Group 15: Machine Tool Simulator

Final Design Review

Members: John Sullivan, Junfei Yu, Tao Wang, Yuteng Mei
Sponsor: Nicholas Edwards (Thayer School of Engineering)
Faculty Adviser: Professor Stephen Taylor

MTS

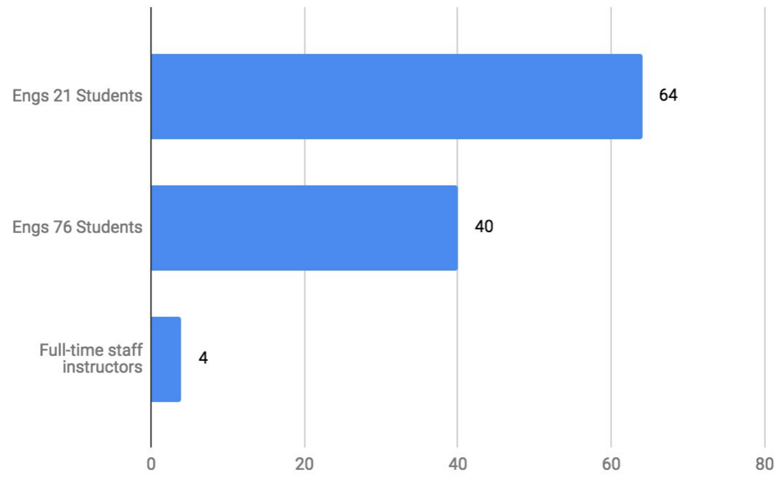
1867

March 4, 2019

Overview / Introduction

- At Thayer, it is a requirement for every engineering student to take a series of instructional sessions on how to use the tools at the machine shop.
- The better the students know how to use the tools at the shop, the more prepared they are for future engineering projects.

Current statistics from the Thayer Machine Shop



Problem Statement

Problem Statement: Students' opportunity to learn and practice in the machine shop is limited by the number of hours that the shop is open and the availability of instructors to teach them.

A New Way of Teaching

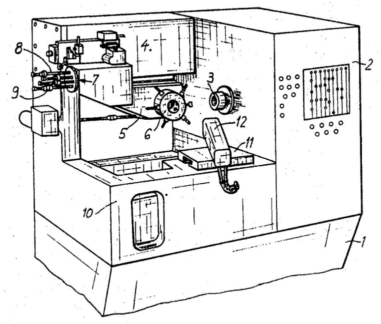
	Teaching style	Place	Time	Quality
Current Instructional Method	Relies on the personal interaction between the instructor and the students	Has to happen in the machine shop	A fixed 2 hours per session per week	Students take turns trying each part on the machine; one-time walkthrough; non-repeatable
Proposed Way	Digitalized. Highly interactive between the students and the digitized solution; supplements personal instruction	Can be done remotely	Can be done at anytime	Could reuse the solution as many times as student wants to.

Current State of the Art

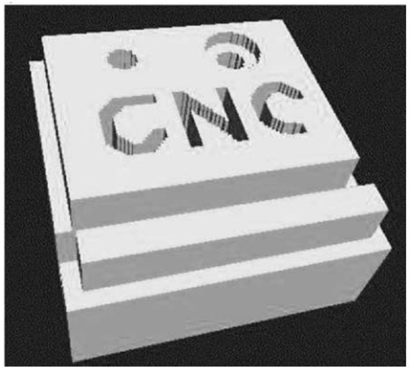
- At Thayer, students attend supervised machine shop learning sessions before they are allowed to use the machines for projects

- Early on, other schools were contacted to learn about their teaching process at the machine shop
- Both U.C. Berkeley and Cornell University have similar machine teaching program to Dartmouth.
- Berkeley has a hands-on orientation that lasts 5 to 6 hours, approximately 380 to 400 students a year.

Current State of the Art



Mechanical simulator
- Patent exists on a mechanical device to simulate machine tools [1].
- From a drawing, the device would allow an advanced user to simulate the motions and find the settings to use on a machine tool.



Website simulator
- Online tools used by advanced user [2].
- Only useful for advanced users, but do not have learning component for beginners.

Design Development

- We determined last term that the videos and simulation benefitted students from ENGS 89
- Using the lathe is a complicated task and we drew inspiration from other simulators, including flight and surgical simulators

HumanSim [3]

SuperJet International [4]

- With help from our sponsor, Nicholas Edwards, **we also expanded the video content of our teaching**

