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Examining industry expectations for content knowledge in mechatronics across career and professional certificate programs

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Abstract

Technological advancements, ever-evolving necessary skillsets, and an aging workforce have all contributed to a growing labor crisis wherein there are not enough qualified candidates available to fill vacant jobs in the manufacturing sector – in essence, a skilled labor shortage. Certificate programs (earned independently in a two-year college, while working in industry, or concurrently with an undergraduate degree) in hybrid fields like mechatronics provide a conduit for producing qualified candidates that ideally are equipped with the skills required by industry. However, it is important to gauge what industry expects from such graduates; in other words, pragmatically, what do they expect these students to know after completing a given certificate? The current study surveyed a range of mechatronics industry professionals on their expectations for content knowledge on a list of relevant skills for two different certificate programs in mechatronics (i.e., career pathway (two-year) and professional (four-year) certificates). Results showed that expectations differed for the two certificates on certain topics, especially related to feedback and control systems. It is hoped that these findings will enable the subsequent development and refinement of certificate programs to best ensure that students are mastering the critical requisite skills to be successful in their manufacturing careers.

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Keywords: mechatronics; engineering education; certificate programs; workforce development; industry expectations

1. Introduction

Globally, manufacturing workers are experiencing a paradigm without precedent: a pace of skills obsolescence that requires continuous learning and "upskilling" to maintain career viability [1]. The rapid integration of technology into the workplace, in addition to other factors such as an aging workforce and the migration of employment opportunities to lower-cost labor markets, have conspired to negatively impact the employment stability of the modern manufacturing worker [2,3,4]. Specific to the training of these employees, it has been speculated that most professional skills have a reported "half-life" of only five years [5]. While the US workforce is currently recognized as one of the most highly skilled and productive in the world, other regions are in fact employing ever-greater numbers of highly-skilled workers [6], which directly challenges and presents growing concerns about maintaining US manufacturing competitiveness.

These concerns perhaps underlie recent findings that fewer and fewer Americans are choosing manufacturing careers; the major driver of these long-term job vacancies is a lack of highly trained, specialized workers who can effectively integrate with advanced applications of automation and mechatronics technology [7,8]. The field of mechatronics represents an amalgamation of mechanical engineering, electrical engineering, and computer science content, designed to prepare students to work in fields like robotics and other industrial or computing applications [9].

This disciplinary breadth highlights a major challenge for manufacturing engineering education: *What is the best way to*

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provide individuals with the opportunity to train flexibly and effectively (and re-train or cross-train as needed) to maintain both employee career ambitions and the competitive edge of US manufacturing?

This engineering education challenge is compounded by broad criticism that the U.S. educational system is failing to produce graduates that have sufficient skills to support manufacturers [10]. For example, there appears to be a disconnect between instructed content and real-world industry expectations [11,12]. Thus, there is a need to provide production engineers and technicians access to education and training opportunities that directly enable them to maintain job proficiency and expand their skillsets in an ever-changing and advancing work environment [13]. There is some evidence that workers, through carefully curated in-person coursework, can develop these relevant manufacturing skillsets (even without a strict engineering background) [14].

Bridging this educational gap is possible, however this process is not simple due to the interdisciplinary nature of some newer engineering fields, specifically within the context of Industry 4.0. These fields (e.g., mechatronics) often represent a hybrid of more *traditional* content areas, and there are often numerous conceptualizations of what this *blending* of fields might (or should) actually look like in practice. Specific to mechatronics, certain programs might be more or less balanced in either mechanical or electrical engineering coursework, for example, reflective of the institutions' perspective of what a degree in mechatronics should entail.

As a discipline, mechatronics has been defined in multiple ways, including as an extension of existing engineering fields, as a separate field of engineering altogether, and as a philosophy [9,15,16,17]. Over the past three decades, multiple projects – some funded by the National Science Foundation (NSF) like ours – have focused on developing mechatronics curricula to stimulate interest in science and technology and bolster existing programs at both community colleges [18] and universities [19]. Some have even gone so far as to argue that mechatronics education should be longer in duration and involve more credits than any single engineering degree, as it involves multiple engineering disciplines. This variance in educational training and perspective that is reflected in the broad skillsets that are currently taught [20] can be problematic, as it increases the likelihood that graduating students are either ill-prepared or less prepared for work in mechatronics positions that perhaps do not perfectly align conceptually with a given school's perspective. In fact, at their conception, mechatronics courses and programs were often developed at an individual programs' discretion, creating multiple curricula templates from the beginning [21]. Thus, due to its numerous conceptualizations, there does not seem to be a universal checklist of expected skills that a mechatronics program should impart. This highlights a burgeoning problem in mechatronics education; quite simply there is no baseline consensus on what mechatronics programs should look like, and thus it becomes difficult to develop new and more effective curricula to best serve students. *How then can educational institutions ensure that their graduates meet their career goals?* Rather than conceptually decomposing curricula and attempting to rationalize why existing programs look like they do, it perhaps would be more insightful to instead start outside of academics and understand what industry professionals expect of graduates with a degree in mechatronics [2].

