

## **Lessons Learned from Remote Access 3-D Printing Machine for Manufacturing Education**

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# Lessons Learned from Development of Remotely Accessible 3D Printer for Manufacturing Education

## Abstract

Remote labs are designed to overcome barriers such as equipment cost and limited lab time, and to provide authentic and self-paced learning experiences. The paper describes the development of a remote 3D printer and learning materials for manufacturing education. The equipment is being evaluated for a robot welding motion planning experiment, but can also be utilized for other manufacturing activities. The materials were evaluated by students during the lab time. Pre and post test results suggest a significant learning gain using the designed materials. Students have responded positively overall to the remote access tool. Suggestions include reducing the time delay and providing a better view of the position of the tool tip. Future directions include splitting the program into subroutines so that a sub-routine will be executed only when requested rather than loading the entire program at the beginning. We will also provide a better view of the 3D rendering model using multiple images from webcams positioned at different locations in the machine work envelope.

## Motivation and Related Work

Most manufacturing engineering-related courses—such as Manufacturing Process and Control, Industrial Welding, CAD/CAM, and CIM—include a laboratory component. Labs help students gain experience in using real and industrial-scale equipment. However, lab time is often limited, students often have to share equipment, and labs need to be completed in a fixed time. As a result, some academic institutions are interested in using remote lab experiences to complement or supplement local lab experiences [1], [2].

Additive manufacturing (AM) systems—also known as rapid prototyping (RP) or 3D printing systems—have received much attention in recent years due to their flexibility in making parts ranging from simple to complex, ease-of-setup for production, and ease of maintenance. There are many publications published from a research perspective, e.g., [3] - [5], and a few from an educational perspective. The focus of this paper is on remote laboratories for 3D printing for educational purposes.

Lan [6] provides a comprehensive review of research on web-based rapid prototyping and manufacturing (RP&M) systems that describes various architectures and key issues, and reviews tools to assist with various aspects of RP&M implementation, such as (1) RP&M process selection, (2) RP price quotation, (3) STL Viewer, (4) RP data pre-processing, (5) job planning and scheduling, (6) remote control and monitoring for RP machines, (7) security management, (8) applying new technologies and concepts to the systems. Fidan [7] describes development and implementation of remotely accessible rapid prototyping laboratory. Fidan and Baker [8] incorporated a remote prototyping lab as part of a STEM Academy for high school teachers. Hsieh [9] described a remotely accessible system consisting of a Stratasys Dimensions SST 1200es printer, work-flow processing, and remote viewing components. Students can submit a job after a credential check. The STL file is sliced and uploaded to the 3D printer. Students can view the part being made via webcam and streaming via internet video-sharing providers. Survey

results suggest that the students found the system to be very relevant to their education and would like to see more tools and systems like this made available.

In recent years, companies such as 3DPrinterOS and AstroPrint have begun offering 3D printer cloud hosting services. These services allow companies and educational institutions to connect their printers to the cloud and access them using any device from anywhere. Users can upload jobs remotely and observe the fabrication process via a camera.

The goal of this effort was to allow users to remotely control a 3D printer located in a laboratory. Users can register and login to the system, and make an appointment to use the 3D printer. Users can control the printer via a graphical user interface and monitor printing process using four types of communication.

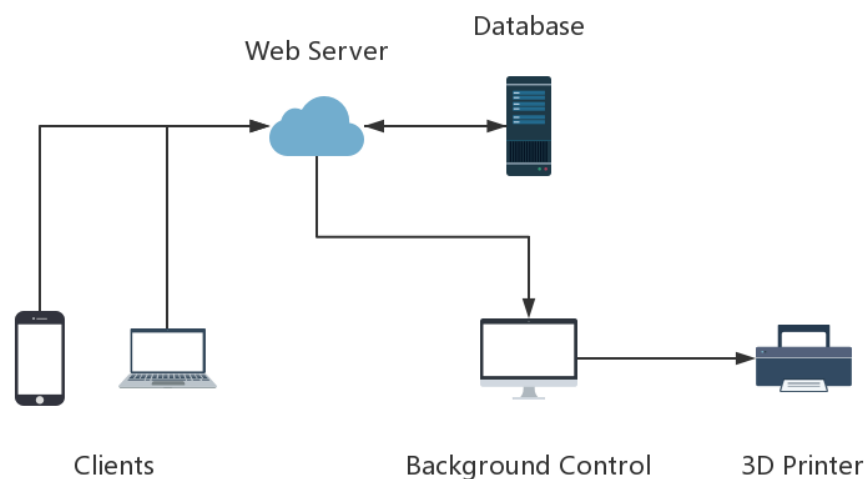
## Development Tools

Tools used to set up and control the remote printing process included the following:

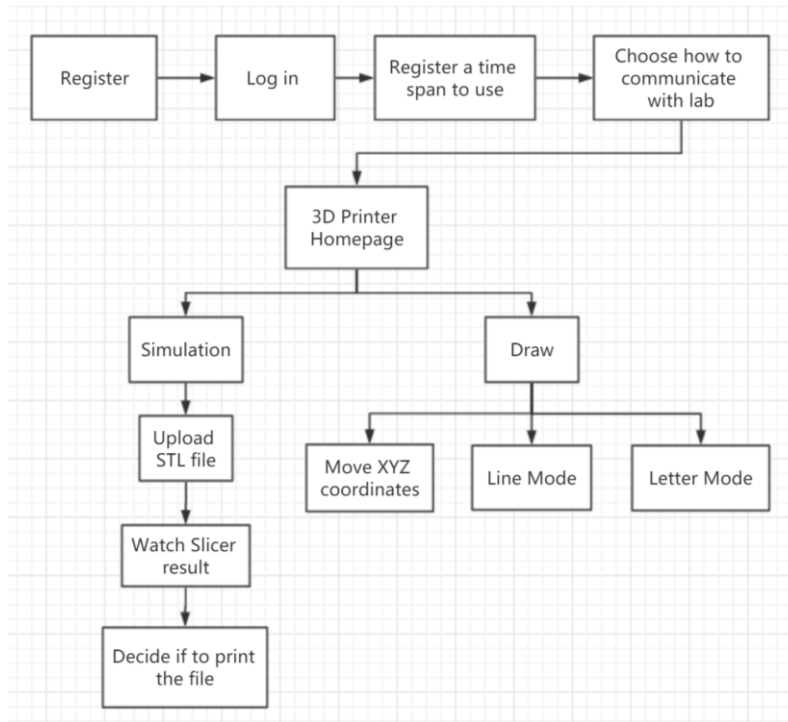
- **Webpages:** PHP, JavaScript, HTML
- **Database:** Access
- **Background control program:** VB.NET
- **Webserver:** Apache, Amazon Web Services (AWS)
- **3D printer and controller:** MTW Create 3D printer, Arduino
- **3D printer control program:** Printron (<http://www.pronterface.com/>)
- **Required software:** Windows Operating System; AWS (Amazon Web Services); Printron (Pronsole.exe); .Net Framework 4.7; Visual Studio 2017

## System Architecture

Figure 1 shows the components of the remote 3D printing system. Figure 2 shows the architecture of the client web page.