Design Development

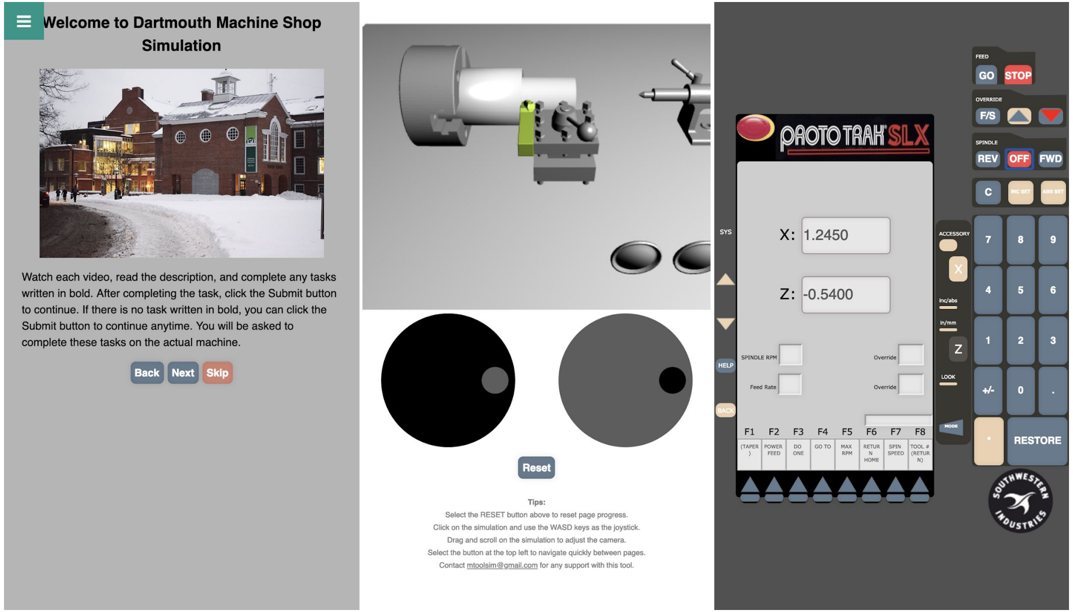
- Like these tasks, we sought to create a 3D simulation that would help users learn to use the lathe
- We explored different options and chose to pursue BabylonJS [5]
- It could be most well integrated with the work that we had already done, be used on any device with a web browser, and required the least overhead to run

	Unity	BabylonJS	D3
Allows 3D simulation	✓	✓	
Works with our current progress		✓	✓
Available on any web browser		✓	✓
Little overhead (no large downloads)		✓	✓

[5] [6] [7]

Design Development

- Over the break and at the start of ENGS 90, we developed our next prototype
- After testing and revisions during this term, the following is the final deliverable:



Design Development

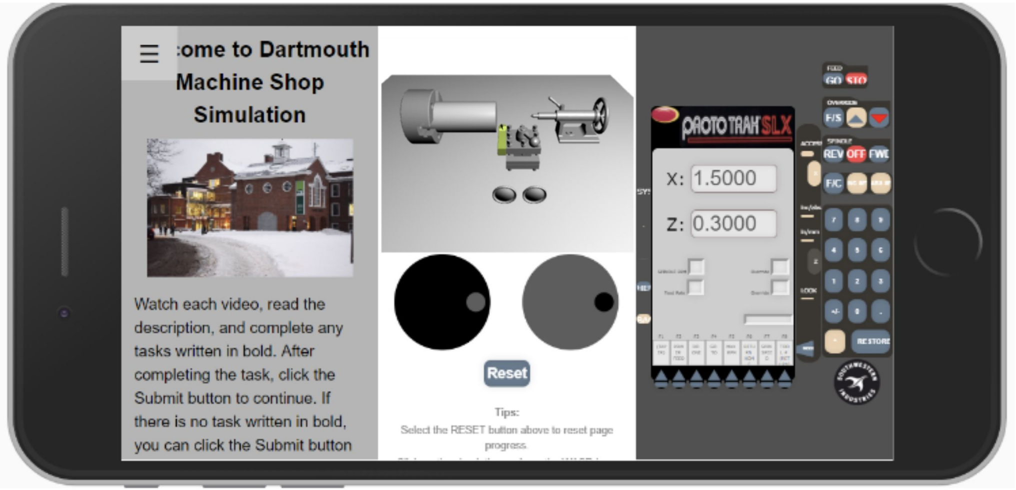
- On the 3D simulator, the user completes the following learning objectives
- These were agreed upon in our deliverables contract and are similar to those taught in the actual machine shop

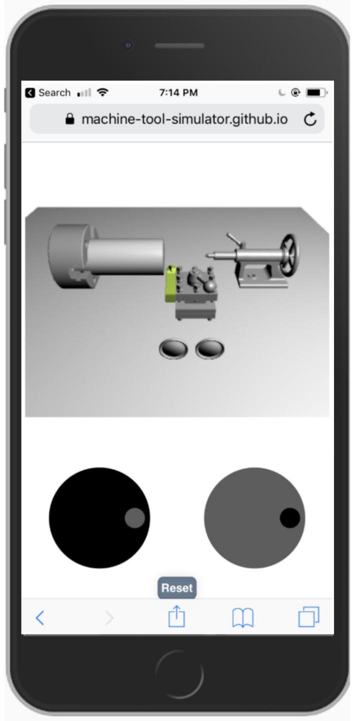
1. Introduction
2. Timelapse
3. Safety
4. Parts of the Lathe
5. Loading the Chuck
6. Turning on the Spindle
7. Constant RPM
8. Constant SFM
9. X and Z Coordinate System
10. X and Z Wheels
11. Fine and Coarse Control
12. Cutting and Setting Z Coordinate System
13. Setting X Coordinate System
14. Setting a GoTo Position