Thus, similar to efforts in Norway and Poland [22] where universities surveyed local companies about their expectations regarding graduates' theoretical knowledge and skills, the current paper adopts an industry-first focused perspective on mechatronics education and surveys mechatronics professionals to create such a rubric, in the hopes that understanding commonalities across industry expectations might in fact eventually shed light on how best to develop a common mechatronics core curriculum. This core curriculum could then be built upon and augmented based on desired specialization, or industry or other worker needs or desires.

2. Methods

As part of an NSF-funded project aimed at developing and distributing an online mechatronics educational program [23], a two-phased investigation was conducted to gain a better sense of industry expectations for engineering educational programs.

In the first phase, it was necessary to identify as many relevant concepts as possible that might be relevant for mechatronics education. To this end, an initial group of industry professionals (N =11) were provided with a list of 32 skills that might be relevant to a mechatronics position. Of the 11 surveyed, six respondents were from companies employing more than 200 people, and five were from companies employing less than 50. These individuals are 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 areas (e.g., operations manager, production director, technical lead engineer, and robotics researcher). Thus, the opinions captured in this paper reflect those of individuals employed in diverse mechatronics fields.

The provided skills were initially compiled by a panel of engineering educators with expertise in both electrical engineering and mechanical engineering as part of NSF project efforts. Respondents were asked to rate each of these skills as either: *very relevant, somewhat relevant, not relevant,* or *unsure*. Importantly, participants rated these skills twice: once to indicate how relevant they are for individuals who would complete a Career Pathway certificate (i.e., two-year community colleges) and again for those that would complete a Professional certificate (i.e., four-year universities). Career Pathway certificates were defined as those offered at local community colleges at the associate degree level. Professional certificates were defined as those completed by individuals who already have, or are working toward, a bachelor's degree in a related engineering field, and are obtaining specialization or certification in mechatronics. Additionally, participants were asked to provide any area of knowledge or skill not included in the list that they believed were necessary if completing either certificate. These skills (including those that were self-reported by respondents as additional and necessary) were then used in the second phase.

In the second phase, a new group of industry professionals (N = 15; independent from the first group) were surveyed to examine the nature of industry expectations for an individual to be hired and work in the field of mechatronics. Ten of the 15 surveyed were from companies employing more than 200 people and five were from companies employing less than 50. Again, these individuals represented a variety of mechatronics fields (i.e., aerospace (N = 3), production (N = 3), automation (N = 1), research (N = 2), educational (N = 3), medical (N = 1), and automotive (N = 2)), and have been employed anywhere from 3 to 42 years in their respective areas (e.g., head of research and development, controls and automation manager, and vice president of engineering). Thus, the opinions captured were akin to Phase 1 in their representation of a balanced perspective.

These respondents were asked to rank order the mechatronics job skills formulated in the first phase (e.g., *ANN coding, actuators and basic control,* and *binary numbers and operations*) from greatest to least relevance for daily work, based on their opinion and workplace experience. Respondents were again asked to rank order the skills twice: once for individuals who would complete a Career Pathway certificate (37 skills), and again for those that would complete a Professional certificate (36 skills) in mechatronics.

These ranked skills were then each assigned a point value based on their ranking per each respondent (e.g., a term ranked 5th out of 20 was assigned a point value of 5 for that one respondent), and the average of all respondents' rankings was computed for each term. Based on these averaged point values, the skills were collated into a final list of job-relevant skills in order from greatest to least perceived relevance for success as a mechatronics employee: one list for Career Pathway certificate holders and another list for Professional certificate holders.

3. Results

Complete lists of the ranked skills (with significantly different skills marked with an asterisk) are listed in Table 1. As can be seen, the lists for both certificates have marked differences as well as some similarities. While there is an overlap in the majority of skills, certain concepts were prioritized as more relevant in the Professional certificate compared to the Career Pathway certificate (and vice-versa).

