12-2019

Assessing the Impact of 3D Printed Terrain on Teaching Topography in Introductory Earth Science Labs

Jay Alan Cockrell

ASSESSING THE IMPACT OF 3D PRINTED TERRAIN ON TEACHING TOPOGRAPHY IN INTRODUCTORY EARTH SCIENCE LABS

by

Jay Alan Cockrell

A thesis submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Master of Science
Geological and Environmental Sciences
Western Michigan University
December 2019

Thesis Committee:

Heather Petcovic, Ph.D., Chair
Peter Voice, Ph.D.
Kathleen Baker, Ph.D.

ACKNOWLEDGEMENTS

I would like to acknowledge a number of wonderful individuals that helped me reach this point. First and foremost, Dr. Heather Petcovic for being patient through this entire process and amazing support to help complete this project and learn so much about the world of science education. Dr. Peter Voice and Dr. Kathleen Baker for joining in this wonderful journey and offering their expertise and general wisdom as well as Dr. Gillespie and his teaching assistants for letting me use their class. Dr. Paul Kelso of Lake Superior State University, for all of the knowledge he has shared through my undergraduate years as well as the encouragement that I could reach this academic achievement. I would like to thank Michelle Wright and Ronald Smith of Kellogg Community College, they helped shape my first years in school and encouraged the first steps on my journey. I would never have made it through the process without Samuel Nyarko and most of all Laura Tinigin for their overwhelming comradery and support. Next, and most importantly to me, my wonderful family must be acknowledged, without my mother Deborah and father Allen's sacrifices I would never have made it this far. Finally my wonderful wife Veronica, every step I take to improve this world in my own little way, I take because you help carry me to greatness.

Jay Alan Cockrell

ASSESSING THE IMPACT OF 3D PRINTED TERRAIN ON TEACHING TOPOGRAPHY IN INTRODUCTORY EARTH SCIENCE LABS

Jay Alan Cockrell, M.S.

Western Michigan University, 2019

Learning to effectively read topographic maps is challenging for students, as these maps contain 3D representations of terrain displayed on a 2D surface map. This project assessed student learning when 3D terrain printed from a portion of the laboratory quadrangle map currently in use was introduced into an earth science course for non-science majors. Using a quasi-experimental design with nonequivalent groups across two semesters, performance on the Modified Topographic Map Assessment (MTMA) administered as a pre- and posttest was used to compare learning outcomes between the traditional lab and the 3D print lab intervention. Students in the traditional (n = 54) and 3D print terrain (n = 24) groups had comparable incoming topographic map interpretation skills as measured by pretest scores on the MTMA ($t(75) = .98$, $p = .33$). Pre- to posttest scores on the MTMA did not significantly improve in the traditional lab ($M = 0.63$, $SD = 3.13$, $t(53) = 1.48$, $p = .15$) but did improve significantly in the 3D print terrain lab ($M = 1.96$, $SD = 2.97$, $t(23) = 3.23$, $p = .004$). Responses on the open-ended items were also more sophisticated in the 3D print terrain lab. Results suggest that the 3D print terrain helped students to "see" the topography, reducing the 2D to 3D visualization burden students have when learning. 3D printed terrain shows promise as a teaching tool that could be adapted to multiple uses including K-12 classes and upper division earth science courses.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ii

INTRODUCTION 1

LITERATURE REVIEW 4

Overview 4

Physical Models 4

3D Projections 5

Stereoscope photography 5

Geowall 7

Coupled Models 8

3D Printed Materials in Education 10

PURPOSE 11

METHODS 13

Research Design 13

Context 13

Instruments 16

The Modified Topographic Map Assessment (MTMA) 16

Demographic survey 18

Lab observation 18

Participant Recruitment and Selection 18

Table of Contents - continued

Data Collection 19

Data Analysis and Interpretation 19

Ethical Considerations 20

RESULTS AND DISCUSSION 21

Participant Demographics 21

Quantitative Results 23

Quantitative Discussion 30

Qualitative Results 31

Qualitative Discussion 36

CONCLUSIONS 37

Implications for Education 38

Limitations and Future Work 39

Limitations of Study. 39

Future Research 40

REFERENCES 42

APPENDICES 45

A. HSIRB Approval 45

B. Student Instructions for the 3D Print Terrain Intervention Lab 47

Table of Contents - continued

C. MTMA Questionnaire 49

D. Demographic Questionnaire 65

E. Compiled MTMA Pre- and Posttest Responses 67

F. Open-ended MTMA Responses 82

LIST OF TABLES

1. Benefits and drawbacks of different tools for teaching topography 12

2. Laboratory procedures in the traditional topography lab (fall semester) and 3D print terrain intervention lab (spring semester) 15

3. Cronbach's Alpha test for reliability of the MTMA 18

4. Demographic data for participants in the traditional (fall) and 3D print terrain intervention (spring) semesters 21

5. Student performance on the MTMA pre- and posttest in the traditional (fall) and 3D print terrain intervention (spring) semesters 24

6. Comparison of MTMA pre- to posttest performance in the traditional (fall) and 3D print terrain intervention (spring) semesters 27

7. Comparison of MTMA pretest performance between the traditional (fall) and 3D print terrain intervention (spring) semesters 28

