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# Mechatronics Education- Current and Future Trends

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***Abstract*—Mechatronics for Technologists and Technicians was recognized as an occupation by the U.S. Department of Labor in 2019 and was given the code 49-2094.00. In 2022 the occupation was migrated to the code 17-3024.00 and titled "Electro-Mechanical and Mechatronics Technologists and Technicians". Several organizations offer certifications in the mechatronics occupation that we list here. The major challenge that faces mechatronics education is the decline in the job market that is projected to stand at -2 % over the next decade for holders of bachelor's or lower degrees. This is attributed to the post-pandemic remote work trend and the hard-hit manufacturing industry during the pandemic. This decline is coupled with an aggressive growth in the job market for holders of graduate degrees (standing at over 11% growth) due to the growing demand in research and innovation and engineering training.**

***Keywords—Mechatronics, Education, Engineering Technology***

## I. Introduction

The term "Mechatronics" was first minted in the early 1970's by Tetsuro Mori at Yaskawa Electric Corporation to describe the synergy through integrating electrical and mechanical systems [1] [2]. In 1982, Yaskawa Electric claimed trademark rights to the name [3]. Nowadays, the term is used to point to systems in which electrical, mechanical, computer, and control systems are integrated together, and encompasses applications that range from micro-mechatronic sensors and actuators, also referred to as Micro-Electro-Mechanical Systems (MEMS) [4] to service and industrial robotics [5].

In the last decade, advanced manufacturing received a surge in educational institutions after the U.S. administration identified it as one of the areas needed for economic growth following the launch of the Advanced Manufacturing Partnership in 2011 [6] [7]. Only eight years later did the occupation "Mechatronics Technician" get approved as an occupation by the U.S. Department of Labor- Employment and Training Administration (DOL-ETA), in April 2019 [8], and was given the occupational code (O*NET-SOC Code 49-2094.00) [9]. The DoL also referred to the Mechatronics Technician occupation as "Electrical and Electronic Repairer - Commercial and Industrial Equipment". In 2022, the "Mechatronics" occupation was migrated to the SOC code 17-3024.00 and was titled "Electro-Mechanical and Mechatronics Technologists and Technicians". The occupation Mechatronics Engineering was added a few years earlier and was given the SOC code 17-2199.05 [10].

Prior to that, in 2015, the DOL-ETA worked with community colleges and the Berks County, and Lancaster County, PA Investment Boards to define the career pathways and skill standards of mechatronics. The work was sponsored by the Packaging Machinery Manufacturing Institute (PMMI). The results of the work were published in the form of a competency model. The competencies start at the base with the general ones, and become occupationally-specific as we move up the model and make up a total of nine tiers [7]. The model was updated in 2017, to include safety-related competency skills. A redrawing of the DOL competency model is shown in Fig. 1.

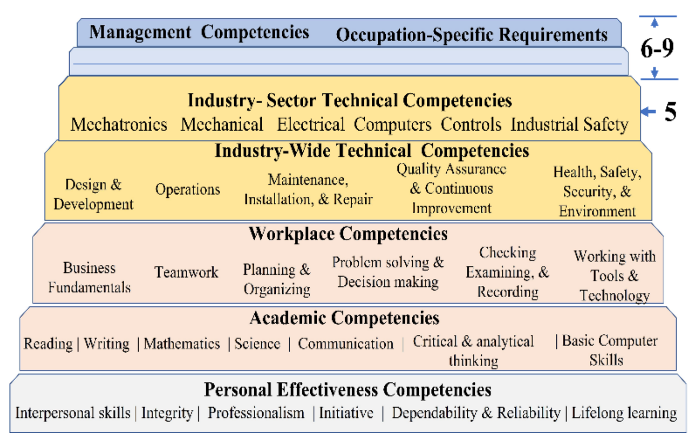


Fig. 1. The 2017 Department of Labor- Employment and Training Administration Mechatronics Competency Model with the recognized competencies.

The tier of interest is tier 5 "Industry-Wide Technical Competencies". Table I below shows the technical content area under each competency in tier 5 in the Mechatronics Competency Model of 2017.