Most striking perhaps, is that the understanding of control systems and feedback is prioritized to a much higher degree in the Professional certificate than the Career Pathway certificate. Five of the 10 skills in which there were observed differences in ratings are related to this topic, and demonstrate a much higher prioritization for the Professional certificate, as these five skills all appear in the upper 50% of ranked skills for the certificate. This is perhaps reflective of a more theoretical design focus for the Professional certificate, but also could reflect a more practical focus on mechatronics and the maintenance of these systems for the Career Pathway certificate. In other words, it may be that controls concepts are sometimes expanded upon later in some four-year (Professional) curricula, but the fact that these skills are ultimately regarded as important for *both* certificates emphasizes industry professionals' opinions of its importance regardless of education type. Aside from *I/O operation*, which was much more highly ranked for the Career Pathway certificate, the remaining skills that were differentially ranked across certificates appear mostly in the lower 50% of overall ranked skills for both certificates, perhaps reflective of unique job variance or lower levels of actual importance. In other words, aside from the control and feedback related concepts, by-in-large the remaining differences were for concepts that were considerably lower in importance for both certificates.

Table 1. Ranking of perceived relevance (based on average respondent ratings) for mechatronics concepts across two different certificate programs.

Skill	Career Pathway Certificate		Professional Certificate	
	Rank	*M* (SD)	Rank	*M* (SD)
actuators and basic control	1	*3.27* (3.03)	6	*6.07* (4.99)
A/D and D/A conversion[a]	2	*4.13* (4.13)	2	*4.67* (3.39)
analog AC/DC circuits[a]	3	*4.20* (3.43)	7	*6.40* (4.53)
actuator and motor selection/design	4	*4.73* (3.03)	-	-
AC to DC conversion	5	*5.13* (3.56)	1	*3.87* (3.78)
sensor principles and applications	6	*6.00* (4.28)	15	*8.93* (6.10)
actuator motor modeling	7	*6.00* (2.83)	3	*5.20* (4.55)
*I/O operation[a]	8	*6.13* (4.07)	23	*10.53* (5.99)
Arduino and C programming basics	9	*6.33* (5.39)	9	*7.53* (4.39)
binary numbers and operations	10	*6.67* (5.14)	24	*10.80* (6.09)
pneumatics/hydraulics	11	*6.87* (4.42)	-	-
electro-pneumatics	12	*6.93* (3.75)	-	-
digital implementation of control laws	13	*7.73* (4.10)	8	*6.40* (3.52)
data sampling	14	*8.47* (3.78)	10	*7.60* (4.34)
*control algorithm design	15	*8.80* (3.57)	5	*5.47* (2.97)
breadboard circuit design	16	*9.53* (6.39)	19	*9.27* (3.63)
*feedback control design (P/PD/PID)[a]	17	*10.00* (3.40)	4	5.27 (3.51)
performance testing using an oscilloscope	18	*10.33* (6.59)	35	*14.13* (5.13)
microcontroller input/output ports	19	*10.47* (5.42)	26	*11.73* (5.43)
ANN coding[a]	20	*10.47* (3.50)	11	*7.73* (3.88)
digital circuits (gates and flip-flops)	21	*10.73* (5.60)	25	*11.27* (5.23)
DC to DC buck/boost converters[a]	22	*10.73* (4.03)	27	*11.80* (1.97)
digital filtering	23	*11.53* (3.60)	16	*9.07* (3.95)
preamplifier for sensors	24	*11.53* (5.54)	36	*14.87* (5.07)

cantilever beam modeling	25	*11.93* (3.92)	21	*9.80* (3.43)
*digital implementation of feedback control	26	*12.33* (2.89)	13	*8.53* (3.56)
*Fourier transformation and FFT[a]	27	*12.73* (2.94)	14	*8.73* (4.08)
microcontroller memory/clock/interrupt	28	*12.87* (5.99)	34	*14.07* (6.17)
types of battery storage	-	-	28	*12.07* (4.92)
image signal processing basics	29	*13.07* (4.28)	30	*13.53* (4.07)
*FFT/STFT coding[a]	30	*13.13* (3.34)	18	*9.13* (4.22)
image sampling and pre-processing	31	*13.33* (3.81)	31	*13.67* (3.46)
*feedback control performance analysis	32	*13.40* (3.14)	12	*8.47* (4.50)
LCD vs. LED[a]	-	-	32	*13.67* (3.24)
*stability of feedback control systems	33	*13.73* (3.97)	17	*9.07* (6.16)
*neural network basics	34	*13.93* (4.53)	20	*9.27* (4.46)
motor dynamics identification	35	*14.13* (4.14)	29	*13.27* (4.70)
*Laplace domain transformation	36	*14.67* (3.68)	22	*10.13* (4.85)
vibration measurement	37	*15.00* (5.52)	33	*14.00* (6.68)

Notes: *M* denotes mean ranking; SD denotes standard deviation of mean ranking. Higher ranking position and lower average ratings indicate higher importance. Skills highlighted in grey indicate those unique to the corresponding certificate type added by survey respondents. Skills marked with an asterisk* were ranked significantly different between certificate types (shown in Table 2).

