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Paper ID #32239

Focusing on the Silver Lining: How COVID-19 Pandemic is Influencing the Pedagogy of Mechatronic Course Delivery to Support the Industrial Role of a Mechanical Engineering Technologist

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Abstract

The COVID-19 Pandemic has created widespread disruption in higher education. This has been especially felt in the engineering field, which has traditionally relied on applied laboratories to deliver course material effectively and efficiently. In particular, courses in the Mechatronic domain that integrate mechanical components, electrical systems, and programing rely heavily on applied labs to instruct students on this interdisciplinary topic through hands-on activities. At New Jersey Institute of Technology (NJIT), these applied labs have been facilitated in the Mechanical Engineering Technology (MET) program by using a combination of LogixPro Mechatronic simulation software and Amatrol Mechatronic learning stations. Up until the Fall 2019 semester, this approach worked very well and there was no real need to re-examine the instructional delivery pedagogy. All this changed very quickly when the COVID-19 Pandemic disruption during the Spring 2020 semester prevented access to the Amatrol equipment, forcing the course to rely heavily on the LogixPro software. Even though it was a very challenging transition, there was still a silver lining to it. The positive result of this situation was revisiting the role of a MET graduate in industry and the focus of a Mechatronic curriculum in preparing for a Mechanical Engineering Technologist role. This paper discusses how the COVID-19 disruption had a profound impact on how a lab-based mechatronic course should be taught using a synergetic blend of the old school and modern teaching pedagogies. This point is presented through the observation of a senior-level Mechatronic course operating under typical conditions (Fall 2019), in an emergency transition to online (Spring 2020), and fully online (Summer 2020). The observations suggest that an Event-Driven Sequencing (EDS) focus can be maintained in an online environment through creative use of the LogixPro software. This finding provides an important option for MET programs seeking not only to survive in this pandemic situation but also to attract more distance-learning students. It also outlines cost-effective methods to conduct applied laboratories in their Mechatronic courses.

1. Introduction

The reshoring of manufacturing in the United States requires a retraining of a workforce to utilize advanced manufacturing tools and techniques and automation **[1]**. Automation requires training in mechatronics, which integrates mechanical and electrical systems to develop automated systems that are controlled with programming. Mechatronics is the foundation of automated systems and has become not only a need to shorten the current manufacturing skills gap **[2]**, but also serves as a platform to provide STEM education.

Mechatronics is an important area of study for several STEM related fields, but specifically for the applied ones such as Engineering Technology (ET). ET as a discipline has existed since the 1950's and developed in response to engineering programs becoming more and more theoretical in nature **[3-4]**. The American Society of Mechanical Engineers (ASME) has a continuum model demonstrating the overlap in an engineering education as opposed to an engineering technology one **[3]**. An engineer's education resides more on the analysis side of the continuum, and engineering technology on the production. The middle area shared by both disciplines are the activities associated with design and development. Therefore, the roles of an engineer and engineering technologist can overlap. Mechanical Engineering Technology (MET) has different forms across the United States. At New Jersey Institute of Technology (NJIT), MET is a focused program for those that are targeting an applied career in industry. MET students in the ABET accredited program at NJIT take similar courses to their Mechanical Engineering (ME) counterparts with the reduction of specific math courses that would be needed for a theoretical background utilized in ME graduate studies. Please see the ME (Click Here) **[5]** and MET (Click Here) **[6]** curriculum differences described on our University's website. The theoretical or intensive math-based ME courses are replaced with MET key courses that are more applied in nature. This includes mechatronics, which has been seen to be a key course for applied engineers entering the industrial workforce. There are different focus areas that can be taken in a mechatronic education program, namely:

- A***utomation design***: including the event driven sequencing (EDS), component selection, electro-mechanical design, programming layout, and respective design documentation.
- A***utomation production***: including the respective wiring, integration of electrical/mechanical components, and fundamental programming of the hardware.