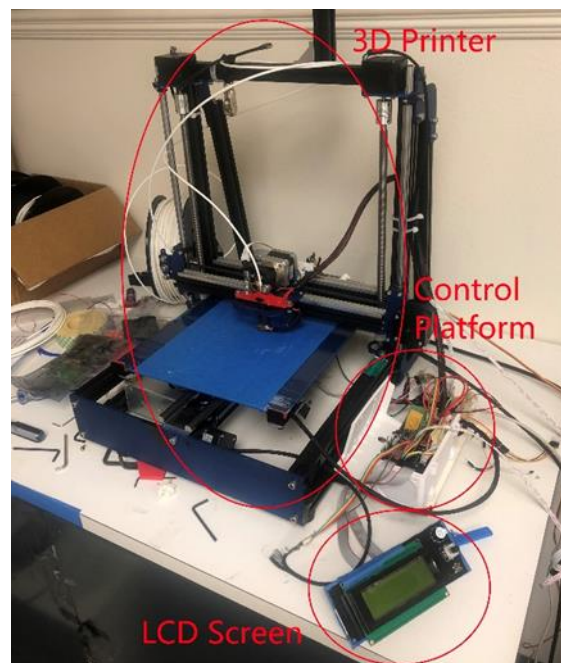
**Figure 1. System Components**



**Figure 2. Client Webpage Architecture**

## Printer Setup

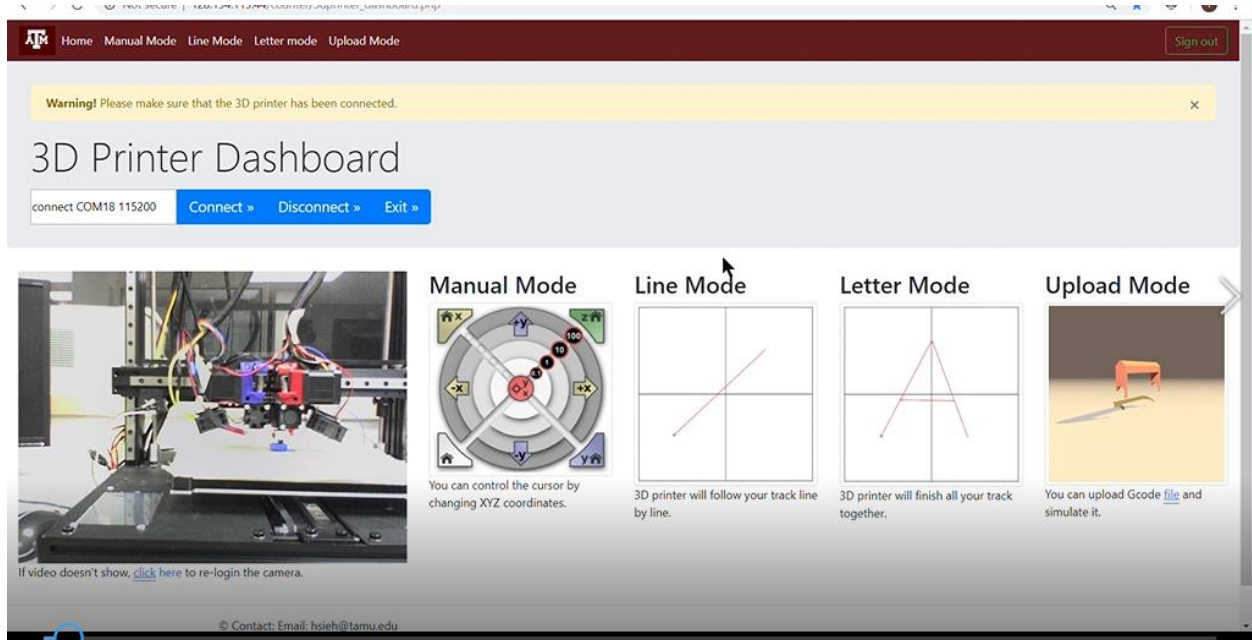
Figure 3 shows the 3D printer and controller platform setup.



**Figure 3. 3D Printer and Control Platform Setup**

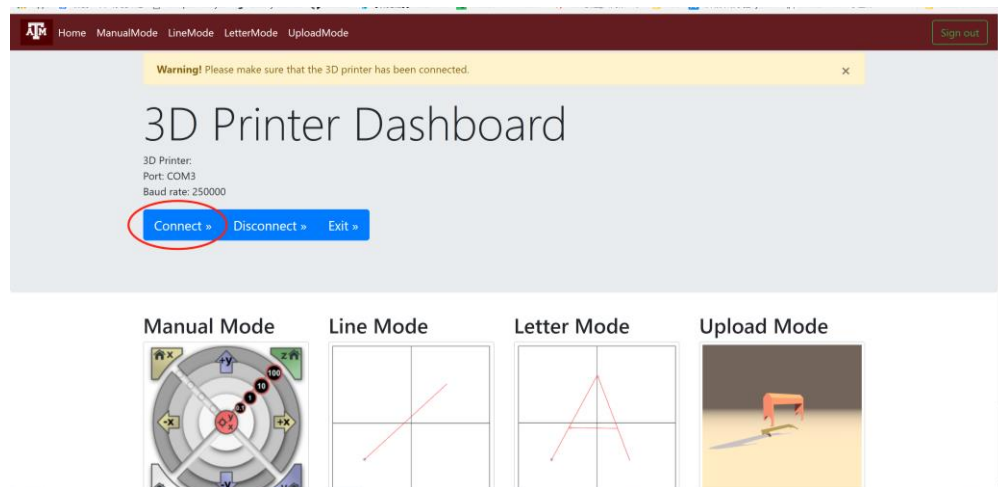
## Remote Interface

New users need to first register for an account in the system. After logging in, they need to register for a one-hour time slot to access the printer. In the current setup, live streaming is presented using an IP camera.