8. Sample incorrect to incorrect responses on item 1 in the traditional (fall) semester 33

9. Sample correct to correct responses on item 1 in the traditional (fall) semester 33

10. Sample incorrect to correct responses on item 1 in the traditional (fall) semester 34

11. Sample incorrect to incorrect responses on item 1 in the 3D print terrain intervention (spring) semester 34

12. Sample correct to correct responses for item 1 in the 3D print terrain intervention (spring) semester 35

13. Sample incorrect to correct responses on item 1 in the 3D print terrain intervention (spring) semester 35

LIST OF FIGURES

1. Physical foamcore model (Image from Logan, 2013) 4

2. Student viewing images using a stereoscope (Image from Queensland Archives, 1949) 6

3. Students sitting in Geowall lecture (Image from University of Alabama, 2006) 7

4. AR sandbox in use (Image from Depauw University, 2019).. 8

5. 3D printed terrain example (Image from Iowa State University, 2017) 10

6. 3D printed terrain overlay onto Kalamazoo topographic map.. 15

7. Comparison of majors between the traditional and 3D print terrain labs 23

8. Histogram distribution of correct score percentages for the traditional semester 25

9. Histogram distribution of correct score percentages for the 3D printed intervention semester.. 25

10. Comparison of MTMA score distribution for the traditional lab (fall semester) and 3D print terrain intervention lab (spring semester)... 26

11. Student performance on individual MTMA items on the pre- and posttest during the traditional lab (fall semester) 29

12. Student performance on individual MTMA items on the pre- and posttest during the 3D print terrain intervention (spring semester)... 30

13. Item 1 of MTMA featuring embedded qualitative question. 32

INTRODUCTION

Topographic maps display data, in this case elevation, through contour lines. These lines represent equal elevation, and their shape and spacing convey the three dimensional (3D) shape of the landscape on a two dimensional (2D) surface. The ability to competently read features on topographic maps, such as relief, gradient, and distance, are important tools for novice geoscience students to learn effectively, as these skills are commonly used in upper level classes and for field work.

Reading topographic maps is also important beyond the geoscience classroom. Being able to interpret topographic maps is critical for land use planning, so that building on steep terrain can be avoided. Topographic maps can be used to evaluate and mitigate potential natural hazards, and to effectively plan routes to respond to hazards such as landslides, wildfires, hurricanes, and floods. Geographers employ topographic maps for a number of uses, from being able to see urban sprawl advancement over time for major cities, to tracking changes in natural environments due to human-caused change.

Proficiency at reading topographic maps is important for outdoor navigation during recreational activities such as hiking, hunting, and off-road cycling or ATV riding - especially when these activities take place in remote areas that do not have cellular service or Global Positioning System (GPS) reception. For example, recreational use of topographic maps occurs when hunters choose the best location and fishermen remember unique and fruitful fishing spots. Even with access to digital positioning, many of the maps and tracking systems use digital topographic maps for location and positioning. The ability to read topographic maps helps to enhance students' scientific literacy in general; for example, the contour system of presenting data used in topography is also used in displaying high and low pressure gradients in meteorology. Beyond contour lines, the skill of visualizing 3D objects from 2D representations is used in many areas of medical science, such as reading computed tomography (CT) scans, magnetic resonance imaging (MRI) scans and x-rays.

The challenge for learning to read and interpret topographic maps involves using the 2D topographic map to visualize 3D landscape features (Hausman, 1917; Atit et al., 2016). Novice map readers need to be able to observe patterns, sometimes complex, in a background of noise (Ishikawa, & Kastens, 2005). Students can interpret tightly spaced contour lines as high elevation, while thinking that loosely spaced contours are low elevation (Ishikawa et al, 2005). Students have issues visualizing terrain from any direction other than the one from which they are viewing the map itself (Ishikawa et al, 2005). Typical errors made by novice map readers are recognized by Clark et al. (2008, p. 403), "some students continue to assume that closely spaced contour lines represent higher elevation and that widely spaced contour lines indicate lower elevations. Similarly, some students continue to assume that wavy contour lines indicate steeper or more extreme landscapes." Because of the assumptions students make with contour lines, students cannot orient themselves effectively to apply important concepts such as slope, gradient, relief, and distance.

Many instructional techniques have been created to help students learn to read and interpret topographic maps. Physical models, such as foamcore, are created from equal layers of foamboard in order to build a 3D model. 3D projections, such as stereoscopic photography, use students binocular vision to create artificial 3D images. New, coupled models, such as augmented reality sandbox (AR sandbox), project contour lines directly onto a building medium like sand to actively change contours in real time as students interact with the system. All of these models and projections have been used to help students overcome difficulty associated with learning to transfer 2D topographic maps to 3D images of terrain. Many of these techniques have limitations that could potentially impede student learning in labs or classrooms. The systems could be outdated, never tested, or come at significant expense to implement effectively.

3D printing is a new technology that could be useful in teaching key concepts, including topographic map interpretation, in the Earth Sciences. This study hypothesized that using 3D printed terrain coupled with the 2D topographic map from which the models were printed would enhance student learning of topographic map skills. Using the 3D terrain with its associated contour maps would, potentially, help students bridge the gap between the 2D map and 3D landscape, as they were able to "see" the landscape rather than having to mentally visualize it from the 2D map. We also hypothesized that after working with the 3D terrain on part of the map, students would have been able to transfer map reading skills to other parts of the map and ultimately to other, more complex maps.

