

## Online Hands-on Embedded System Project in Virtual Classroom

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## Abstract

Across the world, COVID-19 has shifted the education model by forcing classroom in-person classes to transition into the distance and online learning mode. Engineering and technology programs having a curriculum with a strong emphasis on hands-on labs are facing challenges. The education community around the world is looking for options to adopt the online approach to deliver hands-on courses via Zoom, Blackboard, or video conferencing services, using simulators and other digital tools. To measure the effectiveness of the new educational model, the assessment must be redesigned. We must examine student mastery of the course learning outcomes as measured by several instruments, including labs and hands-on projects. In this paper, we present the design of a hands-on project lab for embedded systems and its corresponding assessment instruments. The embedded system project lab includes topics such as circuit analysis, analog, and digital electronics, computer programming skills, basic instrumentation, and computers to aid in the characterization and troubleshooting. As part of the requirements in this hands-on project lab, students must connect the electronic components and devices correctly on the breadboard without the instructor's in-person supervision. Students need to use instrumentation, for example, a multimeter, an oscilloscope, and a function generator in the project lab. The paper also presents a practical approach using the Tinkercad simulator for hands-on labs and teaching students in a virtual classroom. The assessment model includes a rubric and a content validity form with performance indicators to assess ABET Student Outcomes (a) and (b) and the program-specific criteria for Electromechanical Engineering Technology.

**Keywords**— remote online learning, simulator, electronics, instrumentation, embedded project, programming, assessment

## Introduction

COVID-19 has shifted the education model by forcing classroom in-person classes to transition into the distance and online learning mode. Engineering and technology programs having a curriculum with a strong emphasis on hands-on labs are facing challenges [1,2,3]. To keep preparing competent technicians who have the skills needed by the computer industry, there is a need to develop online settings that provide the required learning experiences. So our initial question was, what are some effective approaches during the COVID-19 pandemic to motivate, coach, and deliver online distance instructions to the diverse student body? For AAS Electromechanical Engineering Technology and Similarly Named Programs accredited by ETAC/ABET [4], graduates must demonstrate abilities satisfying ABET program criteria student outcomes: (a) application of computer-aided drafting or design tools to prepare graphical representations of electromechanical systems; (b) application of circuit analysis, analog and digital electronics, basic instrumentation, associated software and computers to aid in the characterization, analysis, and troubleshooting of electromechanical systems; and (c) application

of statics, dynamics (or applied mechanics), the strength of materials, engineering materials, engineering standards, and manufacturing processes to aid in the characterization, analysis, and troubleshooting of electromechanical systems.

The AAS in EMT program prepares students to be proficient in electrical technology, mechanical and electromechanical technology, computer hardware, computer software, computer networks, use of engineering principles to integrate these technologies to control electromechanical devices and develop computer-controlled and embedded systems. The Electromechanical Systems: Software Interface course (EMT 2461) is offered as an Associate-level capstone course to upper sophomores (AAS students) and lower juniors (BTech students). Each lesson has a one-hour lecture and a two-hour laboratory. The class meets every week. The course integrates the base of several engineering technologies (electrical, electronics, mechanical, and computer). The capstone project aims to integrate knowledge, methods, and problem-solving skills that students learn in previous courses. Before this course, students acquire some experience working with electrical circuits, analog and digital circuits, embedded systems hardware development environments, oscilloscopes, function generators, digital multimeters, power supplies, C/C++ programming, and more. The course is designed to build students' competence in integrating and applying basic science, mathematics, and principles to actual technology practice via open-ended design solutions.

This paper introduces a model for a hands-on project lab that fits the online educational approach to deliver hands-on courses via Zoom, Blackboard, and video conferencing services using simulators, portable devices, and other digital tools. The paper is organized as follows. The following section presents the model used to design and assess the hands-on embedded system project lab, which considers the online educational approach, the assessment instruments needed and aims to integrate circuits, electronics components, and embedded systems. In the third section, the assessment results are described and students' competencies are discussed. Finally, the conclusions of our work are summarized, and a short discussion is presented.