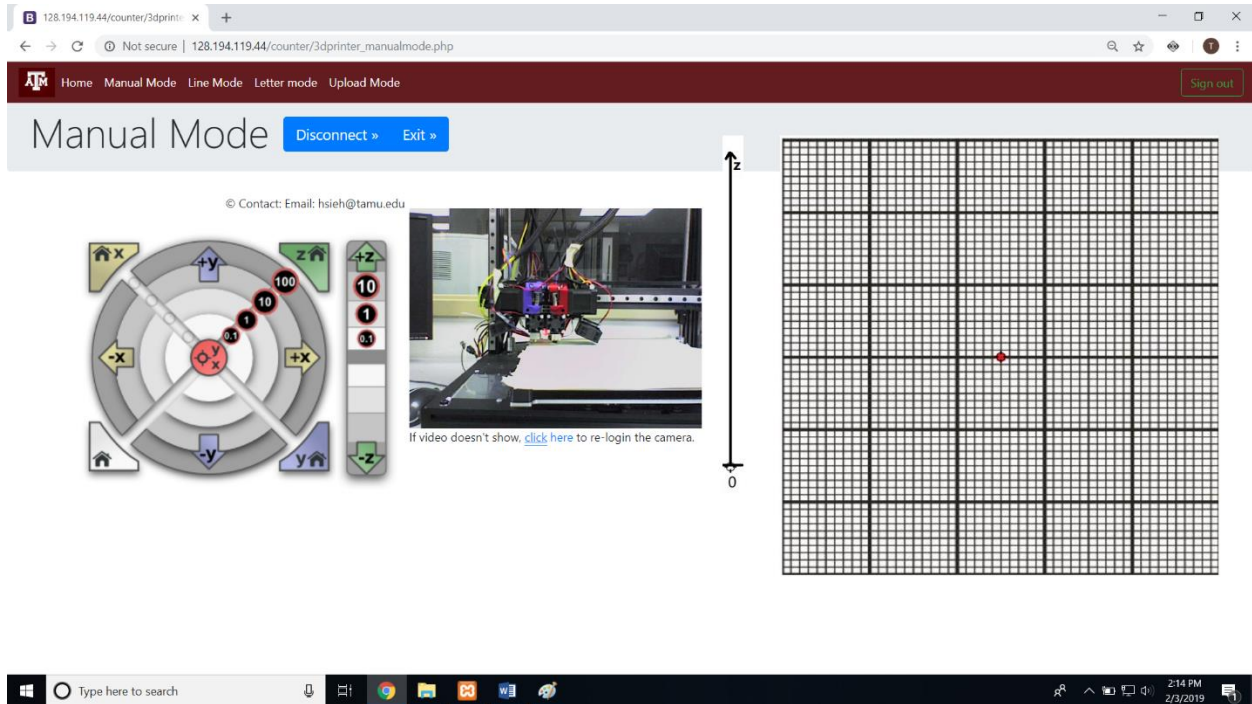
**Figure 4. Remote 3D Printer Main Page After Login.**

Next the 3D Printer Dashboard appears (Figure 5). The user clicks the Connect button to connect to and initialize the 3D printer; this process takes 5-8 seconds. The Disconnect button disconnects the printer, and Exit closes the connection and signs out. The Dashboard has four modes: Manual Mode, Line Mode, Letter Mode, and Upload Mode.