The approach taken at NJIT was to use aspects from these two focus areas towards the development of pedagogy in our senior level course. The constraint of a one semester senior level course prompted us to focus on ***automation design*** with the addition of ladder logic programming on Programmable Logic Controller (PLC) hardware. The course focused on EDS, which not only serves Technologists that want to pursue mechatronics in their careers, but also apply the problem solving techniques to other engineering areas. Understanding EDS is a key principle towards the selection of components and programming of automated systems. EDS is an established method for the engineering of software for manufacturing systems **[7]**. EDS' importance in mechatronics is not only in the development of the software but also in defining the mechanical events needed to achieve the design criteria of the automated system. EDS is defined in mechatronic training manuals **[8]** as the following:

- Automated systems have a number of actions that are needed to complete a specific task.
    - The specific action is termed a sequence-step or ***event***.
- The specific order of these actions is defined as a ***sequence***.
- Automated systems can be defined with a series of numbered steps and the expected ***event***.
    - This is typically done with a respective table.
- EDS can then be used to create the ***sequence*** of ***events***, where an input device is used to sense that one ***event*** has completed and to signal the next ***event*** to begin.

- Software programming (ladder logic) can then be used on a PLC to cause each ***event*** to occur.

The transition away from face to face courses in response to the COVID-19 pandemic forced our department to revisit the course structure and whether an online version could still convey the pedagogy involving EDS. This evaluation required revisiting the role of an MET and their respective role in industry. Many employers familiar with engineering technology programs do not differentiate between engineer technologists and engineers **[3-4, 9]**. However, those that are unaware of engineering technology as a discipline confuse it with 2-year technician programs. Fundamentally, these two areas are different in terms of the level of education. Technologists are those that have completed a four-year degree program in ET whereas a technician is one who has completed a 2-year program **[3]**. The responsibilities of technologists and technicians in industry is different **[3, 10]**. The technologist role includes designing whereas the technician does not have this responsibility **[3]**. Therefore, a Technologist applying mechatronics in industry is expected to have a foundation in the design of an automated process.

Mechatronic design in industry can be conducted completely with software without physical interaction with the constructed equipment. The integration between mechanical and electrical components completed in Computer Aided Design (CAD), electrical schematics produced in CAD, software logic described through software, and control programming done offline. ESD verification can also be conducted through software as well, where developers use the ladder logic software running as an emulator or utilize more advanced methods such as Model-Based-Design **[11]**. It is only at the validation phase of an automated process that a designer requires interaction with a physical system. This software driven approach to mechatronic design provided a guide to how our ***automation design*** focused senior level course could still be delivered online without physical mechatronic lab equipment. The question remained whether the removal of physical mechatronic lab setups would have a significant disruption in the course pedagogy resulting in a failed delivery of learning objectives.

2. Course Structure & Facilities

The senior level mechatronic course is intended to introduce MET students to the use of a PLC as a tool for industrial controls of machines and processes. By the end of the course, the students were expected to be able to:

- Develop simple PLC programs using basic PLC functions.
- Develop PLC Ladder Diagrams.
- Design and develop a PLC automated process.
- Prepare and present a technical report.

The course is designed such that the lectures precede hands-on labs on PLC units. The Petruzella Programmable Logic Controllers textbook from McGraw Hill **[12]** has been implemented in the course. The accompanying Petruzella lab manual provides students with homework utilizing the LogixPro Allen Bradley RSLogix Simulator software (LogixPro). This software is also utilized by the students to conduct their course automation project. The course's hands-on labs utilize the Robotics and Automatic Controls laboratory (**Figure 1**).

Figure 1. Representative image of NJIT's Robotics and Automatic Control Laboratory.

This facility contains five Amatrol Siemen's PLC mechatronic stations (990-PS712) and five custom built IDEC PLC trainer units (**Figure 2**).