This project took place in the lab sections of the Western Michigan University (WMU) Dynamic Earth course, a general education earth system science course specifically for non-science majors. This class was targeted for an intervention in part because the class had a student audience that was non-science majors who were presumably novice map readers. The class was also targeted in part because the instructor and teaching assistants were willing for the intervention to be developed for the course. The study compared students' topographic map interpretation skills between a traditional lab using only the Kalamazoo 1:24,000 topographic map, and an intervention lab the coupled the Kalamazoo map with a corresponding 3D printed terrain. In both the traditional and intervention labs, students' topographic map interpretation skills were measured before and after the lab using the Modified Topographic Map Assessment (MTMA), which was adapted for this study from the Topographic Map Assessment B (TMA-B, Moore, 2018).

LITERATURE REVIEW

One of the more difficult concepts for introductory level Earth Science students to understand is the representation of 3D environments on a 2D surface, such as a map. Topographic maps contain a significant amount of data, and studies acknowledge the gap in student learning. Many teaching approaches attempt to bridge this gap with different interventions such as AR sandbox, computer modeling, foamcore layer models, and stereo visualization maps. Using these tools to supplement teaching topography has produced mixed results.

Physical Models

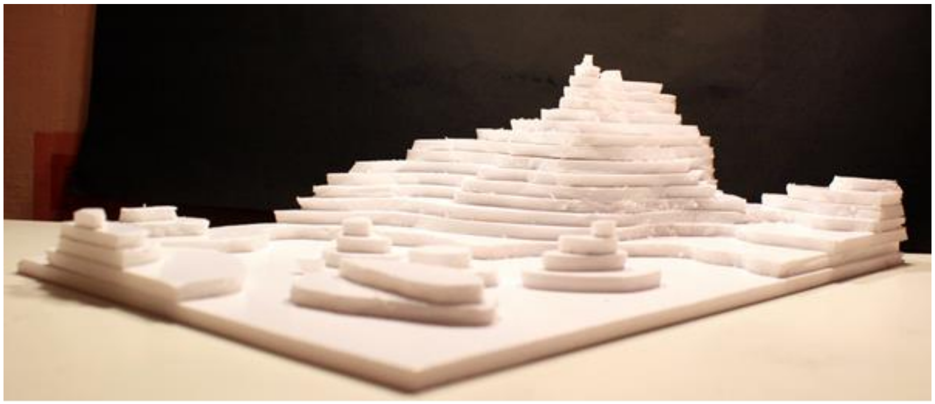


Figure 1. Physical foamcore model (Image from Logan, 2013)

Physical models, which include a wide variety of different styles, such as water level models and US Geological Survey (USGS) plastic elevation models, vary in creation but all attempt to represent topographic maps in 3D. Although many different model types are used in earth science classrooms, foamcore models (Figure 1) are one of the few physical models that are reported in literature. Foamcore models are commonly used as a cost-effective 3D representation for helping students understand topographic maps. In 1917, Hausman published a paper in the *Journal of Geography* discussing the difficulty of students comprehending topography. He recommended teaching topographic interpretation with quasi-realistic models made from foam with clay overlay of the topographic map. The foam and clay model was to be used to help novice learners obtain a reasonably accurate representation of the associated map (Hausman, 1917). Harnapp & King (1991) present the hands-on experience of building the models based on contour lines as a way to promote student learning.

These papers highlight the common suggestion that the more information given to students, the better they will learn. A limitation of this early work is the lack of systematic assessment of how the models actually impact student learning. Another issue with foamcore models as viable tools for classroom use is that they are fragile. Foamcore models are easily damaged, damage makes the model's accurate representation of the map degrade over time with use.

3D Projections

Stereoscope Photography. Stereo visualization is a method of creating or enhancing the illusion of depth in an image through the medium of tools such as stereoscopes.

Figure 2: Student viewing images using a stereoscope (Image from Queensland Archives, 1949)

Students place two images (usually aerial photographs) that partially overlap side by side, and use a set of glasses to combine the images (Figure 2). Rapp et al. (2007) stated that interventions with stereo visualization maps have consistently returned higher results on evaluations than interventions without, after testing students to discover the effectiveness of stereoscopes. Stereo visualization maps are an effective method for viewing aerial photography in 3D and students tend to more rapidly respond to the 3D displays and see terrain than students without a 3D tool (Krakk, 1988).

However, these tools rely on the use of binocular vision. As much as ten percent of the population has difficulty seeing in binocular vision (Coultant and Westheimer, 1993). Students who cannot see with binocular vision have difficulty aligning the photographs to work without distortion, or simply cannot visualize the 3D image (Slocum et al., 2007). These images are also static, so while students can interact with the visual tools, students cannot interact with the environment beyond the static images presented. Stereo visualization also uses aerial photographs, which do not have contour lines on the images. While stereoscopes display 3D imagery, the techniques do not necessarily translate to being able to actually visualize topography in 3D.

Geowall. Though stereo visualization is an older method, advancements such as the Geowall (Figure 3) have sought to use technology and computer systems to adapt old two-image overlays into modern classrooms (Slocum et al., 2007).