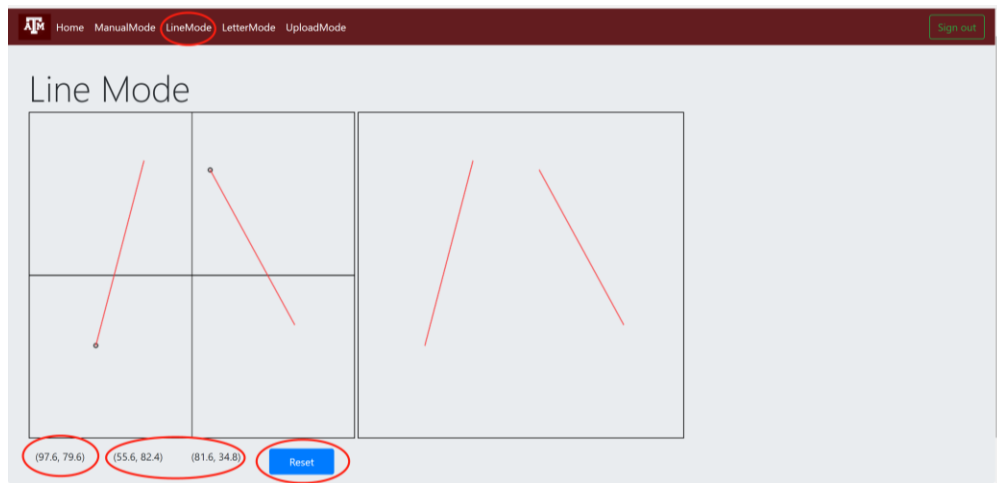
**Figure 5. 3D Printer Dashboard**

**Manual mode.** In Manual mode, users can manually set a step length (0.1, 1, 10, or 100), as shown in the red circle in Figure 6 and direction (+x, -x, +y, -y, +z, -z), as shown in the green areas. The grid on the right shows the simulated XY coordinates. The Z axis shows the simulated vertical height of the print nozzle.



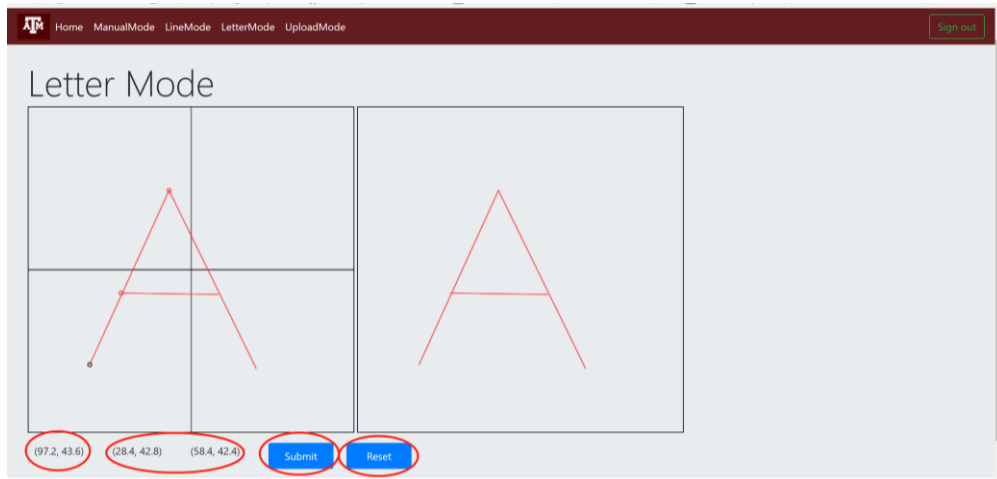
**Figure 6. Manual Mode Page**

**Line mode.** In Line mode, the printer tracks the location of the user's cursor. Pressing and holding the left mouse button will draw a line, then the printer nozzle will follow the same track. At the bottom left of the screen (Figure 7), the first set of coordinates shows the real-time location of the cursor. The next two sets of coordinates show the locations of the beginning and end points of the line. Clicking Reset cleans the canvas.