Video Demo

Design Concepts

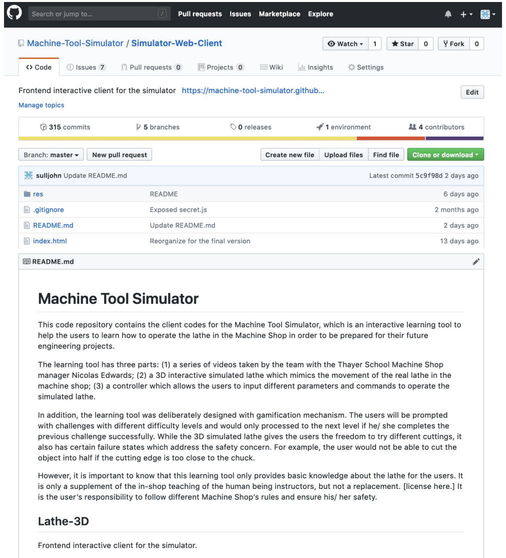
- The video demo showed our solution being used on an iPad
- It is so portable that it can also be used on a mobile phone:





Design Development

- Solution is available on a Github page, which includes code and documentation



Search or jump to... Pull requests Issues Marketplace Explore

Machine-Tool-Simulator / Simulator-Web-Client

Watch 1 Star 0 Fork 0

Code Issues 7 Pull requests 0 Projects 0 Wiki Insights Settings

Frontend interactive client for the simulator https://machine-tool-simulator.github... Edit

Manage topics

315 commits 5 branches 0 releases 1 environment 4 contributors

Branch: master New pull request Create new file Upload files Find file Clone or download

sulljohn Update README.md Latest commit 5c9f98d 2 days ago

res	README	6 days ago
.gitignore	Exposed secret.js	2 months ago
README.md	Update README.md	2 days ago
index.html	Reorganize for the final version	13 days ago

README.md

Machine Tool Simulator

This code repository contains the client codes for the Machine Tool Simulator, which is an interactive learning tool to help the users to learn how to operate the lathe in the Machine Shop in order to be prepared for their future engineering projects.

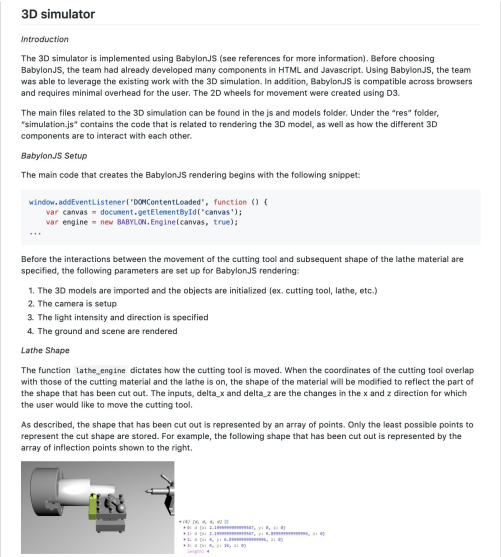
The learning tool has three parts: (1) a series of videos taken by the team with the Thayer School Machine Shop manager Nicolas Edwards; (2) a 3D interactive simulated lathe which mimics the movement of the real lathe in the machine shop; (3) a controller which allows the users to input different parameters and commands to operate the simulated lathe.

In addition, the learning tool was deliberately designed with gamification mechanism. The users will be prompted with challenges with different difficulty levels and would only processed to the next level if he/ she completes the previous challenge successfully. While the 3D simulated lathe gives the users the freedom to try different cuttings, it also has certain failure states which address the safety concern. For example, the user would not be able to cut the object into half if the cutting edge is too close to the chuck.

However, it is important to know that this learning tool only provides basic knowledge about the lathe for the users. It is only a supplement of the in-shop teaching of the human being instructors, but not a replacement. [license here.] It is the user's responsibility to follow different Machine Shop's rules and ensure his/ her safety.

Lathe-3D

Frontend interactive client for the simulator.



3D simulator

Introduction

The 3D simulator is implemented using BabylonJS (see references for more information). Before choosing BabylonJS, the team had already developed many components in HTML and Javascript. Using BabylonJS, the team was able to leverage the existing work with the 3D simulation. In addition, BabylonJS is compatible across browsers and requires minimal overhead for the user. The 2D wheels for movement were created using D3.

The main files related to the 3D simulation can be found in the js and models folder. Under the "res" folder, "simulation.js" contains the code that is related to rendering the 3D model, as well as how the different 3D components are to interact with each other.