Figure 3: Students sitting in Geowall lecture (Image from University of Alabama, 2006)

The Geowall takes the traditional method of using two image overlay and converts this idea to a cinematic experience, much like using blue and red glasses to create a 3D experience. The Geowall allows for whole classrooms to view entire lectures through the medium of stereoscopy. However, this method is very hands-off and students report distortions in the imagery as well as eye strain issues when experiencing whole lectures in stereoscopy, though reports are not as high as traditional stereoscope photography (Slocum et al. 2007). Finally, cost is a barrier. Geowall installations for classrooms can cost several thousand dollars and faculty report worrying that they have to convert entire lectures to project correctly on stereoscopic projectors (Slocum et al. 2007). To effectively experience the Geowall, students still need binocular vision. Finally, while the Geowall is more advanced, technologically, than stereoscopes, the Geowall still focuses on using aerial photography and learning to translate topographic maps from 2D space to a 3D image is still decoupled entirely.

Coupled Models

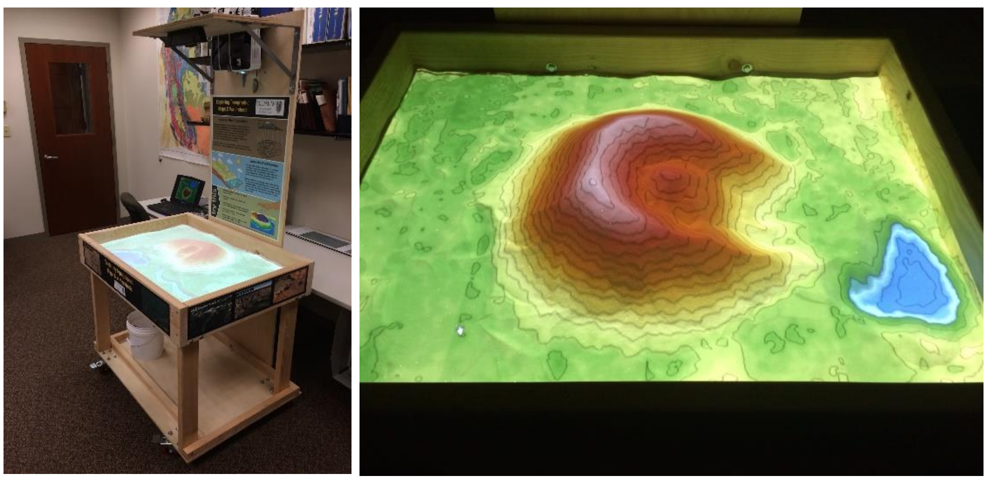


Figure 4: AR sandbox in use (Image from Depauw University, 2019)

Newer teaching techniques, specifically the AR sandbox (Figure 4) use an integration of both 3D displayed imagery and physical 3D models to help teach about topography. Coupled models use a multi-camera sensor and projector to read a tabletop display, such as sand in a box. One camera reads the surface of the display with a light detection and ranging (LiDAR) sensor; the data are filtered and processed through a computer program, and then the projector camera displays equidistant contour lines onto the sand surface. This process creates an active contour map over the tabletop display that students can interact with and change.

Interventions using AR sandbox show promise, though early studies report high student engagement but limited impacts on student learning (e.g., Giorgis et al., 2017). Most of the AR sandbox studies tend to use the tool in a very generalized and open-ended way in established topography teaching activities (Giorgis et al., 2017; Woods, Reed, Hsi, Woods, & Woods, 2016) Teaching interventions using an AR sandbox have, so far, returned mixed results due to student difficulty connecting the 3D representation to the 2D topographic maps. The work of Giorgis et al. (2017) focused on a 20 minute, instructor led program using an AR sandbox. The Giorgis team concluded that the AR sandbox intervention did not yield any statistical learning gains, but did generate significant enthusiasm from students. An earlier study also pointed to increased enthusiasm and perceived learning gains during an AR sandbox activity. Woods et al. (2016) focused on a self-reported assessment of 10 students using AR sandbox in a 45 minute learning demonstration. Students perceived that the hands-on time with the sandbox helped them to better understand complex topography concepts, such as the rule of V's (which states that contour lines will point upwards towards the head of a river system as the river erodes downward). Together, both studies suggest that students react positively to 3D model support in topography analysis, and that coupled systems help students to feel more confident that they better understand abstract concepts and rules of topography.

AR sandbox systems do have limitations, however. While AR sandbox systems dynamically display topography using computer modeling and projection systems, the cost of a complete system can become expensive. Woods et al. (2016) reported that the team built two AR sandboxes for approximately one thousand dollars pulling many of the materials from already available sources. However, Woods team went on to price exhibit grade models upwards of ten thousand dollars, these prices vary widely depending on the already available materials a department can access. Sand has a low angle of repose that ranges from 35-40 degrees, which limits the types of landforms that can be created. Finally, while students perceptions about topography improve with the support of AR sandbox, they still may fail to connect the 3D landform to the 2D map projection. Addressing this issue, Moore (2018) found that the AR sandbox does improve map reading skills for topography when 2D computer displays of the topographic map are coupled with the 3D sandbox display, and students receive cycles of feedback.