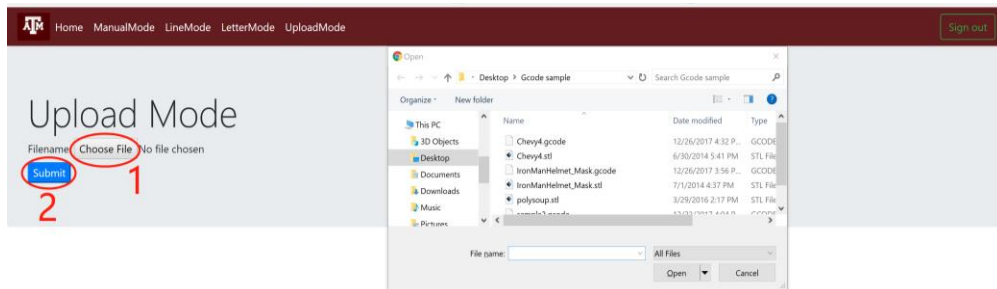
**Figure 7. Line Mode Page**

Letter mode. In Letter mode, the user can draw coherent graphics and then the printer will complete the shape (Figure 8). The user presses and holds the left mouse button to draw lines. When the user clicks Submit, the printer completes the shape.

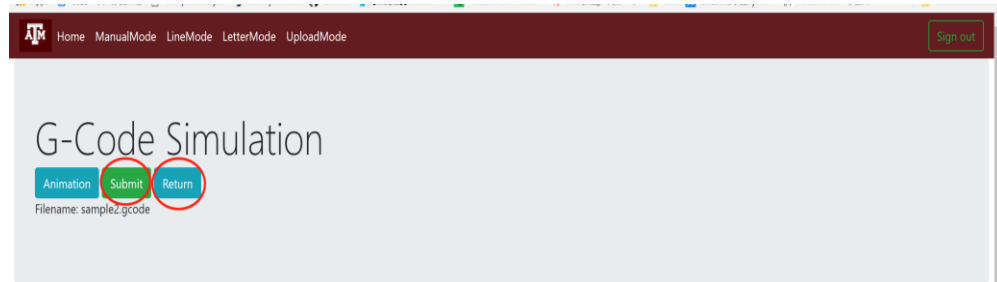


**Figure 8. Letter Mode**

Upload mode. Upload mode allows the user to upload a G-code file to the printer. The user clicks Choose File to select a G-code file from the local computer, then clicks Submit to upload the file (Figure 9). The program then offers to displays an animation of the printing process (Figure 10). Note that the printer can print other 3D file types (such as \*.stl) in addition to G-code, but the simulation/animation feature is currently available only for G-code files. The user can also click Submit to print the file or Return to cancel.

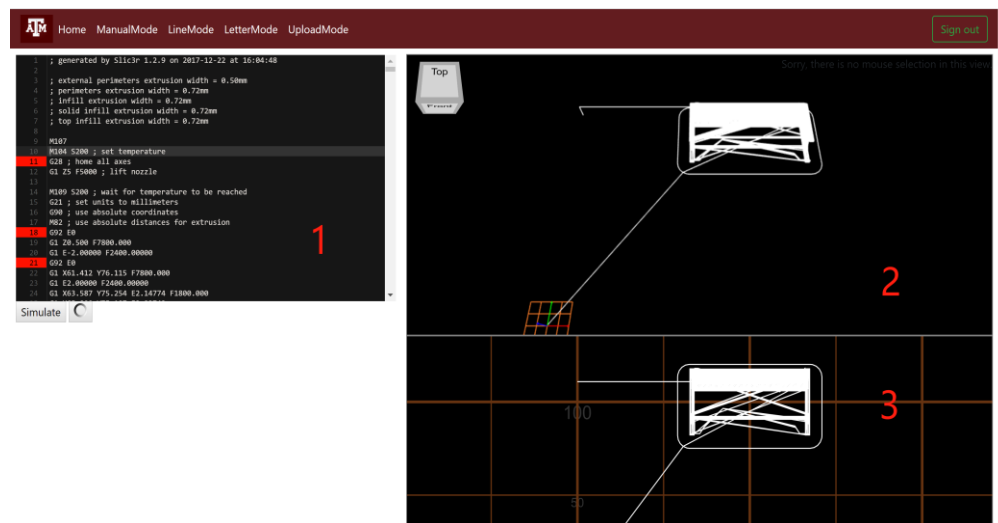


**Figure 9. Uploading a file in Upload mode.**



**Figure 10. G-code Simulation Panel**

If the user opts to view the animation, the system then displays an animation of the printing process (Figure 11). On the left (1), the G-code is displayed. In the upper right (2) is a 3D reconstruction of the file; users can use the mouse button to rotate camera angles. The lower right (3) provides a view from the top. Users can edit the G-code and watch the simulation change accordingly.