## **Online hands-on embedded system project lab design**

### **A. Challenge**

Engineering Technology students benefit from hands-on laboratory education and take-home project. As part of the requirements of the AAS in the EMT capstone hands-on project lab, students must connect the electronics components and devices correctly on the breadboard. Students must know how to use basic instrumentation to test and monitor the embedded system, such as to use an oscilloscope, function generator, power supply, and multimeter. The students also need to know how to write and debug programs to control electromechanical devices, such as motors. Traditionally, the instructor would go to each workbench to check and help the students in groups. However, COVID-19 has disrupted face-to-face laboratory teaching. During the pandemic, the engineering technology education model has been shifted by forcing in-classroom classes to go into distance online learning mode [5,6,7]. It is very challenging for students to work on a hands-on embedded project and understand how instruments to be used to measure and test without seeing these devices and electronics components in person. Without the real physical equipment, it is difficult for instructors to show demos and teach as well. So, the project guidance must be

redesigned, and the assessment must be updated accordingly to measure the effectiveness of the new education model. For redesigning the project and the instructions, first, we redesign the assessment rubric. Then we developed a hands-on embedded system project lab to integrate the Tinkercad simulator and a real portable device to replace physical laboratory equipment, and a programming IDE. Finally, we developed a content validity worksheet form that forces a mapping between the rubric's performance indicators to the actual project handout. The form also works as a guide for instructors. During the project deploying phase, the form helps to identify the content to be covered. And during the grading phase, it helps to identify the work of the student project that should be used to score each performance indicator.

## B. Assessment Rubrics for ABET PC-A and PC-B

In the CET department, faculty members are usually free to develop their own approaches to evaluating the students' performance in their class, but they are required to show the evaluation standards. We redesigned the assessment rubrics to cover the Program Specific Criteria of ABET/ETAC 2019-2020 specifications. The rubric's performance indicators map to student outcomes described in the Program Specific Criteria for Electromechanical Engineering Technology, criteria (a) and (b), namely, PC-A and PC-B. The rubric for PC-A contains only one performance indicator associated with it. The rubric for PC-B has two performance indicators. The rubrics' scoring scale is made up of four levels: excellent (level 4), good (level 3), acceptable (level 2), and unacceptable (level 1), as shown in Figure 1.

<b>Assessment Rubric For Student Outcome ABET/ETAC 2019-2020 (PC-A):</b> Application of computer-aided drafting or design tools to prepare graphical representations of electromechanical systems				
<b>Performance Indicator</b>	<b>Excellent 4</b>	<b>Good 3</b>	<b>Acceptable 2</b>	<b>Unacceptable 1</b>
<b>Construct a schematic drawing of an electrical circuit using CAD</b>	Construct a detailed schematic of an electrical circuit	Construct a schematic of an electrical circuit	Construct a partial schematic of an electrical circuit	Cannot construct a schematic of an electrical circuit
<b>Assessment Rubric For Student Outcome ABET/ETAC 2019-2020 (PC-B):</b> Application of circuit analysis, analog and digital electronics, basic instrumentation, associated software and computers to aid in the characterization, analysis, and troubleshooting of electromechanical systems				
<b>Performance Indicator</b>	<b>Excellent 4</b>	<b>Good 3</b>	<b>Acceptable 2</b>	<b>Unacceptable 1</b>
<b>Apply instruments and knowledge of circuit analysis to characterize a circuit used in a prototype electromechanical system</b>	Accurately characterize the behavior of the circuit and present precise and complete technical results.	Accurately characterize the behavior of the circuit.	Present a partial characterization of the circuit	Fail to present a circuit characterization.
<b>Build or simulate, program, and test a circuit using analog or digital electronic devices.</b>	Build or simulate, program, and test a working electrical circuit using analog or digital electronics devices and presents the results of a comprehensive testing process.	Build or simulate, program, and test a working electrical circuit using analog or digital electronics devices and presents the results of a simple testing process.	Build or simulate, program, and test a working electrical circuit using analog or digital electronics devices, but no evidence of a testing process.	Build or simulate an electrical circuit that does not work.

Figure 1 Assessment rubrics with performance indicators

### C. Development of hands-on embedded system project for distance learning

The design of the online hand-on embedded system project lab covers the follows:

- (1) Control the position and direction of a servo motor by supplying varying resistance to the circuit, using a potentiometer;
- (2) Build a circuit on the breadboard by using electronics and motor components;
- (3) Measure and analyze PWM signals from the microcontroller by using the oscilloscope;
- (4) Write a software code to program a servo controller and input a command into Arduino serial monitor to control a servo motor's direction;
- (5) Apply computer-aided CAD software to design the schematic of the system and construct the circuit.

