.e., 12 Engineering Fundamentals skills/ 36 total skills offered). These proportions were then averaged together for all similar programs (e.g., certificate or 2-year or 4-year). These were then compared to the industry identifications of skills for each surveyed certificate (e.g., Career or Pathway). Results are summarized graphically in Figure 1.

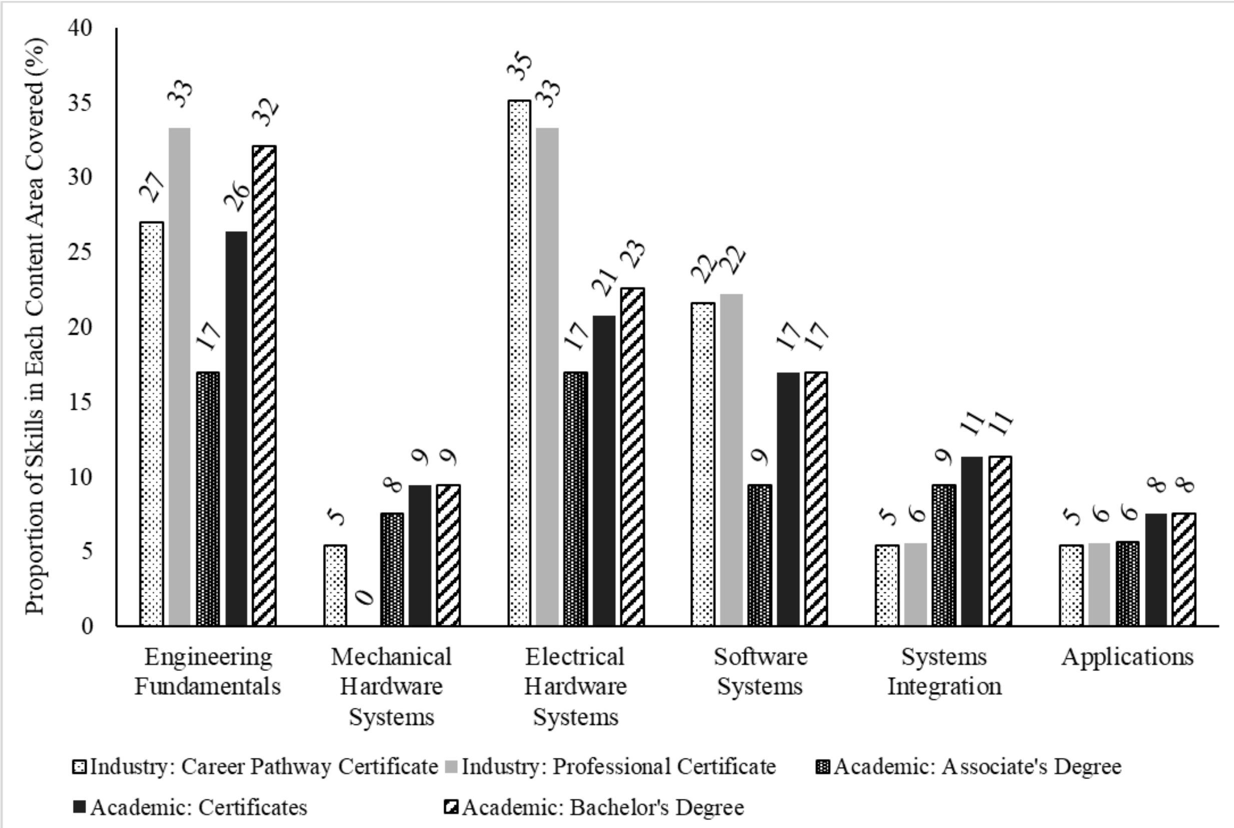
Results

A comparison of the overall distribution of the proportion of skills instructed or expected across conceptual categories showed some similar overall patterns of skill relevancy across programs and industry expectations. First, when examining industry expectations for different certificates, it appears that proportional expectations are nearly identical across Career Pathway certificates and Professional certificates. There is a slight difference between industry expectations of these certificates for Engineering Fundamentals and Mechanical Hardware Systems, but these differences are small.