TABLE I. MECHATRONICS TECHNICAL COMPETENCIES AS IDENTIFIED BY THE DOL-ETA:

| *Competency* | *Technical Content Areas under the competency* |
|---|---|
| 1. Mechatronics | Project planning & execution; Codes and standards |
| 2. Mechanical | Mechanical components; Measurements; Complex Components; Lubrication; Pneumatics; Hydraulics; Advanced Techniques |
| 3. Electrical | AC/DC Circuitry: Circuits, transformers, protection, 3 phase; Electrical components: Transformers, circuit breakers, fuses, sensors, and others; logic Gates; Wiring: color coding, electrical panels, labeling; Input/ output devices; Power distribution, conductors, overcurrent protection; Electric Machines; Schematic symbols |
| 4. Computers | Installation and maintenance of hardware (Memory, Buses, using TCP/IP, internet connections); Programmable Logic Controllers; |
| 5. Controls | a. Basic Process Controls<br>b. Controllers: manual and PID, Tuning<br>c. Batch Control<br>d. Control System Type: process controller, PLC control, SCADA<br>e. Control system documentation<br>f. Control system documentation: P& ID, Process flow, standards<br>g. Motion control: Servo and Stepper motors<br>h. Robotics<br>i. System Integration |
| 6. Industrial Safety | a. Alarm management<br>b. Reliability<br>c. Machine and Process Guarding<br>d. Manufacturing safety<br>e. Safe use of electrical apparatus<br>f. Safety Controller equipment |

Although significant effort was put into developing very descriptive competencies of the occupation, the model left room for institutions to include other competencies that are tailored for local industries. For example, the Mechatronics Diploma programs at the Tennessee Colleges of Applied Technology include courses in welding and CNC milling and turning operations.

However, in some areas ambiguities could arise. For example, the DOL-ETA model did not point to any competencies in solid state devices, despite that the Mechatronics Technician occupation and the "Electrical and Electronic repairer- Commercial and Industrial Equipment" occupations shared the same number. In addition, it did not include any competencies in embedded systems nor milling operations. These competencies are considered core 2-year educational competencies by the widely-adopted curriculum of the Siemens Professional Education in the Siemens Technik Akademie [11].

Furthermore, the DOL-ETA model left room for more advanced competencies in tiers 6-9, but the door was open for specifications. For example the model did not list knowledge of Manufacturing Processes as a competency, but it is a competency commonly adopted in 4-year mechatronics technology programs such as in Pennsylvania Western University (formerly known as California University of Pennsylvania) [12], Greenville Technical College, University of Tennessee at Chattanooga [13], and Austin Peay State University [14].

In addition to the DOL, many state and federal agencies contributed significantly in the development of mechatronics educational and training programs. Table II below lists some of the projects and institutions that were funded by the National Science Foundation that contributed to promoting mechatronics education in their respective communities.

TABLE II. SOME FEDERALLY-FUNDED PROJECTS THAT RESULTED IN THE PROMOTION OF MECHATRONICS EDUCATION IN THEIR RESPECTIVE COMMUNITIES.

| *NSF Award Number* | *Project Title* | *Sponsor Institution/ State* | *Year* |
|---|---|---|---|
| 1204751 | Florida's Advanced Technological Education (FLATE) Center of Excellence | Hillsborough Community College, FL | 2012 |
| 1400571 | Partnership for Advanced Career Education in Mechatronics Engineering | Virginia Western, VA | 2014 |
| 1304835 | Mechatronics Engineering Technology Distance Learning | South Central College, MN | 2013 |
| 1501854 | Advanced Manufacturing Technicians: Education for an Emerging Workforce | Hagerstown Community College, MD | 2016 |
| 1601544 | Mechatronics with Instrumentation and Controls | Central Community College, NE | 2016 |
| 1601168 | Central Virginia Advanced Manufacturing Initiative | Piedmont Virginia Community College | 2016 |

## II. CURRENTLY AVAILABLE CERTIFICATIONS THAT TARGET MECHATRONICS EDUCATION

There are several major certifications, that have become widely accepted in mechatronics (Siemens Mechatronic Systems Certification (SMSCP), the Packaging and Processing Technologies Association (PMMI), the National Coalition of Certification Centers (NC3), and the recently developed certifications of the Smart Automation Certification Alliance (SACA). Table III summarizes main strengths, features, and shortcomings of three of these certifications.