A **B**

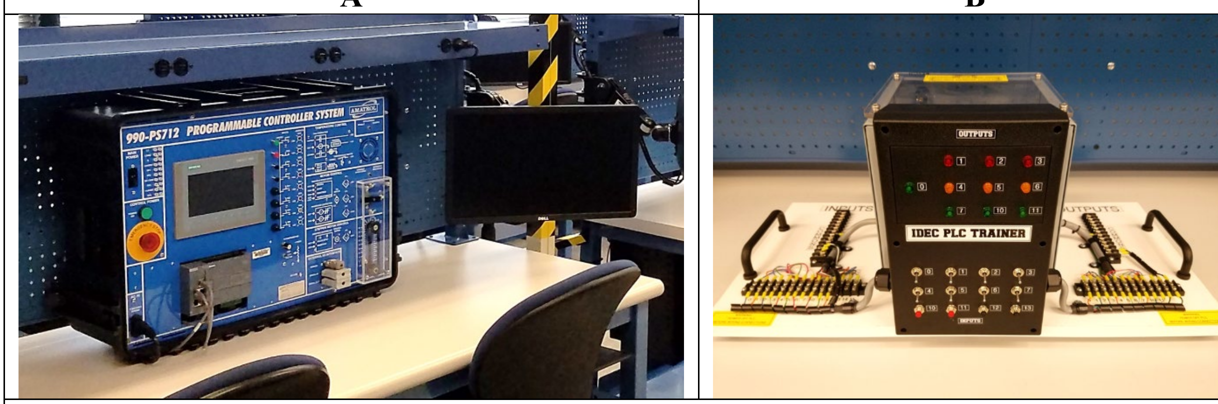


Figure 2. Representative image of (**A**) Amatrol Siemen's PLC mechatronic training units and (**B**) IDEC PLCs in custom enclosure and light/switch panel.

The Amatrol PLC Training System includes a Human Machine Interface (HMI) panel, motor control components, toggle/push button switches, lights, and analog inputs and outputs. The IDEC trainers consist of toggle/push button switches, and lights. The use of the Siemens and IDEC PLCs as well as RSLogix simulator (e.g. Allen Bradley) provide students with the opportunity to explore the differences in PLC programming languages while at the same time understanding that automatic control programming with ladder logic has a consistent structure.

2.1.Fall 2019 Laboratory Structure

The laboratory schedule during the pre-pandemic period (Fall 2019 and earlier) is described in **Table 1**. These labs utilized the Amatrol and IDEC units.

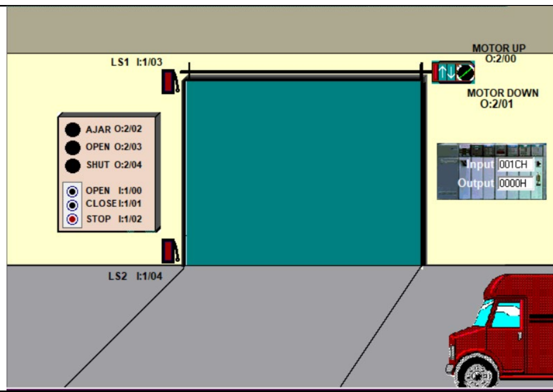
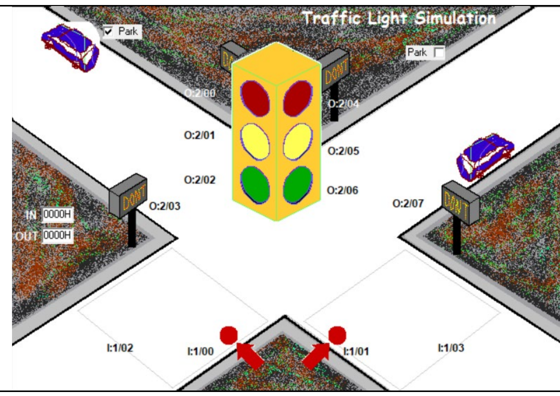
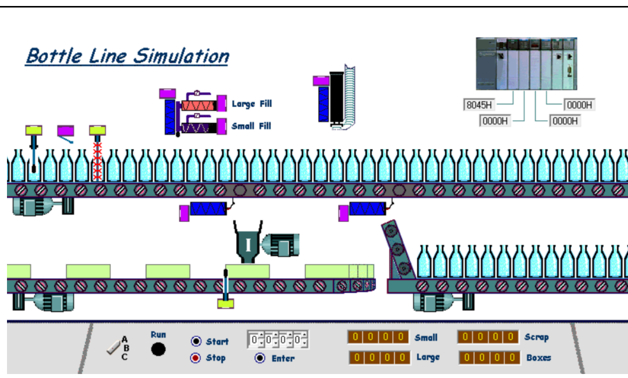
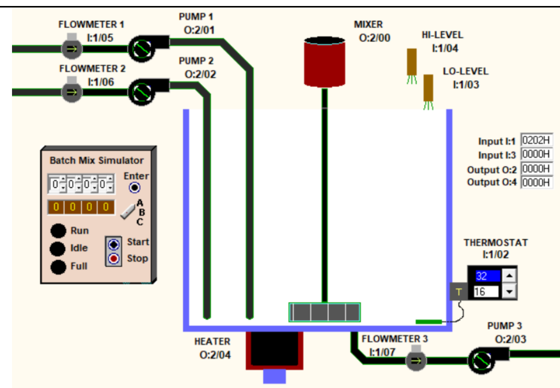
Table 1. Labs conducted during the Fall 2019 semester.