Further, if one compares the patterns for industry expectations for both certificates, and all academic programs, a consistent overall pattern likewise emerges. For example, there appears to be a consistently high prioritization on Engineering Fundamentals (with a caveat; see below), and a consistently low emphasis on Mechanical Hardware Systems, Systems Integration, and Applications. Thus, overall, the pattern of results suggests that there is at least some broad similarity between the degree to which certain skills are instructed in these various degree programs relative to what industry professionals rate as important.

Figure 1

Proportion of skills instructed in academic programs and expected by industry professionals, by conceptual category.



However, upon closer examination there are also several interesting disparities. In general, it appears that Associate degree programs tend to diverge from Certificate and Bachelor's programs in several areas. In some cases this difference appears trivial (e.g., Systems Integration, Mechanical Hardware Systems, and Applications categories), but in other areas this difference is more prominent, especially once one also considers industry expectations. For example, examine the category of Engineering Fundamentals. While the proportion of skills instructed in Certificates and Bachelor's degrees (~29%) are more or less consistent with industry expectations (~30%), Associate degree programs tend to *not* emphasize this skillset as much as they perhaps should (16.98%). There is a similar disparity for these Associate programs in the Software Systems category as well (9.43%), when comparing these programs to either industry expectations (~22%), or the other 2 classes of academic programs (16.98%). This seems to capture important differences specific to Associate programs, which may be a result of the conceptualization and execution of these 2-year programs.

Finally, while a small difference when considered in terms of overall instruction, it also appears that all types of academic programs are *over*-emphasizing certain concept categories, at least when proportionally compared to industry expectations. For example, in both Mechanical Hardware Systems and Systems Integration, these categories are proportionally expected at a very low level by industry for either certificate (~4%), but the 3 types of academic programs are emphasizing these skills at over twice this level on average (~10%). Again, while a single digit difference, this perhaps identifies an area where academic programs might trim content to make way for more job-relevant information.

The need to proportionally cover more job-relevant skills seems especially pronounced in the Electrical hardware systems category. Industry survey results indicated Professional and Career Pathway certificate holders should proportionally spend roughly 1/3 of their education on these concepts (~34%). However, on average, identified academic programs spend only ~20% of their instruction on these electrical hardware systems skills (see Table 3 for more detail). This is especially prominent in Associate programs, which proportionally offer the least focus on this class of concepts (16.98%). A similar lack of proportional focus is also evident in the Engineering Fundamentals and Software systems categories for all academic programs, but to a much less degree than for the Electrical Hardware Systems category.

Table 3

Count of electrical hardware systems skills taught in each mechatronics program.

School	Program	Electrical Hardware Systems Skills Taught
Certificates		
Clark College	Mechatronics Fundamentals Certificate of Completion	3
Clover Park Technical College	Mechatronics Co-Op Certificate A - Power	3
Clover Park Technical College	Mechatronics Co-Op Certificate B - Control	1
Greenville Technical College	Mechatronics I Certificate in Applied Science	4
Greenville Technical College	Mechatronics II Certificate in Applied Science	2
Hofstra University	Mechatronics Online Certificate Program for Practicing Engineers	3
Linn-Benton Community College	Mechatronics: Industrial Refrigeration Career Pathway Certificate	1
Rochester Institute of Technology (RIT)	Mechatronics Engineering Certificate	5
The University of Utah	Mechatronics Certificate	5
University of Michigan-Dearborn	Industrial Mechatronics Certificate	7
Associate Degree		
Clover Park Technical College	Mechatronics AAS-T Degree	4
Clover Park Technical College	Mechatronics AAT Degree	3
Greenville Technical College	Mechatronics Technology Associate in Applied Science	6
Linn-Benton Community College	Mechatronics or Industrial Automation Technology, Associate of Applied Science	3
Portland Community College	Associate Degree: Mechatronics, Automation, and Robotics Engineering Technology Option within Electronic Engineering Technology	5
Rogue Community College	Mechatronics Associate of Applied Science Degree	6
Bachelor's Degree		