BabylonJS Setup

The main code that creates the BabylonJS rendering begins with the following snippet:

```
window.addEventListener('DOMContentLoaded', function () {
    var canvas = document.getElementById('canvas');
    var engine = new BABYLON.Engine(canvas, true);
...
```

Before the interactions between the movement of the cutting tool and subsequent shape of the lathe material are specified, the following parameters are set up for BabylonJS rendering:

1. The 3D models are imported and the objects are initialized (ex. cutting tool, lathe, etc.)
2. The camera is setup
3. The light intensity and direction is specified
4. The ground and scene are rendered

Lathe Shape

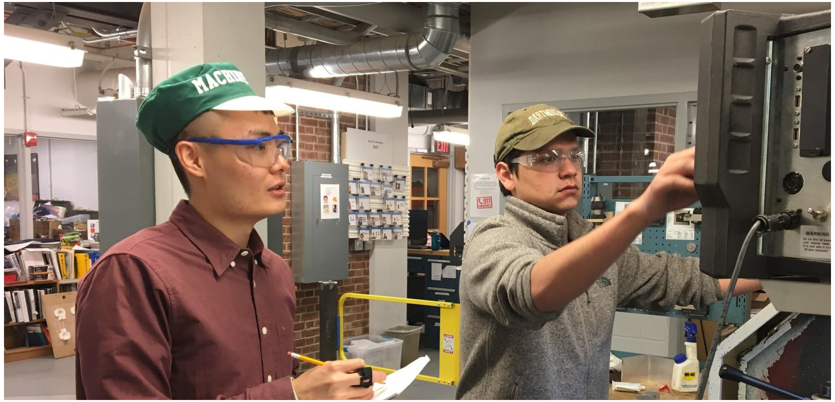
The function `lathe_engine` dictates how the cutting tool is moved. When the coordinates of the cutting tool overlap with those of the cutting material and the lathe is on, the shape of the material will be modified to reflect the part of the shape that has been cut out. The inputs, delta_x and delta_z are the changes in the x and z direction for which the user would like to move the cutting tool.

As described, the shape that has been cut out is represented by an array of points. Only the least possible points to represent the cut shape are stored. For example, the following shape that has been cut out is represented by the array of inflection points shown to the right.

- The documentation includes information on maintenance and steps to expand the current online teaching tool for the lathe to include other tools

Testing Protocol

- We conducted tests during ENGS 90 to enhance the final prototype
- Skill retention from online learning was tested by having students demonstrate their skills on the lathe control with this check sheet:
- In the machine shop, skill retention was measured by these 2 criteria:
  1. Number of tries for task
  2. Time to complete task



SKILL CHECKS

1. Statement: Turn on the spindle.

Checklist:

[ ] Presses “FWD”
[ ] Presses “OFF”

Completed successfully? Y / N

No Tries (1 if only 1): _________

Duration: _______________

(Start: ________ / End: ________)

- After, students also received a survey with questions about their experience.

Hypotheses

<u>*MTS: simulation-video hybrid solution</u>
<u>*Video-only: the solution with only the videos</u>

- **Hypothesis I**: The MTS group has a better learning outcome in terms of their accuracy, indicated by the number of tries until successful completion.
- **Hypothesis II**: The MTS group has a better learning outcome in terms of their proficiency, indicated by the time taken for each task.
- **Hypothesis III**: Both the MTS and the Video-only learning materials have improved from the initial prototypes, indicated by better learning outcomes from the students during this iteration of testing.

ENGS 90 Testing - Overview & Outlier Test

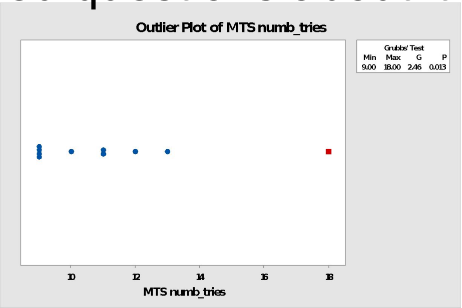
- Sample background overview statistics:

	# Participants	% Aspiring Engineers	% Been in the Machine Shop	Users w/ Lathe Exp.	% Completed Online Before Testing
(1) MTS	10	80%	70%	0%	90%
(2) Video-only	11	73%	64%	36%	93%

- The team found one outlier in the MTS group out of all of the samples.
- There were indications that the individual had not properly completed the online tool before arriving at the machine shop when asked questions about it.

Grubbs' Test

Variable	N	Mean	StDev	Min	Max	G	P
MTS numb_tries	10	11.100	2.807	9.000	18.000	2.46	0.013
Video numb_tries	11	13.909	3.208	10.000	20.000	1.90	0.416
MTS total_time	10	213.6	84.5	108.5	370.5	1.86	0.411
Video total_time	11	290.7	102.4	192.9	522.2	2.26	0.086



ENGS 90 Testing - Overview

- With the outlier removed, the team conducted statistical analysis on the groups to find the average, standard deviation, and other statistics.