**Figure 11. G-code Simulation Page**

## Evaluation

The remote 3D printer was evaluated by 114 undergraduate students during Spring and Fall 2018. The goals were to learn:

- To what extent does the remote 3D printer help students to learn more about remote access architecture and robot path planning for industrial welding?
- Student feedback about various aspects of the remote 3D printer, such as user friendliness, features, objective, emphasis on important information, use of multimedia, and relevance to their education.
- Student comments

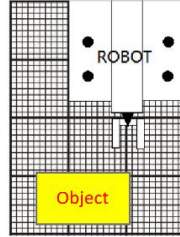
## Participants, Materials, and Experimental Procedures

Participants. Participants in this evaluation were 114 undergraduate students enrolled in a Manufacturing Automation and Robotics course where they were learning about programmable logic controller, sensor technology, interfacing, industrial robot, and machine vision. Evaluation activities took place after the lab session.

Materials. Students' knowledge of robot welding path planning and additive manufacturing was assessed before and after using the remote 3D printer. Figure 12 shows sample pre and post test questions.



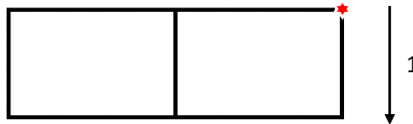
1. When planning a path, use \_\_\_\_\_ if possible.
  - a. Curves
  - b. Straight lines
  - c. The shortest path
2. What is the best starting point for welding the steel plate in the figure? Please mark on the figure.



3. The height of the plate below is 2 in. What is the minimum Z-axis value you should use to position the tip of the robot arm? \_\_\_\_\_



4. Please finish the path for a welding application if we use selected position (top-right corner) as the starting point and move to the bottom first.



5. For a spray application, choose the best practice to spray the whole surface: \_\_\_\_.

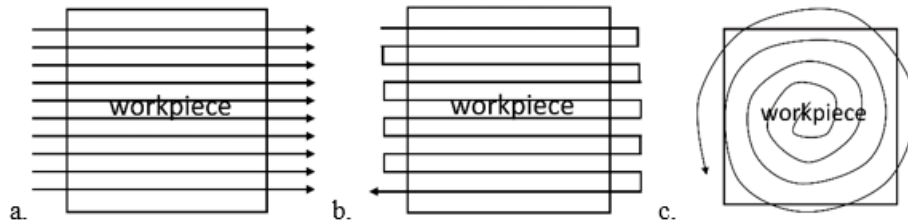


Figure 12. Sample pre and post test questions.

After the lab exercise in which the remotely accessible 3D printer was used, students also completed an opinion survey. This survey asked students to rate various characteristics of the prototype on a 7 point Likert scale. Students rated features, objectives, use of multimedia, instructional sequence, interaction with computer, emphasis on important information, relevance to education, and overall quality.

Procedure. Because we did not want the evaluation activities to interfere with students' learning, the unit on automated system design was taught in the usual way with lectures followed by lab. The evaluation activities were treated as additional lab activities. We evaluated students' knowledge before and after using the remotely accessible 3D printer. Figure 13 shows the sequence of the evaluation activities.



Figure 13. Evaluation event sequence.

### Data Analysis and Results

This section summarizes results in terms of instructional effectiveness (as measured by the pre and post tests), student ratings (as measured by the opinion survey), and student comments.

Test Data. We analyzed the test data to see if there was statistically significant score improvement among tests. Two stages of tests were performed on the data sets. In stage I, Shapiro-Wilk's test is used to test the normality of the data set. If the data set follows a normal distribution, then a t-test can be used to do the paired data comparison. However, if the data set fails the normality test, a Wilcoxon Ranks test will be used to perform paired data comparison. The null hypothesis  $H_0$  for stage I is that there is no difference between the distribution of the data set and a normal distribution. The null hypothesis  $H_0$  for stage II is that there is no difference between the two sample sets. Two different tests were conducted; **Test 1** (after lecture, but before remote 3D printer), and **Test 2** (after remote 3D printer) for the entire class of 2018.