As shown in Table 1, The project's design includes hands-on activities to work with software and real hardware, coding, and using an open-source simulator for hardware. This virtual class project for the capstone class has seven parts. Each part maps to a performance indicator from the rubrics described before.

Table 1 Project lab's software and hardware requirements

<b>Hardware</b>	Computer with software IDE installed Microcontrollers such as Arduino Mega 2560 board or UNO board with USB cable PWM signal on the board Digital Multimeter Oscilloscope 10k $\Omega$ potentiometer Servo motor (SG92R or SM-S2309S or MG90S) or other standard motors 1 x 50nF Capacitor + 1 x 0.33 $\mu$ F Capacitor + 1 x 0.1 $\mu$ F Capacitor 1x LM78xx regulator (1x LM7805) (if 5V is required) NPN transistors Battery Jumper wires and breadboard
<b>Circuit Design Software</b>	Tinkercad or Fritzing
<b>Open-source hardware simulator</b>	Computer with internet access Virtual software IDE The simulation will be completed using Tinkercad Circuits Virtual microcontroller such as Arduino UNO board with virtual USB cable available on Tinkercad Virtual PWM signal on the virtual board Virtual Digital Multimeter Virtual Oscilloscope Virtual 10k $\Omega$ potentiometer Virtual Servo motor or other standard motors Virtual 1 x 50nF Capacitor + 1 x 0.33 $\mu$ F Capacitor + 1 x 0.1 $\mu$ F Capacitor Virtual 1x LM7805 regulator Virtual NPN transistors (if ample power is required) Virtual Battery Virtual Jumper wires and breadboard

Part I introduces the project's background knowledge, such as a voltage divider, polarized and non-polarized capacitors, 3 terminal voltage regulator, PWM signal, duty cycles, and the principle of servo motor control.

Part II shows how to build schematics with open-source Tinkercad [8]. Tinkercad has a realistic and straightforward interface that makes designing circuits intuitive. Students can follow the schematic drawing to use the breadboard and connect the electronics components and devices correctly.

Part III describes creating a Tinkercad account, placing virtual instruments and electronic components connected by colored wires, and building a virtual embedded system to run C code on a virtual Arduino board. If students have a real Arduino microcontroller board, it can be used instead. This section also covers programming and analyzing simulations. Through these simulations, students can measure and record the voltage across the potentiometer and observe the duty cycle of the PWM signal displayed on the virtual oscilloscope. Instructors can use the simulation to present and demonstrate how to build an online hands-on embedded system project through Zoom, Blackboard, or other video conferencing services. Interactive Arduino simulation within Tinkercad designs can be shared over the Internet via collaborative links so that students can remotely request design assistance from their peers or professors. Students do not need face-to-face meetings to get help.

Part IV demonstrates how to use analog or digital electronics to physically build and test circuits in a hands-on manner. Most students have Multimeters, breadboards, resistors, capacitors, LEDs, DC motors, servo motors, sensors, IC chips, colored wires, and starter kits for Arduino projects. The analog and digital IC chips are included in the starter kit, for instance, potentiometers, LEDs, 5V relays, L293D transistors, ULN2003 driver boards, 74HC595 shift registers, etc. Students can follow the realistic Tinkercad schematics to find similar components in their starter kits and physically build hands-on embedded projects at home. Figure 2 shows building and testing circuits by using analog and digital electronics components conducted by students in a hands-on manner remotely.