Lab	Lab Title	Overview
1	Overview of Programmable Controller System and Operation of Basic PLC Logic Elements (Amatrol)	Students become familiar with components on the Amatrol Mechatronic unit. They begin basic programming with Ladder Logic.
2	Introduction to PLC Programming (Amatrol)	Students continue the basic PLC ladder logic programming using the Amatrol units.
3	Timer Instructions (Amatrol)	Students build on their ladder logic programming implementing timer instructions.
4	Motor Control (Amatrol)	Students combine their ladder logic basis and timers towards the control of the motor on the Amatrol mechatronic system.
5	Counter Instructions (Amatrol)	Students build on their ladder logic programming implementing counter instructions.
6	Event Sequencing (Amatrol)	Students explore how to accomplish the tasks for an automatic machine with EDS. The specific order in which these actions are performed is called a sequence and each action is called an event.
7	Human Machine Interface (Amatrol)	Students explore how to use a Human Machine Interface (HMI) to trigger events and monitor systems.
8	Introduction to IDEC PLC Programming (IDEC)	Students become familiar with components on the IDEC unit, learn how to conduct basic ladder logic programming, and differences/similarities with Siemen’s PLC unit and Allen Bradley Logix Pro simulation software. Event sequencing is emphasized with the toggle switches, push buttons, and lights.
9	IDEC PLC Timing (IDEC)	Students learn how to conduct timer instructions, and differences/similarities with Siemen’s PLC unit and Allen Bradley Logix Pro simulation software. Event sequencing and is emphasized with the simplified PLC system. Event sequencing is explored with timing routines coupled with the toggle switches, push buttons, and lights.
10	IDEC PLC Counters (IDEC)	Students learn how to conduct counter instructions, and differences/similarities with Siemen’s PLC unit and Allen Bradley Logix Pro simulation software. Event sequencing is explored with counter routines coupled with the toggle switches, push buttons, and lights.

2.2. Spring 2020 Laboratory Structure

The Spring 2020 semester was interrupted by the COVID-19 pandemic. Approximately 60% of the course was conducted face-to-face until it had to be transitioned to synchronous online. Synchronous online is defined as an online course taking place during day and time noted for the face-to-face course. Laboratories 7-10 described in **Table 1** had to be transitioned to an online option. The option involved supporting the EDS education. This involved the use of LogixPro and the series of automated process simulations available (**Table 2**). LogixPro has been suggested as a possible online alternative for mechatronic instruction **[13-14]**.

Table 2. Simulators on LogixPro

Door Simulator	**Traffic Simulator**
	
Bottle Line Simulator	**Batch Simulator**
	

The industrial process simulations consist of input (e.g. push buttons) and output (e.g. motors and lights) components to provide the students with an environment to learn EDS and control programming through ladder logic. The simulations let the students know if their choices result in a process failure. This includes motors catching on fire or bottles breaking if the appropriate EDS is not selected and implemented. Thus, the simulation provides a platform to not only verify a function but also to validate the automated process design. **Table 3** describes the online transition labs implemented during the Spring 2020 semester.

Table 3. Online transition labs conducted during the Spring 2020 semester.	
Lab Title	**Overview**
Utilizing Door Simulator	Students write a documented program that will implement a hardwired reciprocating motion machine. Simulation is done with a door simulator.
Utilizing Traffic Simulator	Students write a documented program for traffic flow on a one-way street, which is to be controlled by means of a pedestrian pushbutton. Simulation is done with a traffic simulator.
Utilizing Bottle Line Simulator	Students write a documented program for an automatic stacking process, where a conveyor is used to stack metal plates onto another conveyor. Simulation is done with a bottle line simulator.
Utilizing Batch Simulator	Students write a documented program to trigger events for a batch mixing process. Simulation is done with a batch mixing simulator.
Utilizing I/O Simulator	Students write a documented program to trigger events for a can count program. Students utilize a Math count routine for cans that are introduced and removed with conveyors. Simulation is done with a I/O simulator.