The analysis results revealed that the null hypothesis was rejected for average test score and standard deviation of test score. This suggests that using the remote 3D printer causes significant improvement in learning. Table 1 summarizes the test statistics, critical value and conclusions for each test, where the null hypothesis is  $\mu_d = 0$ , sample size for remote 3D printer is 114, and the  $\alpha$  value is 0.05. The average before and after scores were 48.1 (before) versus 90.2 (after) for Spring 2018, and 59.10 (before) versus 94.12 (after) for Fall 2018.

#### Spring 2018 T1 vs T2

Shapiro-Wilk Normality Test:  $W = 0.8985$

$P > 0.01$  Do not reject Null Hypothesis

#### Fall 2018 T1 vs T2

Shapiro-Wilk Normality Test:  $W = 0.8701$

$P > 0.01$  Do not reject Null Hypothesis

The above tests suggest that the the data from Fall and Spring 2018 were normally distributed. Therefore, t-test and F-test were used.

Table 1. Results from t test of means and f test of variance for Remote 3D Printer

		Test statistic	Critical value	Conclusion
S2018	After Lecture vs. After 3D Printer (t-Test)	14.52	2.002	Reject Null Hypothesis
	After Lecture vs. After 3D Printer (F-Test)	4.265	1.552	Reject Null Hypothesis
F2018	After Lecture vs. After 3D Printer (t-Test)	14.02	2.004	Reject Null Hypothesis
	After Lecture vs. After 3D Printer (F-Test)	4.01	1.56	Reject Null Hypothesis

## Opinion Survey

The work was evaluated by undergraduate students in Spring 2018 and Fall 2018. The remote 3D printer was used in the context of learning robot path planning concepts and welding procedures. Using the remote 3D printer was helpful for illustrating robot path planning because the 3D printer architecture resembles a Cartesian robot. As shown in Figure 14, overall the responses were very positive (mean: 5.72, min: 5.52, max: 5.90), especially for the item “I would like to have more tools like this available to help me learn.”

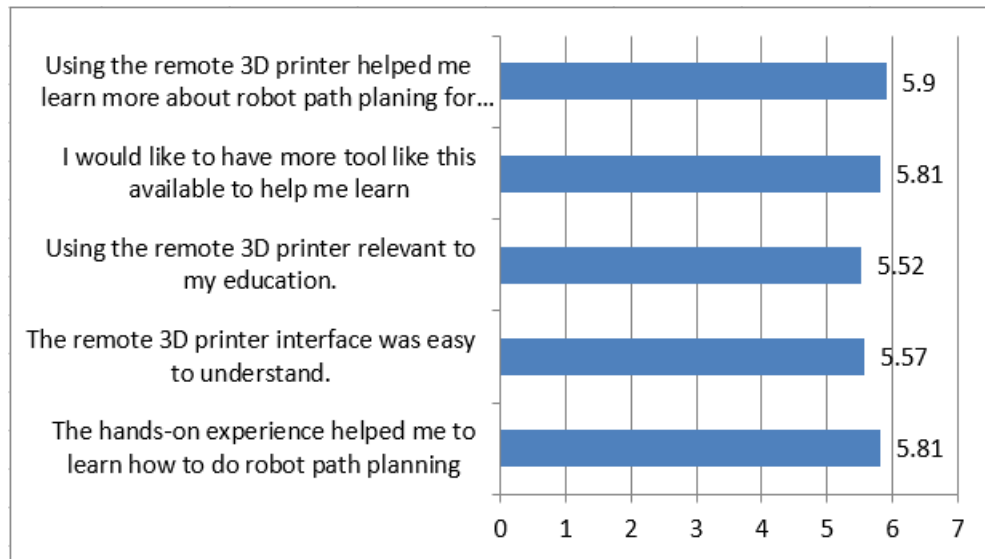


Figure 14. Mean responses to opinion survey questions.

## Conclusion and Future Directions

Overall, students have responded positively to using remotely accessible 3D printer. Suggestions include reducing the time delay and providing a better view of the position of the tool tip. Future directions include splitting the program into subroutines so that a sub-routine will be executed only when requested rather than loading the entire program at the beginning. We will also provide a better view of the 3D rendering model using multiple images from webcams positioned at different locations within the machine work envelope.

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