3D Printed Materials in Education

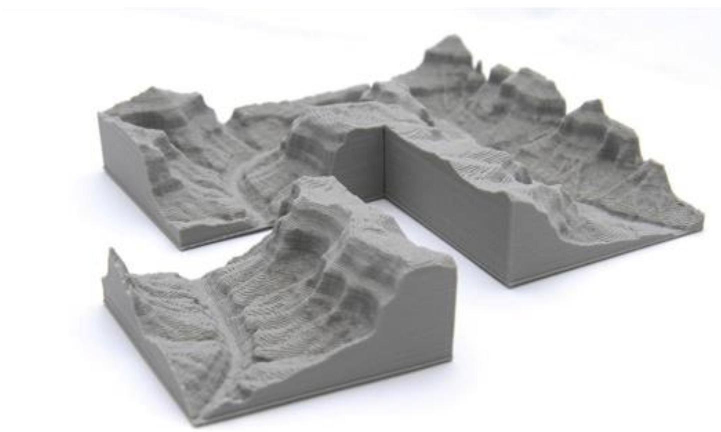


Figure 5: 3D printed terrain example (Image from Iowa State University, 2017).

3D printing has been used in other fields of education, such as medical science education to replace the use of cadavers as detailed in McMenamin, Quayle, McHenry, & Adams (2014) and in engineering to support 3D visualization in AutoCAD and Trimble SketchUp (Alvarez, Parra, & Tubio, 2015). The greatest breakthrough comes from a new free to use, open-source application known as TouchTerrain that generates 3D printable files from USGS mapping databases (Figure 5). TouchTerrain makes it far easier to generate accurate 3D models without the need for complex understanding in computer software engineering.

Although no published literature yet reports using 3D printed models to teach topography, 3D models have been used in the fields of medical science education and engineering. In medical science education, 3D printing is used to create highly detailed replicas of different aspects of human anatomy, even down to accurate blood vessel and nerve distribution through CT scan data. This method allows for the creation of more than just human anatomy, creating virtually unlimited veterinary and zoological research applications (McMenamin et al., 2014). Much like in education through anatomy, topography is complexly detailed, intricate features that can be easily visualized with the use of 3D printed technology.

TouchTerrain is a free open-source application used to help print terrain accurately by converting USGS data to 3D printer files. The goal of TouchTerrain is to overcome technical barriers in 3D printing terrain so that printable landscape features can be more widely used in classrooms (Hasiuk et al., 2017). With the technical aspects of 3D printing terrain for classrooms overcome, there is now an opportunity to use these tools in a classroom to test impacts on student learning. Hasiuk et al.'s (2017) paper on TouchTerrain set the foundation for accessibility of the technology to the classroom. It was the goal of this research project to see what kind of impact these newly accessible tools have on student learning.

PURPOSE

Learning to visualize 3D data from 2D topographic maps has been and remains a difficult skill for students. Many attempts have been made to help bridge the gap in learning topography including physical models, 3D projections, and coupling both physical models and 3D projections. Each of these teaching methods has strengths and weaknesses (Table 1). 3D printed terrain is less expensive and more robust than other previous techniques, and the terrain can be printed accurately from topographic maps. Another highlight of 3D printed terrain includes easily implementing the terrain into a current class, with little to no conversion of content in the laboratory. Students directly see a 3D example of the terrain matching the map used in a lab, which gives students the potential to mentally project what they are seeing on the terrain to the rest of the map, directly linking a 3D image to a 2D surface.

Table 1: *Benefits and drawbacks of different tools for teaching topography.*

	Researched in classroom	**Hands on activity with students**	**Expense to implement**	**Repeated classroom use**	**Other notes**
Physical Models	Little to none	Yes	Minimal	No	Displays tend to be non-realistic
3D Projections Stereoscopes	Yes	Yes	Units range ~$25.00 per student set	Yes	~10% population exclusion Adverse reactions to extended use
3D Projections Geowall	Yes	No	Minimal Input cost ~$1000.00	Yes	~10% population exclusion Whole presentations must be converted to use
AR sandbox	Yes	Yes	Thousands of Dollars	Yes	Currently being researched with mixed results
3D Printed Terrain	This Thesis	Yes	~$10.00 per printed tile	Yes	Realistic, Vertical Exaggeration of 1, Can overlay topographic map

The purpose of this study is to develop and evaluate a topography teaching intervention that uses 3D printed terrain. Printed terrain is a return to physical models. However, 3D terrain offers the advantage of using data taken directly from a 2D topographic map and accurately representing the topography shown on the map in 3D in a more durable format.

METHODS

Research Design

The study used a quasi-experimental design with a pre- and posttest deployed in nonequivalent groups (Shadish, Cook & Campbell, 2002). The study took place in the same course across two semesters, with participants drawn from existing sections of the traditional lab in the Fall 2018 semester, and the intervention deployed in lab sections during the Spring 2019 semester. Within this design, the study used a simultaneous, explanatory mixed-method approach in which quantitative data dominated and qualitative data served to further explain the quantitative findings. The major source of quantitative data assessing students' knowledge of and skill with topographic maps was the Modified Topographic Map Assessment (MTMA). Qualitative data served to further explain the quantitative results and included written responses to open-ended questions on the MTMA and classroom observations. Quantitative and qualitative data were collected at the same time, then analyzed separately and finally merged to inform overall findings. Performance on the MTMA was compared between the traditional topography lab (fall semester) and 3D printed terrain intervention lab (spring semester) in order to determine what changes occurred when the 3D terrain was used in the classroom.

Context. This project took place across multiple lab sections of GEOS 1000: Dynamic Earth, a general education course specifically for non-science majors. The face-to-face course consisted of one large lecture section (taught by a faculty instructor) and 8-10 lab sections (taught by graduate teaching assistants). The same faculty member and four teaching assistants were the instructors in both semesters of this study. The topic of topography is not covered in the lecture, so students learn the material entirely in the lab.