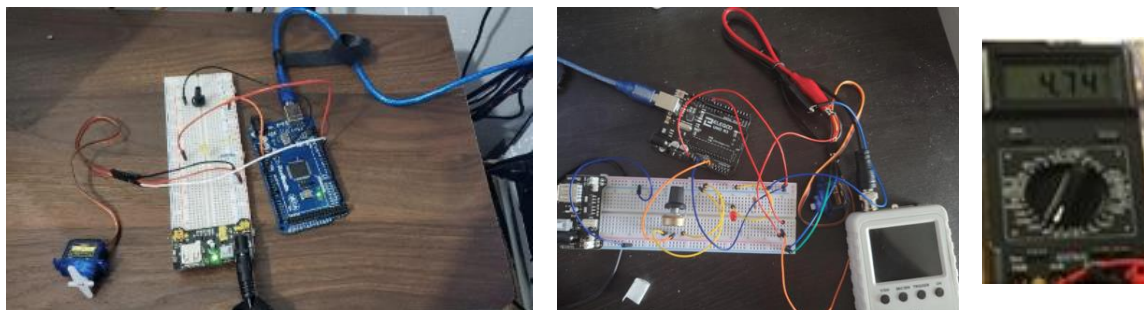


Figure 2 The project lab setup from students remotely

There are handheld pocket digital oscilloscope kits and portable signal generators on the market at affordable prices for students (Figure 3). Students can use portable physical devices to measure

the signals across the potentiometer or LEDs or motors or the output from IC chips on the hands-on project lab and have a troubleshoot at home.



Portable function signal generator



Handheld pocket oscilloscope

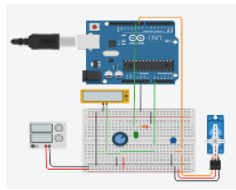
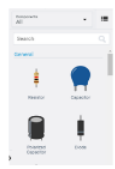
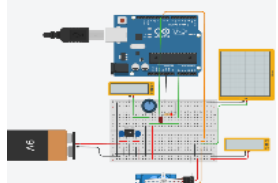
Figure 3 Handheld pocket signal generator and oscilloscope

Part V shows the sample source code for controlling the servo motor. Arduino environment is open-source and easy to use [9,10, 11]. It runs on various platforms such as Windows, Mac OS X, and Linux, which makes it convenient for students to use. The tested code can be copied from the Arduino simulation within Tinkercad to the local computer Arduino IDE. Students shared their lab work via webcam from zoom or Blackboard.

Part VI demonstrates how to measure and characterize circuit behavior and provide accurate and complete results. For this reason, data must be collected by recording the input voltage value and calculating the input resistance value. The Arduino's serial monitor is used to find the analog reading and motor angle in degrees; these are the outputs produced by the code running in the Arduino. The duty cycle of the PWM signal can be calculated by the reading data from either a virtual or portable oscilloscope.

Part VII addresses some topics that students can discuss further based on their interpretation of the results. Students can draw the graph from the collected data and predict the trend. Students should also discuss the use of circuit analysis, electronics, basic instrumentation, and computers to aid in the system's characterization, analysis, and troubleshooting. A sample of the project content for each part and their corresponding performance indicators are shown in Table 2.

Table 2 Samples of the content expected in the project mapped to each performance indicator

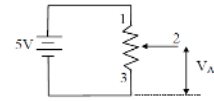
Performance indicator	Sample content in the project
Construct a schematic drawing of an electrical circuit using CAD	A sketch of the designed circuit. Students can use Tinkercad software for Part II.  
	A sketch of the setup, including the virtual oscillator, multimeter, and electronics components for Part III. 

Apply instruments and knowledge of circuit analysis to characterize a circuit used in a prototype electromechanical system

Project background review in Part I.

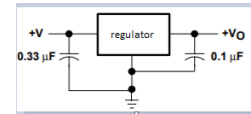
(a) Calculate the duty cycle when receiving a 1.5ms pulse every 20 ms

(b) Find the resistance between the terminal 2 and terminal 3



(c) How to use Servo.h library to create a servo object associated with the PWM output

(d) Study the application of the fixed output regulator



Record the data to characterize the behavior of the circuit and present precise and complete results in Part VI

Record No.	Input voltage (measured) (Volt)	Input resistance (calculated) (Ω)	Read Value (from an analog input) (the record from the serial monitor)	Position (angle in degree) (the record from the serial monitor)
1				
2				
3				
4				
5				
6				
7				
8				
9				

Potentiometer Voltage (V) (sample data)	Pulse Width, Tw (mS)	Period, T (mS)	Duty Cycle $= \frac{T_w}{T} \times 100\%$ (Calculated)	Servo Position (Degrees) (record from a serial monitor)	analogRead Value (record from a serial monitor)
4.50 V					
4.20 V					
3.25 V					
2.50 V					
1.50 V					
1.00 V					
500mV					

The example of topics to discuss in Part VII

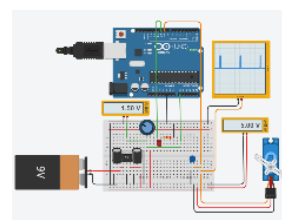
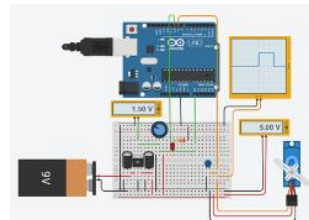
(a) Find the relationship between the servo position and input resistance.