2.3. Summer 2020 Laboratory Structure

Due to strict federal/state/local government restrictions related to the COVID-19 pandemic and following the university policy guided by it, the Summer 2020 semester was completely conducted online. The mechatronic course in the summer is not administered over a shortened time period. The course takes place over an entire summer session period (May through August), which is a similar time period to how it is administered in the fall and spring semesters. This is the typical operating mode of the mechatronic course (e.g. pre-pandemic). The laboratories were fully conducted with LogixPro.

The labs were structured to continue providing the students a similar structure to the Fall 2019 semester. Students learned new control techniques and mechatronic design principles towards implementation of EDS strategies. This included

- Becoming familiar with mechatronic components.
- Performing basic ladder logic programming
- Building on ladder logic skills with timer and counter operations.
- Utilizing EDS for automation design.

These labs are described in **Table 4**. The topics in **Table 4** cover all those listed in **Table 1** except for a lab that directly covers the HMI topic. The LogixPro simulators outlined in **Table 2** inherently have an HMI component. Therefore, the HMI topic is covered in lecture where real world examples are shown and then is highlighted in the LogixPro simulators used in each lab topic described in **Table 4**.

Table 4. Labs conducted during the Summer 2020 semester.		
Labs	**Lab Title**	**Overview**
1	Overview of Programmable Controller System and Introduction to Logix Pro software	Students become familiar with components on the PLC unit. They begin basic programming with Ladder Logic.
2	Introduction to PLC Programming	Students continue the basic PLC ladder logic programming.
3	Timer Instructions	Students build on their ladder logic programming implementing timer instructions.
4	Motor Control	Students combine their ladder logic basics and towards the control of motors in a Silo Simulator.
5	Counter Instructions	Students build on their ladder logic programming implementing counter instructions.
6	Event Sequencing	Students explore EDS and how to accomplish the tasks for an automatic machine with timing plc operations.
7	Utilizing Door Simulator	Students write a documented program that will implement a hardwired reciprocating motion machine. Simulation is done with a door simulator.
8	Utilizing Traffic Simulator	Students write a documented program for traffic flow on a one-way street, which is to be controlled by means of a pedestrian pushbutton. Simulation is done with a traffic simulator.
9	Utilizing Bottle Line Simulator	Students write a documented program for an automatic stacking process, where a conveyor is used to stack metal plates onto another conveyor. Simulation is done with a bottle line simulator.
10	Utilizing Batch Simulator	Students write a documented program to trigger events for a batch mixing process. Simulation is done with a batch mixing simulator.
11	Utilizing I/O Simulator	Students write a documented program to trigger events for a can count program. Students utilize a Math count routine for cans that are introduced and removed with conveyors. Simulation is done with a I/O simulator.

3. Course Observation During Transition

RSLogix has been shown for several semesters (2019 and prior) to be an effective homework compliment to mechatronic physical labs. Although the software has been successful for homework, there were still several challenges during the transition to utilize it fully for synchronous online labs. The main challenge was management of student expectations. Students initially demonstrated disappointment that they would not be able to directly apply skill sets to physical equipment. The students soon saw; however, that the simulation software presented more of an opportunity to practice and grasp the key aspects of automation. The availability of the simulation software on the student's PC provided more opportunities for them to practice their skill sets (e.g. EDS planning and implementation) as opposed to the hard-wired physical units, which have limited access even under normal (pre-pandemic) conditions. The simulations also provided a rapid feedback system for students to try concepts and receive immediate input on whether their programming achieved the result. The simulation clearly demonstrated the deleterious effect of incorrect event sequencing and programming, which resulted in motors overheating, bottles crashing, or tanks overflowing with liquid in respective simulations. Although there were several advantages to the simulation software, students still lamented not having access to the equipment. That tangible feel of triggering a switch and watching a mechanical item activate still appeared important for several students.