This class was specifically targeted for an intervention because of the non-geoscience majors in the course and the known difficulties of teaching topographic map skills effectively. The Dynamic Earth course reaches approximately 100 non-science students every semester; understanding the effect of the 3D terrain on learning topography could not only improve the learning experience for these students but could be widely used in introductory geoscience courses elsewhere.

In the traditional topography lab for this course (Table 2), students hear a mini-lecture introducing the topic, complete a computer-based tutorial intended to teach the basic skills of map reading and interpretation, and then answer a series of questions based on the Kalamazoo, Michigan USGS 1:24,000 topographic map. The intervention lab (Table 2) followed an identical format as the traditional lab, except that it included a piece of 3D terrain printed from a portion of the Kalamazoo topographic map (Figure 6). The teaching assistant gave students a handout explaining how to align the 3D printed terrain piece on the map, and discussed that the terrain piece is a representation of the contour lines and topographic data (Appendix B).

Table 2: Laboratory procedures in the traditional topography lab (fall semester) and 3D print terrain intervention lab (spring semester).

Traditional Topography Lab(Fall Semester)

Direct Instruction ***PowerPoint***	Explanation of terminology
	Introduction to map and contour lines
	Fill-in-the-blank hand-out associated with PowerPoint
Conceptual Application ***Map***	Intro to the Kalamazoo quad map
	Fill-in-the-blank hand-out associated with Kalamazoo quad

3D Print Terrain Intervention Lab (Spring Semester)

Direct Instruction ***PowerPoint***	Explanation of terminology
	Introduction to map and contour lines
	Fill-in-the-blank hand-out associated with PowerPoint
Conceptual Application ***Map***	Intro to the Kalamazoo quad map
	Intro 3D terrain tool
	Fill-in-the-blank hand-out associated with Kalamazoo quad

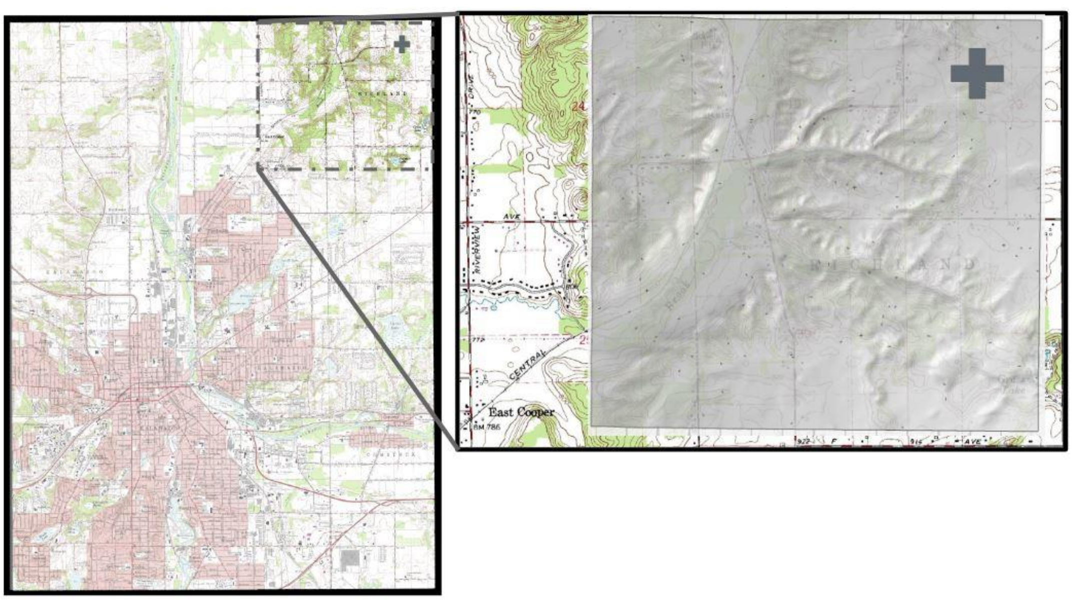


Figure 6: 3D printed terrain overlay onto Kalamazoo topographic map.

Instruments

Two instruments were used in this project to assess student learning of topography. Lab sections in both the traditional and intervention semesters were also observed to ensure that the 3D print terrain was used as intended, and that teaching practices were comparable across different teaching assistants.

The Modified Topographic Map Assessment (MTMA). This instrument (Appendix C) consists of 15 multiple-choice and 3 open-ended items used to assess students' topographic map reading skill. Jacovina et al. (2014) designed the original Topographic Map Assessment (TMA) as a 23-item, open-ended instrument. In order to make the instrument easier to score and more accessible for use by non-science students, Moore (2018) converting the open-ended items to multiple choice items and renamed the instrument the Topographic Map Assessment-B (TMA-B). This study further modified one item of the TMA-B as described below and renamed the instrument to the MTMA. The MTMA was chosen to assess topographic map reading skills for this study because the instrument is shown to be valid and reliable with a comparable population of college-aged, novice topographic map readers.

The original TMA was collaboratively developed with cognitive psychologists, geoscientists, and educators (Jacovina et al., 2014). This original test consisted of 23 open-ended items scored for 28 possible points (Newcombe et al., 2015). The psychometric characteristics of the original TMA were evaluated with a large sample of psychology students (N = 261). Internal consistency (α=.76) indicated that the TMA was useful for assessing topographic map reading abilities in novice students (Newcombe et al., 2015).