(b) Discuss the relationship between the duty cycle and the servo position in degrees in Part VII

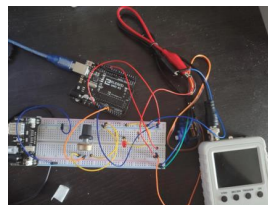
Build or simulate program and test a circuit using analog or digital electronic devices

Use Tinkercad to build and simulate the circuit, observe the PWM signal and different servo angle positions by changing the potentiometer.

Set up and operate virtual test equipment such as virtual oscilloscopes, multimeters, breadboards, electronic components, circuit wiring, and Arduino boards in Part III



Physically build and test a circuit using analog or digital electronic components, portable oscilloscope, and Arduino board (Hands-On) in Part IV



The sample source code to program and control the Arduino embedded system in Part V

```
void loop() {
  val= analogRead(potPin);
  ledDimVal= map(val, 0, 1023, 0, 255);
  analogWrite(ledPin, ledDimVal);

  pos= map(val, 0, 1023, 0, 180);
  if (pos > current_pos)
  {
    for (i =current_pos; i<=pos; i++)
    {
      myservo.write(i);
      delay(15);
    }
  }
}
```



## D. The Content Validity Worksheet for Assessment

The EMT 2461 (Electromechanical System: Software Interface) course is suitable for juniors and sophomores. Multiple sessions are offered every semester, taught by different full-time and part-time professors. A content validity worksheet is a good instrument to help avoid the bias of online embedded projects evaluated by different professors and maintain the consistency of individual scores. The content validity worksheet for assessment (Figure 4) was created to systematically interpret the score decision by each faculty member. The worksheet was developed to assess the associate degree graduating students' competencies and skills using computer-aided drafting, circuit analysis, computer programming, analog and digital electronics, basic instrumentation, and computers to help characterize and troubleshoot in a virtual classroom.

**CET Department Assignment Sample:** Controlling a Servo Motor with a Potentiometer and the PWM Signal from Microcontroller

**ABET/ETAC 2019-2020 program criteria a (PC-A):** Application of computer-aided drafting or design tools to prepare graphical representations of electromechanical systems

**ABET/ETAC 2019-2020 program criteria b (PC-B):** Application of circuit analysis, analog and digital electronics, basic instrumentation, associated software, and computers to aid in the characterization, analysis, and troubleshooting of electromechanical systems

*Instruction: Please read the assignment and the rubric for the student outcomes (PC-A and PC-B). The following is a mapping aiming to help you during the assessment of the following performance indicators.*

***Performance indicator (PC-A): Apply computer-aided drafting to construct a schematic drawing of an electrical circuit using CAD***

*To complete the lab successfully, students have to construct a schematic drawing, as part of the system's design, as the initial task. Students must complete and include **PART II or PART III** (draw a schematic of an electrical circuit using Tinkercad or Multisim) in the lab report. Instructors must check carefully that the microcontroller and all required motor and electrical components are included and connected correctly.*

***Performance indicator (PC-B1): Uses instruments and knowledge of circuit analysis to characterize a circuit used in a prototype electromechanical system***

*In **PART I**, students shortly review the theory and background about electromechanical and electronic devices such as motor, capacitor, resistors, and PWM signal. Students demonstrate their understanding by applying their knowledge while completing the table and graph in **PART VI**. For collecting the data and technical results from the electromechanical system in **PART VI**, students need to use instruments and knowledge of circuit analysis to characterize the circuit. A report of the experiment results, including the students' interpretation, must be provided in **PART VII**-discussion and analysis.*

***Performance indicator (PC-B2): Builds or simulates and tests a circuit using analog or digital electronic devices.***

*The students should be able to set up and operate testing equipment such as Multimeter and Oscilloscope. It is required that all students can follow the schematic drawing to use the breadboard and connect the electronics components and devices correctly. Students must complete and include **PART IV** (build and test a circuit using analog or digital electronic devices) of the lab report. The instructor can also look at **PART V** (Computer programming languages) to evaluate if students can write computer programming and record data for each test.*