4. Preliminary Analysis of Student Performance in Course Across Different Modalities

The summative assessments including, exams, automation project, homework, and lab reports remained the same across the different modalities. The formative assessments; however, changed during the transition to the online mode. This was seen especially in the laboratory portion of the course, where the online lecture still allowed for the instructor to challenge students with concepts and have a discussion. The typical modality (Fall 2019) for the laboratory portion allowed the professor to approach a lab group's station, challenge the students on a concept or troubleshooting scenario, and observe if they were able to implement a solution on a PLC mechatronic station. This mode of formative assessment was efficient in a face to face environment, where the instructor could move seamlessly from group to group, and also interpret student body language to determine whether support was needed. The emergency shift to online seen in the Spring 2020 semester eliminated this formative assessment methodology. The instructor adjusted by pausing the students during the online sessions and asking for feedback. This was helpful to address problems; however, the online modality did not clearly allow the instructor to interpret in real time when students were having difficulties. In addition, not all students had a web camera to allow for a body language interpretation of student difficulty. The instructor used the Spring 2020 experience to increase the number of pause points during the laboratory portion of the fully online Summer 2020 semester. Anecdotally, this did not demonstrate a clear improvement in assessing student difficulties.

The formative assessment in the Spring and Summer sessions could potentially have been improved with the further use of web cameras. Unfortunately, this could not be made a requirement for the course under this emergency implementation of online education. The hardship of purchasing a web camera could not be enforced as this was not a clear requirement established in the beginning of the Spring 2020 semester. In addition, even those students that wanted to purchase the hardware prior to the Summer 2020 semester had issues sourcing it as demand was high across the United States. There were also privacy concerns expressed by students that were thrust into an unexpected online situation. Future established online mechatronic courses could require students to have this hardware as well as understand that its use is a needed aspect of the course.

New or modified summative assessments may also be needed to evaluate the effectiveness of the EDS education delivered in an online environment. The LogixPro simulations are detailed, and clearly define all components. This is a powerful tool to convey principles, but in practice electro-mechanical components are not always so clearly defined. The physical mechatronic laboratory setups provide a platform to assess if a student can not only apply mechatronic principles on a textbook figure/animation but also on physical components. Therefore, a new or modified summative assessment may need to be implemented to assess the student's ability to translate an EDS education to a physical electro-mechanical system. This may involve enhancing the final project by including the integration of a physical mechatronic education kit that students can utilize at home. The selection of such a kit would involve balancing the assessment needs of the course with the financial burden on the students.

The preliminary performance of the students in the course is described in **Tables 5-6** and **Figure 3**. A one way ANOVA was conducted demonstrating there was no significant difference between the groups ($p<0.05$). This indicates that the change in the course did not significantly affect the student preliminary performance and hence students meeting the desired learning outcomes. Since the transition of the course from face-to-face to online was a forced one and not because of a pre-designed experiment; this is a general analysis and did not factor in all aspects that could affect student preliminary performance. This includes other areas that could affect student performance such as the introduction of proctored online exams.

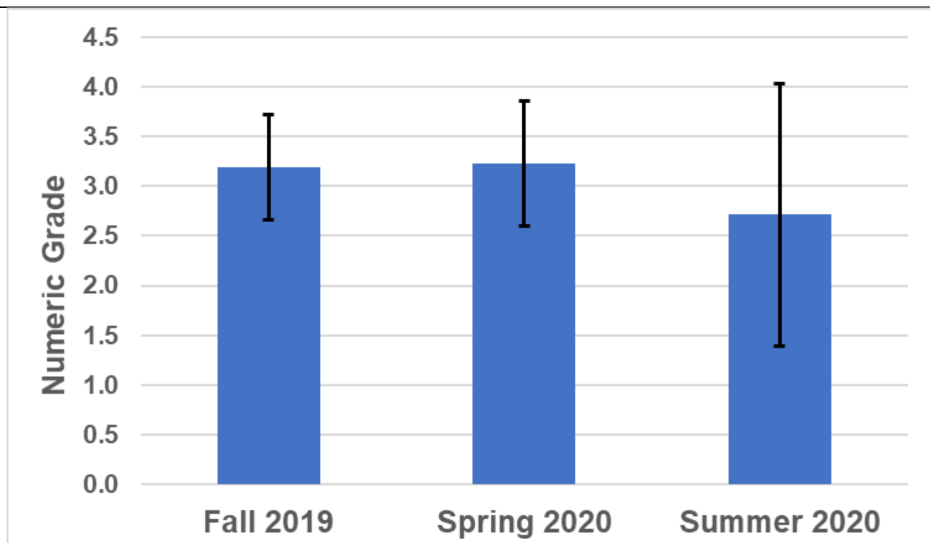


Figure 3. Comparison of average grades for Fall 2019, Spring 2020, and Summer 2020.