As part of a recent study of student learning of topography using an AR Sandbox, Moore (2018) converted the open-ended items of the TMA into closed-response items. The TMA-B preserved the reliability (α = .74) of the original TMA but is easier to score, faster to administer to novice map readers, and can be adapted to administer in an online format. The TMA-B consisted of 15 questions, including 13 nested sub-items and 3 open-ended items, scored for a total of 20.5 points (Moore, 2018). Moore's study population included college undergraduate students with little to no prior map reading experience (N=102) similar to this project's participants (Figure 5).

This study adopted Moore's (2018) 15-item TMA-B because of the ease of instrument scoring and the ease of use with a comparable novice undergraduate student study population. However, the correct response to Item 12 on the TMA-B was a topography term ("saddle") that was not explicitly taught in the WMU Dynamic Earth lab. In order to better align the instrument with what was taught in the lab, the image for this item was replaced with a different image for which the correct term ("valley") was taught in the lab. The term "saddle" remained as a response option in this and other items. This study used the original scoring procedure of Jacovina et al. (2014), awarding 1 point per closed-response item or nested sub-item for a maximum score of 25 possible points. Responses to the three open-ended items were not scored and were used only as an insight into student thinking. The resulting instrument was called the MTMA. The reliability of the MTMA administered with this study's student population was comparable to the original and modified instruments (α = .71; Table 3)

Table 3: *Cronbach's Alpha test for reliability of the MTMA.*

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.71	.75	24*

*SPSS excluded item 4, due to the low number of correct responses to this item.

Demographic Survey. These items asked for personal characteristics of participants including gender, year in school, and previous experience with topographic maps (Appendix D). These items were intended to describe the participants and are reported only in aggregate. The survey was also developed to help the researcher identify whether students may have had previous experience with topographic map interpretation (e.g., in Boy or Girl Scouts, military experience, outdoor navigation, other courses, etc.)

Lab Observations. The thesis author observed all topographic map lab sessions in both semesters of the project in order to understand typical teaching practices and student experiences of the labs. Observations focused on the general flow of teaching (e.g., instructor actions) and how students responded to verbal instruction and to the computer and written materials in the lab (e.g., where students had questions or appeared to struggle). No individual students were observed; the intent of the observations was to ensure that the teaching was comparable across lab sections and that the 3D print terrain was introduced to each section using the materials provided.

Participant Recruitment and Selection

The study took place at WMU, a Midwestern research university with a total enrollment of approximately 23,000 students (18,000 undergraduates). All students enrolled in all face-to-face lab sections of Dynamic Earth in the 2018-2019 academic year were invited to participate in this study. The thesis author verbally invited students in all lab sections to participate by reading a recruitment script at the beginning of the laboratory section the week of the topography lab. Each student was given a copy of the consent/assent document. They were invited to read the document and check the appropriate box(es) to indicate whether or not they consent to participate in the survey, and returned the document to a folder at the front of the room. All students who gave consent to participate were included in the study.

Data Collection

In both semesters of the study, data collection from student participants took place at two points: before the topography lab session began and the lecture class following the lab session. At the beginning of the topography lab prior to any instructions, students completed the MTMA as a pre-test. On the days of the topography lab sessions, the thesis author observed the lab and took notes. At the beginning of the Dynamic Earth lecture following the topographic lab section, participating students completed the MTMA as a posttest, as well as completed the demographic survey and a feedback questionnaire, which was used for informing the Dynamic Earth professor and teaching assistants on future direction for possible improvements to the lab and is not reported in this study.

Data Analysis and Interpretation

The multiple-choice responses from the pre/post MTMA (Appendix E) were entered into a spreadsheet, along with participants' demographic data. Each item was scored as correct or incorrect, and scores were totaled for each participant out of 25 possible points. Descriptive statistics (mean, standard deviation, median, and mode) were reported for the MTMA scores for each semester. In order to assess changes in student learning during the traditional and 3D print terrain intervention labs, a paired samples t-test was conducted for each group. In order to assess whether students' incoming knowledge of topography was comparable between the traditional and intervention groups, an independent samples t-test and Levene's test for equality of variances were performed on pretest scores across the two groups. All statistical analyses were carried out in SPSS version 25, and a p value of $<.05$ was considered statistically significant.

Responses to the open-ended MTMA items (Appendix F) were also entered into a spreadsheet. Similar response patterns were grouped and used to describe general trends in responses for each item in the traditional lab and 3D print terrain intervention lab. While not formally coded, simple trends found in the data are discussed in the qualitative section of the research results.

Ethical Considerations

Because the research study drew data mainly from normal classroom work and procedures, there were very few known risks to the subjects. Students may have felt inconvenienced or frustrated at completing the MTMA survey and questionnaire, particularly when they encountered the MTMA as a pretest without prior instruction in topography. Students were informed that their answers were for research and had no impact on their class performance.

The course instructor and laboratory teaching assistant in each semester did not participate in obtaining consent or collecting data, in order to reduce possible student perceptions of coercion. Students were also informed that the purpose of the research was to better develop and teach the targeted lesson. They were aware that their instructor and laboratory teaching assistant did not know who was participating in the research study, and that their participation (or declining to participate) had no effect on their course grade or performance. Due to the nature of the lab environment, students were seated in and working in groups; students were informed that confidentiality of responses could not be guaranteed. All research was carried out under an approved HSIRB protocol (Appendix A).