The Siemens Mechatronic Systems Technician certification is curricular-based with focus on system applications and offered in multi-levels upon successfully passing computer-based examinations. The main strength of this certification lies in its level 1 certification, which links academic courses, with on-ground skills and applications through a systems approach troubleshooting training. The PMMI certification is an occupation-based certification and offered upon completion of laboratory-based and paper-based examinations. In addition, both SACA and PMMI are non-profit organizations. The SACA certification started as a volunteer-based and is more oriented towards Industry 4.0 technologies, and certifications are offered upon successfully completing computer-based examinations in specialized areas such as Internet of Things (IoT) [15], Smart Manufacturing [16] , and Industrial Robotics [5]. The National Coalition Certification Centers (NC3) administers a fourth mechatronics certification that is gaining market share in the Tier 5 competency area of the DOL model. NC3 offers individual certifications in three levels per subset of mechatronics, and climax into one overall certification. Table III compares three certifications in terms of competencies. Due to space limitation, only three certifications are listed in Table III.

Therefore, of the three certification organizations, SACA certifications are application-oriented and fit with tiers 6 to 9 of the DOL model, while the Siemens and PMMI certifications cover fundamental competency areas in Tier 5 of the DOL model of the occupation.

TABLE III. ALIGNMENT OF THE SMSCP, SACA, AND PMMI CERTIFICATIONS WITH THE MECHATRONICS COMPETENCIES RECOGNIZED BY THE U.S. DEPARTMENT OF LABOR.

| **Alignment to DOL-ETA Technical Competencies:** | **Siemens Mechatronic Systems Certification** | **Smart Automation Certification Alliance** | **Packaging and Processing Tech. Association (PMMI)** |
|---|---|---|---|
| • **Mechatronics:** | | | |
| Project Planning: | Yes | Not known | Not known |
| Symbols | Partially aligns | Not known | Partially aligns |
| • **Mechanical:** | | | |
| - Mechanical Components | Yes | Not known | Yes |
| - Measurements | Yes | Not known | Yes |
| - Complex Components | Yes | Not known | Yes |
| - Lubrication | Not known | Not known | Yes |
| - Pneumatics, Hydraulics, Advanced techniques | Yes | Yes | Yes |
| • **Electrical:** | | | - |
| - AC/DC, electrical components, logic gates | Yes | Partially aligns | Not known |
| - Wiring | Not known | Not known | Not known |
| - Power Distribution | Not known | Not known | Not known |
| - Electric machines, schematic symbols | Yes | Not known | Yes |
| • **Computers: PC, PLCs** | Yes | Yes | Yes |
| • **Controls** | | | |
| Process control: | Not known | Not known | Not known |
| System documentation: | | Not known | Not known |
| Motion Control: | | | |
| Motors | Partial | Partial | Partial |
| Robotics | Not known | Advanced | Not known |
| • **Industrial Safety** | | | |
| - Alarm management, Reliability | Not known | Not known | Not known |
| - Machine Guarding | Not known | Not known | Not known |
| - Manufacturing Safety | Not known | Not known | Not known |
| - System Troubleshooting | Yes | Not known | Not known |
| **Industry 4.0 competencies** | | | |
| - Additive Manufacturing | Not known | Not known | Not known |
| - Machine Vision | Not known | Yes | Not known |
| - Internet of Things (IoT) | Not known | Yes | Not known |
| - Intelligent (Collaborative) Systems | Not known | Not known | Not known |

The features of each of the three certification organizations are shown in Table IV.

TABLE IV. COMPARISON OF THE THREE MAIN MECHATRONICS-RELATED CERTIFICATIONS.

| | **Siemens Mechatronic Systems Certification** | **Smart Automation Certification Alliance (SACA)** | **Association for Packaging and Processing Technologies (PMMI)** |
|---|---|---|---|
| **Non/For-Profit** | For-Profit | Non-Profit | Non-Profit |
| **Features** | - Covers Tier 5 competencies in the DOL model<br>- Certification examinations are computer-based in three levels.<br>- Comprehensive Certification | - Covers primarily Tiers 6-9 in the DOL model<br>- Certifications focus on latest Industry 4.0 technologies<br>- Application-oriented certifications | - Covers core Tier 5 competencies<br>- Examinations map to clearly stated competencies<br>- Thorough examinations that include Laboratory-based assessments |

## III. JOB MARKET AND GROWTH TRENDS

According to the O*NET database system that is maintained by the U.S. Department of Labor- Employment and Training Administration, the occupation of Mechatronics Technologists and Technicians (17-3024.00) exhibited a median wage of $60,360 annually, and the top industries at which job placement takes place are the Manufacturing industry and the Professional, Scientific, and Technical Services. The projected growth rate is -2 % or lower in the next decade, which coincides with other engineering and engineering technology occupations, particularly in the post-pandemic era. Table V shows the job growth projections for the decade 2021-2031 for different occupations.