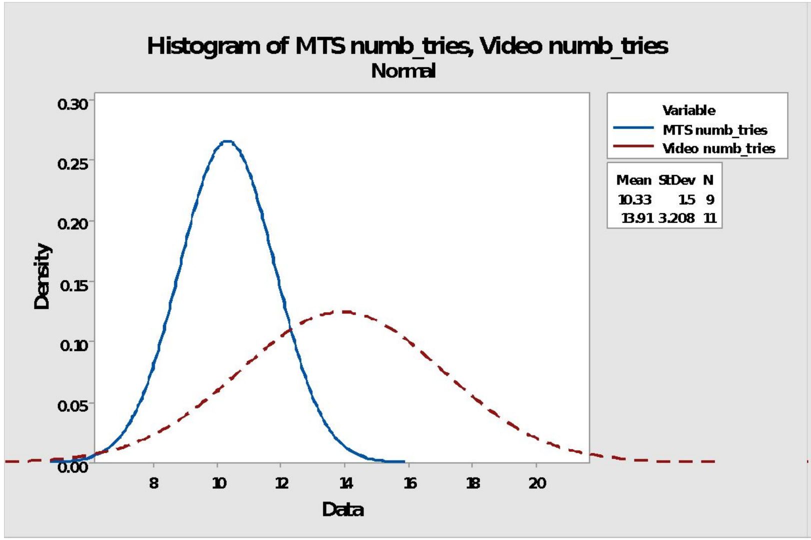
Variable	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
MTS numb tries	9	10.333	0.500	1.500	9.000	9.000	10.000	11.500	13.000
MTS total time	9	196.2	22.7	68.0	108.5	128.4	200.4	258.4	289.2

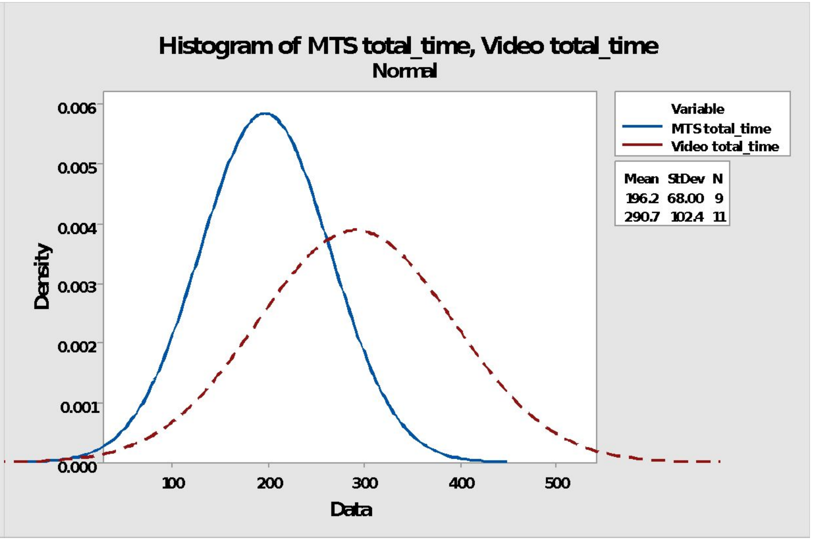
Variable	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
Video numb tries	11	13.909	0.967	3.208	10.000	11.000	14.000	16.000	20.000
Video total time	11	290.7	30.9	102.4	192.9	212.0	242.6	364.0	522.2

- These groups are presented graphically on the next slide.

ENGS 90 Statistical Analysis

- MTS outperformed Video-only by
  - **26%** for the number of tries
  - **32%** for the time taken
- T-test values (0.005 and 0.025) verified they were **statistically different.**





Comparison between old and new versions

- Slight improvement for the new version of MTS from the version last term
  - Still have the **peak performance**
  - Took longer to finish due to more deliberations of the users
- Larger improvement for Video-only new:
  - **47%** by the number of the tries
  - **22%** by the time taken

	MTS old	MTS new	Video-only old	Video-only new
Average (times)	6.00	5.78	16.25	8.55
Std. Deviation	1.00	1.09	5.06	2.81

	MTS old	MTS new	Video-only old	Video-only new
Average (seconds)	52.84	72.16	182.49	142.43
Std. Deviation	27.88	25.09	42.41	46.94

ENGS 90 Results and Discussion

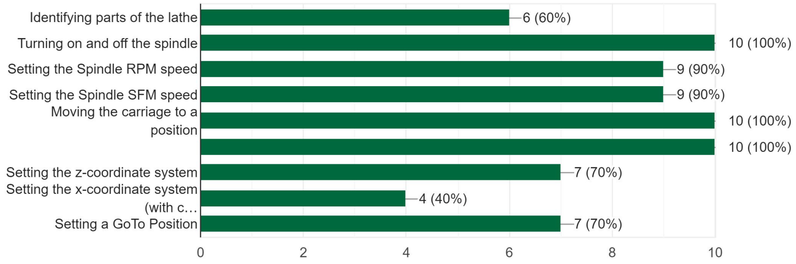
- **Hypothesis I**: The MTS group has a better learning outcome in terms of their accuracy, indicated by the number of tries until successful completion. **(Verified)**
- **Hypothesis II**: The MTS group has a better learning outcome in terms of their proficiency, indicated by the time taken for each task. **(Verified)**
- **Hypothesis III**: Both the MTS and the Video-only learning materials have improved from the initial prototypes, indicated by better learning outcomes from the students during this iteration of testing. **(Verified. The Video-only showed a larger improvement.)**
- Discussions about return-of-investment for the machine shop.
  - Faster result: Video-only
  - Peak performance: MTS