Figure 4 The content validation worksheet for assessment

## Assessment results for student outcome

The rubric criteria directly addressed conceptual and detailed embedded project content design. The content validity worksheet for assessment is created to guide all instructors to grade the project systematically. In Fall 2019, the curriculum has adopted the developed hands-on project "Controlling a servo motor with a potentiometer and the PWM signal from microcontroller". We have conducted a pilot study to assess ABET-PCA and ABET-PCB in Fall 2019. Two sessions of EMT 2461 face-to-face classes participated in the pilot study. The target rate was set up as 70 (score 3 out of 4). The assessment result for 37 students is shown in Figure 5. At the beginning of Spring 2020, the newly developed distant learning online hands-on lab handout and project report template were sent to all instructors who taught EMT 2461 remotely. There were four sessions in total of 63 students who were taking an online AAS level capstone course. The Spring 2021 assessment result is shown in Figure 6 with the same target rate of 70, a score of 3 out of 4.

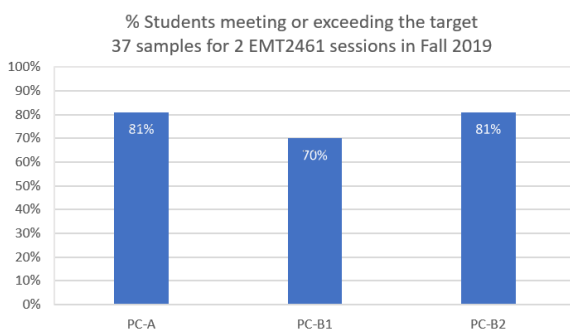


Figure 5 In-person class assessment results in Fall 2019

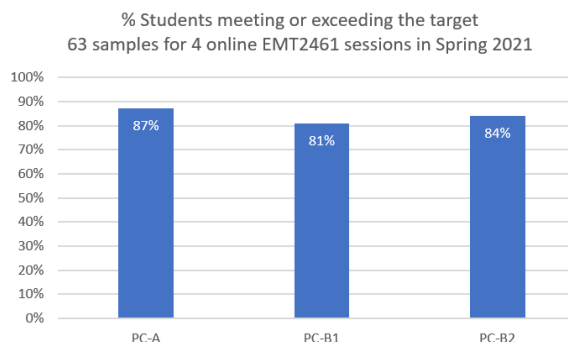


Figure 6 Online class assessment results in Spring 2021

As a result, the PC-A in distance learning models meeting or exceeding 70 reached 87% in Spring 2021, even better than the face-to-face pilot study in Fall 2019, of which 81% of students reach or exceed 70. Similarly, the percentage meeting or exceeding a score of 3 out of 4 for PC-B1 increased to 81% for online learning in Spring 2021, compared to 70% meeting or exceeding the target in Fall 2019. The improvement rate changes up 11% on average. For PC-B2, the rate went up to 84% in Spring 2021 and had a 3% increment compared to the percentage rate in Fall 2019. This shows that tailored instruction designed to use virtual instruments and virtual breadboarding can facilitate hand-on learning with remote students, especially with today's online distant technology education challenges. Using Tinkercad virtual instruments and virtual electronics component, as well as virtual Arduino board provides more opportunities for hands-on learning and activities in the online classroom and get students making, producing, and designing. We also can see the platforms can provide similar experiences as conventional laboratory activities and benefit physical hands-on learning experiences at home.

## Conclusion and future work

The virtual embedded system project design makes the student learning experience more intuitive and engaging. We presented a non-traditional approach to transforming our laboratory course into a virtual online format using elements such as the Tinkercad platform. The student outcomes were

assessed by redesign of the PC-A and PC-B assessment models. In the future, this model will be extended to the course of Computer-Controlled Systems Design (CET 4711) to assess ABET Student Outcomes (a) application of electric circuits, computer programming, associated software applications, analog and digital electronics, microcontrollers, operating systems, local area networks, and engineering standards to the building, testing, operation, and maintenance of computer systems and associated software systems and (c) analysis, design, and implementation of computer system hardware and software for Computer Engineering Technology.

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