Please note that the variation is higher in the Summer 2020 semester (**Table 5**) primarily due to low enrollment numbers, which is quite typical for a summer semester. This may be reduced with a larger student population. This would have to be further explored in the Fall 2020 semester, where a larger student population would be available and the delivery method will remain the same as in Summer 2020.

Table 5. Grades for Fall 2019, Spring 2020, and Summer 2020.			
Semester	**Average Grade**	**Grade Standard Deviation**	**Number of Students**
Fall 2019	3.2	0.5	24
Spring 2020	3.2	0.6	40
Summer 2020	2.7	1.3	7

The grade distribution also demonstrates similarities between the Fall 2019 and Spring 2020 semesters (**Table 6**). The Summer 2020 demonstrated differences from the regular fall and spring semesters, but again this may be affected by a low sample number and would have to be further explored with a larger data set in the Fall 2020 semester.

Table 6. Grade Distribution

Semester	A	B+	B	C+	C	D	F
Fall 2019	5	4	10	5	0	0	0
Spring 2020	12	6	12	8	2	0	0
Summer 2020	1	2	1	2	0	0	1

5. Conclusions

The COVID-19 pandemic forced the MET program at NJIT to determine the best methods to still convey hands-on laboratories. The definition of the role of MET students had to be revisited in order to determine whether the solutions presented for the laboratories would meet what is expected of MET graduates in industry. The MET professional in the area of mechatronics needs to have a thorough understanding of the hardware and software used in the automation space. They should be familiar with all technical aspects in terms of mounting and wiring systems. However, of paramount importance in their role is the ability to design an automated solution. This requires a thorough understanding of EDS. The mechatronic program at NJIT has delivered EDS education with lectures, face-to-face labs, and the use of simulation software for homework. The switch to synchronous online did not show a marked change in the student grade performance as seen in the Fall 2019 through summer 2020 semesters. This suggests that mechatronic simulation software, such as LogixPro, could provide a viable alternative to physical mechatronic laboratories. The effectiveness of this transition to simulation based mechatronic labs is still being evaluated. Further data will be available after the Fall 2020 semester. Although the simulation software appears effective for the learning objectives in mechatronics education, the reaction from students was not overwhelmingly in favor of abandoning face-to-face laboratory setups. The students still expressed the feeling that they are not learning mechatronics unless they are physically touching a unit. These observations would have to be explored further in future work. Nevertheless, this type of simulation software could serve as a compliment to programs using existing face-to-face lab equipment. In addition, this software could serve as a cost effective alternative for programs that financially cannot afford physical mechatronics systems.

6. Future Work

The Fall 2020 semester is very important to further understanding the impact of the change in mode of delivery for this course on student performance and learning outcomes of the course. Since the enrollment in Fall 2020 is comparable to Fall 2019 and Spring 2020, the shortcomings of the comparative analysis using Summer 2020 data will likely be overcome with the inclusion of new data obtained at the end of the semester. Furthermore, it is also important to understand how this forced transition has affected students' perception of and expectations from the course. The authors are working on setting up a survey to gauge students' perceptions and expectations. This survey, which will be based on an existing (tried and tested) instrument, will be sent to students in all the four semesters referenced in this paper. The authors hope to get a satisfactory response rate, which will provide sufficient data, information and insight to further enhance this study and provide guidance for future course offerings. Moreover, the authors will use experiences from the Fall 2020 semester to evaluate if new/modified summative assessments are needed, and to determine how to construct a study to evaluate the effects of online mechatronic education on formative assessment. Finally, all courses strive to meet the learning outcomes that are usually in-line with the expectations of accreditation agencies. The authors intend to access the course to gauge how effectively students met the learning outcomes through different modalities. This evaluation will be done using ABET style rubrics and will form the basis of a follow-up paper.

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