TABLE V. PROJECTED GROWTH RATES FOR DIFFERENT OCCUPATIONS.

| Occupation | O*NET number | Projected Growth |
|---|---|---|
| Mechatronics Technician & Specialist | 17-3024.00 | -2 % |
| Mechatronics Engineers | 17-2199.05 | 0 % (no change) |
| Mechanical Engineers | 17-2141.00 | 2 % (Below Average) |
| Electrical Engineers | 17-2071.00 | 2 % (Below Average) |
| Computer Network Support Specialists | 15-1231.00 | 4 % to 7 % (Average) |
| Engineering Teachers, Postsecondary | 25-1032.00 | 11 % or higher (Much faster than average) |
| Lawyers | 23-1011.00 | 8 % to 10 % |
| Clinical Nurse Specialists | 29-1141.04 | 4 % to 7 % |

## IV. Results and Discussion

### A. Mechatronics Future Growth:

From table V, the projected negative and lower than average growth rates are common across engineering and engineering technology occupations that require Bachelor's or lower degrees, but remarkably strong for occupations that require a postsecondary engineering education (the Engineering Teachers Occupation). This is attributed to two factors: the first one being the near saturation in the job market for Bachelor's or lower degrees, and the increased demand for research and innovation, and high-level engineering training. Historically, the United States job market depended on foreign talent to cover the gap in research and innovation and associated engineering training.

The second contributing factor is the post-pandemic "New Normal" trend of remote work that caused significant changes in occupational profiles. The recovery process from the CoVid-19 Pandemic has taken two diverging routes: the "Back to Normal" and the "New Normal" routes [17]. Due to their hands-on nature, the engineering and engineering technology fields had adapted conservatively to the "New Normal" trend. In addition to that, the hard-hit manufacturing industry due to the pandemic has a long-term effect on the job placement of technicians and engineers that is detailed in the next section.

The results also indicate that future trends will shift towards individuals with master's degrees or higher, and that young engineers and technologists will eventually have to pursue graduate degrees to secure spots in the highly competitive job market.

### B. Impact of CoVid-19

The CoVid-19 pandemic affected almost every aspect of the human civilization. It resulted in severe supply chain disruptions and exposed the need to develop self-sufficiency on the regional and national levels [18] [19]. One of the results of the pandemic was the emergence of virtual classrooms, scientific conferences and workshops, and even engineering labs that are controlled remotely [20]. While many fields may benefit from the increased demand for remote learning, in other fields of science, the trend in remote learning may be an impediment. Mechatronics education is one of the fields in which typically hands-on engineering and technology practices are required for meeting the learning outcomes [21]. One way to counter that is the use of micro-labs that can be sent to students, or web-connected equipment to microcontrollers, and advanced software such as NI™ LabVIEW. In another approach, an onsite operator assists in carrying out the lab experiments that require specimen replacements, or part replacements, and data collections for each student [21]. However, in all these approaches, cost may be considerably higher due to the need of specialized equipment and the required number of physical stations that are needed to satisfy the number of students, or a dedicated lab operator over an extended period of time. Digital twinning stands out as the only method that can effectively assist in remote training with virtual hands-on practice that allows the user to interact with a virtual model in real time that is identical to the real physical system [22].

On the long term, the pandemic had its impact on the Mechatronics field as in other fields, with increased demand for technologies that can assist in contactless tasks [19] [23], such as the utilization of service robotics in contactless material handling in non-industrial settings, as well as the demand for additive manufacturing that skyrocketed during the pandemic to counter supply chain disruptions and increase self-sufficiency [24].

## V. Conclusion

The Mechatronics Technologist and Technician occupation was formalized as an occupation by the DoL-ETA in 2019, and finalized in 2022 under the occupation number 17-3024.00 as "Electro-Mechanical and Mechatronics Technologists and Technicians". Multiple organizations offer certifications for Mechatronics graduates that range from occupation-based to curricular-based and that assess graduates in the competencies in tiers five and higher in the DoL Mechatronics occupation model. The major future challenge that faces mechatronics education is the decline in the job market that is projected to stand at -2 % over the next decade for holders of bachelor's or lower degrees. This decline is coupled with an aggressive growth in the job market for holders of graduate degrees (standing at over 11% growth). This significant difference is due to the growing gap between the demand for personnel in the research and development area, and associated engineering training, as well as the oversaturation of labor force at the process engineering and maintenance levels.

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