Survey Results

- We also surveyed students who tested our product for qualitative feedback

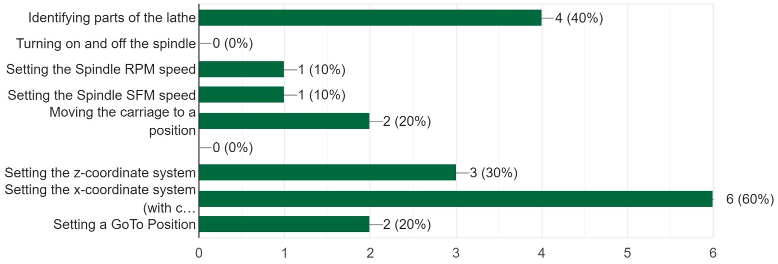
Which of the following skills did you feel comfortable performing in the machine shop?

10 responses



Which of the following skills did you NOT feel comfortable performing in the machine shop?

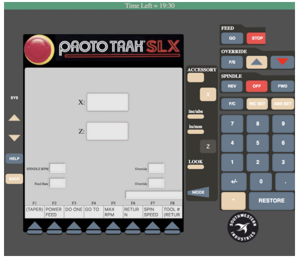
10 responses



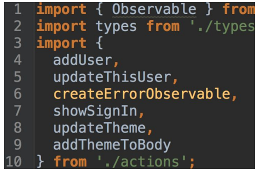
- **91%** of the students who did not have access to the simulation said that they “would have liked to have interacted with a simulation of the tool before being tested” on their skills.

Deliverables Contract

Software Tool - A fully functional software tool (including videos as necessary) that enables students to learn and practice learning goals for the lathe remotely.



Maintainable code - A GitHub repository with functioning computer code.



Documentation - Instructions for how to maintain and expand the code to other tools as well as basic instructions on how to use the software.

(The exact specifications for each deliverable are included in the deliverable contract.)

Requirements

We returned to our original requirements and verified that our solution met each. We verified that it met each of our ten original requirements by verifying that it quantitatively met the criteria for the tests.

1. **More efficient** teaching in the machine is possible
2. **More extensive** teaching in the machine shop is possible
3. **Students are more comfortable** entering formal on-site instruction
4. **Evaluation framework** is provided
5. Software is useable **anytime and anywhere**
6. **Any computer** can run the software
7. Software is **applicable to other machines in the shop**
8. **Software can be maintained** well into the future
9. Software is **free from bugs**
10. Software **cannot be used in unintended ways**

Objectives	Requirement	Test	Metric	Rank
Teaching in the machine shop is more efficient	The amount of time that it takes an instructor to teach skills to students is reduced	Time to teach the students machine shop skills is measured before and after they use software	Reduces time to instruct students by at least 10 minutes; as a reach, reduces by 20 minutes	1

Obstacles and Risks

- **Getting enough testing samples:** Finding volunteers to test the software product who did not have any machine shop training.
- **Remote cooperation:** Software development during winter break.

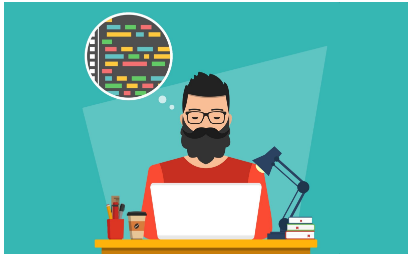
Economic and Cost Analysis

- **Costs associated with project -** Incentives given to the volunteers to participate testing of the software, $500 of our budget.

Value for machine shop	● Total number of working hours for all Thayer Teaching Assistant (2018) : 8,654.62 ● Thayer Teaching Assistant dedicate 50% of their work time to training ● $15/hour - wage for a Thayer Teaching Assistant ● Reduce one-fifth of the time each teaching assistant spent training. (8,654.62 hours)($15/hour)(1/2)(1/5) **= $12,982 in value per year based on the wage of a teaching assistant**

Costs on Larger Scale

Hiring developer for future development and maintenance



- $15/hour - wage for a Thayer Teaching Assistant
- Work time - 10 hours a week over 10 weeks
- $1,500 per term

- The team spent 6 hours recording new videos but over 100 hours improving the software; improving videos is a more economics way for quick results

Backend Server

- Tracking data on users
- Average cost varies from $5 to $250 per year.

Implementation on a Larger Scale

MIT License - Grant other developers software end-user rights such as copying, modifying, merging, distributing, etc.

Open Source Software - Available for all users.