[a]A/D: analog-to-digital; D/A: digital-to-analog; AC: alternating current; DC: direct current; I/O: input/output; P: proportional controller; PD: proportional + derivative controller; PID: proportional + integral + derivative controller; ANN: artificial neural network; LCD: liquid crystal display; LED: light-emitting diode; FFT: fast Fourier transform; STFT: short-time Fourier transform.

Though there appear to be slightly altered expectations from industry professionals for those entering the mechatronics workforce with a Career Pathway (two-year) or Professional (four-year) certificate, there are some important parallels. Notably, the following skills were all ranked in the top 10 skills for both certificates:

- *actuators and basic control*
- *analog AC/DC circuits*
- *A/D and D/A conversion*
- *AC to DC conversion*
- *actuator motor modeling*
- *Arduino and C programming basics.*

These results indicate that these concepts are universally expected for any mechatronics graduate, regardless of level of degree program or career trajectory. See Table 2 for a list of the top 10 skills for both certificates.

Table 2. Top 10-ranking skills for both certificate types.

Rank Order	Career Pathway Certificate	Professional Certificate
1	actuators and basic control	AC to DC conversion
2	A/D and D/A conversion	A/D and D/A conversion
3	analog AC/DC circuits	actuator motor modeling
4	actuator and motor selection/design	feedback control design (P/PD/PID)
5	AC to DC conversion	control algorithm design
6	sensor principles and applications	actuators and basic control
7	actuator motor modeling	analog AC/DC circuits
8	I/O operation	digital implementation of control laws
9	Arduino and C programming basics	Arduino and C programming basics
10	binary numbers and operations	data sampling

Additionally, the ranked skills from survey respondents were statistically compared to determine which, if any, were ranked significantly differently between the two certificates (i.e., as significantly more or less relevant from one certificate to the other). Pairwise comparisons of ratings indicated that 10 skills were rated significantly different (p-values < .05) across the two certificates (see Table 3).

Table 3. Pairwise comparisons of significantly different skill rankings by industry professionals between certificate types.

Skill	Certificate with Higher Ranking	Statistical Analysis Results
feedback control performance analysis	Professional	$t(28) = 3.47, p < .01$
feedback control design (P/PD/PID)[a]	Professional	$t(28) = 3.75, p < .01$
stability of feedback control systems	Professional	$t(28) = 2.47, p = .02$
neural network basis	Professional	$t(28) = 2.84, p = .01$
Laplace domain transformation	Professional	$t(28) = 2.89, p. = 01$
I/O operation[a]	Career Pathway	$t(28) = 2.35, p. = 03$
Fourier transformation	Professional	$t(28) = 3.08, p < .01$
FFT/STFT coding[a]	Professional	$t(28) = 2.88, p. = 01$
digital implementation of feedback control	Professional	$t(28) = 3.21, p < .01$
control algorithm design	Professional	$t(28) = 3.47, p = .01$

[a]I/O: input/output; P: proportional controller; PD: proportional + derivative controller; PID: proportional + integral + derivative controller; FFT: fast Fourier transform; STFT: short-time Fourier transform.

In sum, these results provide a general idea of what knowledge is prioritized and expected of graduates entering the workforce both consistently (and inconsistently) across different certificate programs.

4. Discussion

In an effort to identify industry expectations for individuals completing with either a Career Pathway or Professional certificate in mechatronics, industry professionals were asked to rank order various mechatronics skills from greatest to least relevant. The resulting lists resembled one another in that many skills were consistently prioritized – especially the top four. However, there were also marked differences across certificate expectations. As such, there does appear to be an implicit prioritization of different skills amongst industry professionals, consistent with the level and degree of training.

One limitation of this study was the possibility that different industries or companies might have varying expectations of skillsets for their employees. Future work should focus on such employer differences and examine how such differences color or bias such expectations. That said, however, this study did succeed in obtaining ranked listings of skills that are likely representative of industry expectations, given that both large and small manufacturers of various mechatronics fields were represented in the survey. An additional explicit strength of this work is that professionals were asked to consider two different levels of certification, which can potentially illuminate how industry expectations can fluctuate within a single type of credentialing.

In conclusion, this study provides an initial documentation of the skills that manufacturing industry professionals might expect with varied academic credentialing in mechatronics. It is hoped that this work can better inform not only academic providers of said credentials, but also might prove useful for individuals beginning to pursue education in this field. A recent review of existing two- and four-year mechatronics programs [24] found that they do include most if not all of the skills ranked in this paper, and knowing what is especially pertinent to a successful career can help ensure individuals pay special attention to develop those particular skills. This would go a long way towards addressing existing labor shortages and shortfalls, while also increasing the speed and efficiency with which students can move through their education and into the workforce.

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