Boise State University	B.S. Mechanical Engineering with Certificate in Mechatronics	1
California State University Chico	B.S. Mechatronic Engineering	12
Canton State University of New York	B.S. Mechatronics Technology	6
Clover Park Technical College	Mechatronics BAS-META Degree	0
Kennesaw State University	B.S. Mechatronics Engineering	7
Kent State University	B.S. Mechatronics Engineering	6
Kettering University	B.S. in Engineering (Mechatronics Systems Concentration Program)	8
Michigan Technological University	B.S. Mechatronics Engineering	8
Middle Tennessee State University	B.S. Mechatronics Engineering	8
Northern Illinois University	B.S. in Mechatronics Engineering	10
Old Dominion University	B.S. in Engineering Technology with major in Electrical Engineering Technology and concentration in Mechatronics Systems Technology	2
Tennessee Tech	B.S. Mechanical Engineering (Mechatronics Concentration)	2
University of Detroit - Mercy	B.S. Robotics and Mechatronics Systems Engineering with a Concentration in Electrical Engineering	11

Overall, the results suggest that academic programs are consistent in many ways with industry expectations for degree holders in mechatronics, but there do appear to be several opportunities to refine or improve the match between educational programs and industry expectations for Career Pathway and Professional certificate holders.

Discussion

To determine the degree of match between the skills taught in academic mechatronics programs and those expected of a graduate with a mechatronics degree, the proportional focus on skills taught in undergraduate mechatronics programs was tabulated and compared to expected proportions derived by industry professionals. Broad categorization of these skills revealed that academic programs cover a wide range of skills across six content categories, while industry professionals seemed to prioritize certain skills and require more in-depth knowledge of only a few select categories. Electrical hardware systems, in particular, were highly emphasized from an industry perspective. However, these electrical hardware skills were not prioritized to the same degree in any of the various class of academic programs (i.e., certificates, Associate's or Bachelor's degree programs). Similarly, the identified Associate degree programs seem to be most disconnected from industry expectations across several categories, including Engineering Fundamentals, and might be reflective of the more restricted focus of such degree programs. As such, there are several disparities between industry expectations and educational programs. Considering the industry expectations as a baseline, this enables the identification of broad ways current programs might adjust their curriculum to better prepare future technicians or engineers to enter the workforce, or to help current workers upskill for new positions in emerging automation, robotics, and mechatronics fields as efficiently as possible.

This study has several limitations that should be recognized. For instance, the sample of industry professionals is limited in many ways and does not encompass the entire range of professions within the field of mechatronics. This is important as different fields can have slightly differing expectations of mechatronics certificate- and degree-holders. While the current sampling does include a variety of industry perspectives (both small and large companies; across a range of applications), future work might focus more deeply and explicitly on these industry-specific requirements, and thus provide more detailed guidance for coursework and training modules for domain specific applications or positions. Related to this point, this study was also limited geographically in its focus and consideration of educational programs, and by what educational material was accessible to researchers in this study. For example, expanding coverage to study educational programs and industry professionals outside the U.S. might refine the industry expectations reported here (or even change them outright). Similarly, it would be advantageous to have access to more nuanced details of every mechatronics course, in all of the identified programs, to ensure that skill coverage is appropriately identified. While this would be a large amount of data and also likewise require follow-up interviews and engagement with representatives of each program, it might prove useful in explaining not only the disparities observed here, but also provide some additional context on why these differences exist.

In conclusion, while the restructuring of educational programs to reflect industry requirements is not easy, and perhaps also not ideal for many reasons (e.g., it may neglect theoretical aspects or skills necessary for knowledge abstraction, generalization, and application to new, unforeseen problems), the current study provides an initial starting point for both industry and academic professionals to initiate conversations on what an effective degree offering in mechatronics should look like. The current research provides the first evidence to date of what industry experts might expect for a mechatronics graduate, and further, contrasts this expectation to various levels of degree offerings across mechatronics programs in the U.S. While there are many similarities, there also appear to be several areas where industry and academics might more effectively align. Ideally, increasing (or at least recalibrating) this alignment should provide students and professionals a clearer roadmap of not only how to train (or re-train as needed) for a career in this field, but also ensure that a robust and vibrant mechatronics industry persists for the foreseeable future.

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