Resources

Client/Consultants

- **Nicholas Edwards -** Project sponsor
- **Professor Taylor -** Project advisor
- **Kevin Baron**
- **Lee Schuette**
- **Jason Downs**

Project Development

- **Jones Media Center -** Filming and video editing
- **Skype -** Remote team meeting, progress update.
- **Github -** Hosts code repository, enables effective collaborative development.

Recommendations for Future / Next Steps

- Add features to the current tool (i.e. lathe)
- Add support for more tools used in the machine shop
- Add capability for the software to be easily maintained by non-CS oriented developers such as shop instructors or engineering students from other areas
- Provide help as a service to future potential users
- Thayer Computing Services: are willing to help with hosting the program as a static website without server support

Client Outreach

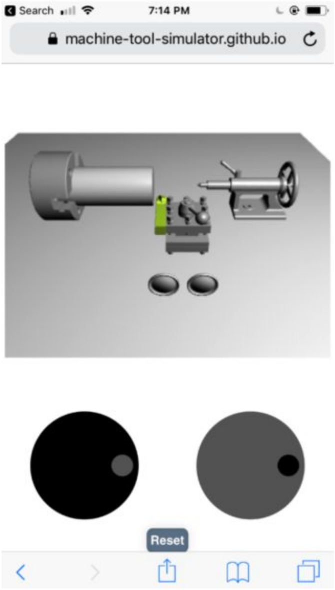
- Larger Universities (e.g. Cornell): content with their current tools and teaching methods, currently not interested in expanding the horizon of machine shop teaching tools.

- Walla Walla University, WA: Interested in learning about the software and after trying out the demo, is willing to use the software as a supplementary tool for their engineering students given the interface synchronized with the specific tools in their labs.

Conclusion

- The solution met all the initial requirements
- Machine shop received final deliverables on Github (site, code, and documentation)

- Recommendation for future work
    - Consider the return-of-investment and make the appropriate decision between MTS and Video-only.



Acknowledgements

Thank you everyone who helped with our project!

Special thanks to:

- Machine Shop
- Nicholas Edwards
- Professor Stephen Taylor
- Kevin Baron
- Lee Schuette
- Jason Downs
- Tim Tregubov from the Computer Science
- Professor Steven Kahl from Tuck School of Business
- Professor Halter
- Professor Collier and all of the volunteers

Works Cited

[1] M. Matthey, “Machine-tool simulator (us3555690a),” Jan 1971. [Online]. Available: https://patents.google.com/ patent/US3555690A/en

[2] S.-H. Suh and Kim, “Modelling and implementation of internet-based virtual machine tools,” May 2003. [Online]. Available: https://link.springer.com/article/10.1007/s001700300061

[3] “Humansim provides advanced virtual healthcare training.” [Online]. Available: https://www.healthysimulation. com/4035/humansim-provides-advanced-virtual-healthcare-training/

[4] SuperJet International, “Full Flight Simulator.” [Online]. Available: https://www.flickr.com/photos/48440363@N06/5573438825/

[5] “Trak machine tools.” [Online]. Available: https://www.southwesternindustries.com/

[6] “Unity,” 2019. [Online]. Available: https://unity3d.com/

[7] D. Catuhe, D. Rousset, and S. Vandenberghe, “Babylonjs demos and documentation.” [Online]. Available: https://www.babylonjs.com/

Appendix A: Breakdown of Lathe Session

Minutes	Duration	Activity	Outside shop *
0-9	9	Machine shop quiz	Yes
9-13	4	Introduction to the control (** control)	Yes
13-16	3	Description of spindle, RPM, and SFM (** control)	Yes
16-17	1	Description of spindle parts	Yes
17-20	3	Description of chuck	Yes
20-22	2	How to load stock into chuck	No
22-22	0	Students practice	No
22-24	2	Introduction to cutting tool	Yes
24-26	2	Introduction to axes	Yes
26-26	0	Students practice skills	No

Minutes	Duration	Activity	Outside shop *
26-28	2	Student cuts off part of stock	No
28-30	2	Demonstration of cutting tool	No
30-33	3	Zeroing out the control	Yes
33-38	5	Setting coordinate system	No
38-40	2	Students practice	No
40-44	4	Demonstration of lathe cutting project	No
44-47	3	Demonstration of shallow cut	No
47-51	4	Students practice	No
51-55	4	Demonstration of aggressive cut	No
55-59	4	Other concepts	No
	Sum: 59 mins		Sum: 20 mins

Appendix B: All Requirements

Type	Objectives	Requirement	Test	Metric	Rank
Time	**Teaching in the machine shop is more efficient**	The amount of time that it takes an instructor to teach skills to students is reduced	Time to teach the students machine shop skills is measured before and after they use software	Reduces time to instruct students by at least 10 minutes; as a reach, reduces by 20 minutes	1
	Teaching in machine shop can be more extensive	Instructors are able to teach additional skills in the same amount of time	Compare number of skills taught before and after students use software	Record number of skills taught before and after software use	2
Proficiency	**Student is able to comfortably enter formal on-site instruction**	The student is able to learn at least one of the skills necessary to use the lathe	A list of instruction skills for the lathe has been provided by Nick; at least one of these skills can be checked off without formal instruction	Students rate on a survey that they are comfortable with one of the skills more than 80% of the time	3
	Evaluation	An evaluation framework is provided that gauges student success	Have students use the software and evaluate their performance	Students meet 95% of the learning goals for the shop	4
Accessibility	**Student is able to use software anytime and anywhere**	The software / website is available for the student to download / view when necessary	Monitor the uptime of the software by periodically testing	Software is available >20 hours / day	5
		Software can be used anywhere	Any student that we send the link to is able to access the software	Software is accessible in each of the places that we test	6

Appendix B: All Requirements

Type	Objectives	Requirement	Test	Metric	Rank
Accessibility (cont.)	**Software can be used on any computer**	Software works on any computer that a student might be using	Check functionality on different operating systems	Compatible with Windows, Mac, and Linux	7
		Software works in any browser students might be using	Check functionality in different browsers	Compatible with Chrome, Firefox, and Safari	8
Scalability	**Software can be applied to other machines**	The software provides a framework that can be used to add other machines	Check whether a plan can be laid out to incorporate another machine	The code is modularized and a workflow and framework are developed for applying to other machines	9
	Software is able to be maintained well into future	Documentation is provided	Documentation is provided for each component	Documentation is provided for main components: instruction, evaluation, scaling	10
		Any code used is easy for users to understand	Software is made open-source and is reviewed by others	A third party reviews our repository and confirms they understand each component	11
Technical issues	**Software bugs**	Bugs in the software could affect user experience	The software passes test cases that simulate real world use	All software bugs raised have been carefully handled	12
	Unintended uses	User should not be able to manipulate software	We have students try to pass teaching tool steps without completing individual parts	All tasks must be completed before finishing the teaching tool	13

Appendix C: Final Deliverables Contract

The requirements for the final deliverable are to:

A final deliverable that satisfies the following criteria will be made available to the sponsor (Thayer Machine Shop, Nicholas Edwards) by the group (John, Junfei, Tao, and Yuteng) by the end of Engs 89/90 in March 2018.

The final deliverable must contain the following components:

1. **Software Tool** - A fully functional software tool (including videos as necessary) that enables students to learn and practice these learning goals for the lathe remotely:
    - Understanding what the spindle, chuck, carriage, cutting tool, tailstock, and control are
    - Turning the spindle on and off
    - Setting spindle speed for constant Revolutions per Minute
    - Setting spindle speed for constant Surface-feet per Minute
    - Switching the control between Fine and Coarse mode
    - Understanding X and Z coordinates
    - Moving the tool in the Z direction
    - Moving the tool in the X direction
    - Establishing the Z coordinate system
    - Establishing the X coordinate system
    - Using the GoTo function
2. **Maintainable code** - A GitHub repository with functioning computer code that meets the following requirements:
    - Every function is supplemented by a comment that explains what the function does
    - All functions and variables are named semantically so the name communicates the purpose
    - Every function has only one purpose instead of many purposes
    - There are no repeated lines of code
    - There is a suite of automated tests that can be run with a single command to verify whether the application works as expected
3. **Documentation** - Instructions for how to maintain and expand the code to other tools:
    - How the code should be maintained
    - How to run the automated test suite
    - How to develop new features for teaching new learning goals
    - How to deploy new versions of the application to production
    - How to test new versions of the software on users

John Sullivan Yuteng Mei

John Sullivan, Yuteng Mei,
Junfei Yu, and Tao Wang (3/1/2019)

Nicholas Edwards, Thayer Machine Shop
(3/1/2019)

Appendix D: Initial Prototype

- Our first prototype last term consisted of simulation of the control in 2D

Actual Control

Our Prototype

Appendix E: Skill Check Sheet More Detail

SKILL CHECKS

NOTE: *Always mark whether task actually complete; max duration at 1 minute to accommodate others.*

1. Statement: In order, identify the **tailstock**, the **carriage** (cutting tool), and then the **chuck**.

Checklist:	Completed successfully? Y / N
[ ] Identifies **tailstock**	No Tries (1 if only 1): __________
[ ] Identifies **carriage** (cutting tool)	Duration: ____________________
[ ] Identifies **chuck**	(Start: ________ / End: ________)

2. Statement: **Turn on** the spindle. Then **turn off** the spindle.

Checklist:	Completed successfully? Y / N
[ ] Presses **"FWD"**	No Tries (1 if only 1): __________
[ ] Presses **"OFF"**	Duration: ____________________
	(Start: ________ / End: ________)

Appendix F: ENGS 89 Trade Studies Recap

- 3 prototypes were developed:
  - Group 1 - Full package of videos, texts and simulated controller.
  - Group 2 - Texts and simulated controller.
  - Group 3 - Videos.
- A/B testing was conducted with 15 volunteers. Group 1 outperformed others.