RESULTS AND DISCUSSION

Participant Demographics

A total of 78 students across both the traditional lab semester (n=54) and the 3D printed terrain intervention semester (n=24) participated in this study. All of the students were undergraduates. Both semesters were dominated by self-reported freshmen (Table 4). The mean student age was comparable across both semesters (19.8 years) although the traditional lab semester had a slightly wider age range. The 3D intervention semester had a slightly higher number of male students and a higher number of students of color as compared to the traditional lab semester (Table 4).

Table 4: Demographic data for participants in the traditional and 3D print terrain labs

	Traditional Lab (Fall) n=54	3D Print Intervention Lab (Spring) n=24
Age range (mean)	18-26 (19.8)	18-21 (19.8)
Male	46.3%	54.2%
Female	46.3%	41.7%
White	68.5%	66.7%
Students of color*	18.7%	29.2%
Freshmen	46.3%	50.0%
Seniors	7.4%	0.0%

*Includes: Hispanic/Latinx, Native American, Asian/Pacific Islander, and Black/African American responses.

The largest population of students in both the traditional and intervention labs self-reported as business majors; in the intervention semester, the proportion of business majors increased by 25.7% (Figure 7). There were similar proportions of arts/humanities, social science, and science, technology, engineering, and math (STEM) majors in both semesters (Figure 7). The number of undecided majors decreased during the intervention semester (presumably because more freshman had declared majors by their second semester). Finally, no students reported heath or education majors during the 3D intervention semester. It is worth reiterating that while these percentages are similar between semesters, the number of volunteers was much lower in the intervention semester.

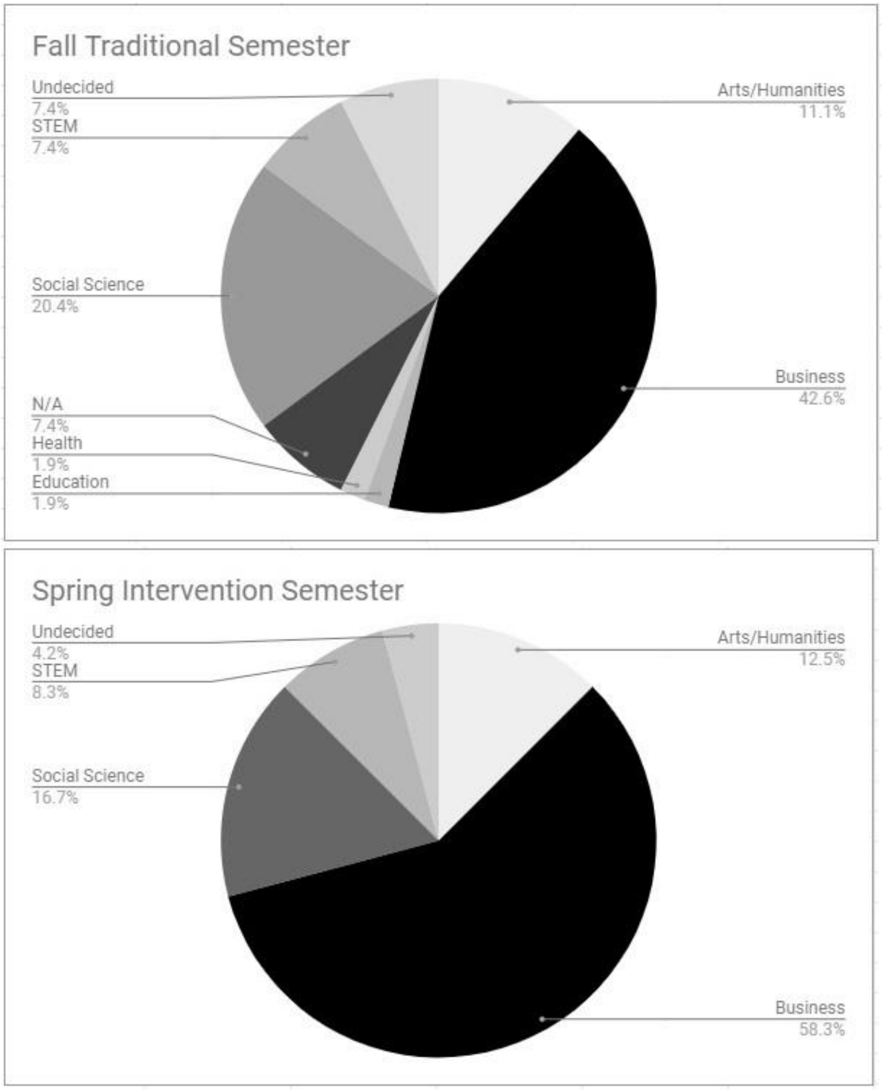


Figure 7: Comparison of student majors between the traditional and 3D print terrain labs.

Quantitative Results

Student performance on the MTMA is presented as means and distribution of overall scores for each semester, then compared statistically between semesters. Finally, pre- and posttest performance on individual items is considered.

In the traditional lab, the mean score on the MTMA (Table 5) improved from 16.07 (SD = 3.96) to 16.70 (SD = 4.47). This means that there was minor improvement in scores from pre- to posttests, however, the improvement was less than one point on average. In the 3D print terrain intervention semester, the mean score on the MTMA improved from 15.08 (SD = 3.61) to 17.04 (SD = 3.74) (Table 5). This indicates, on average, test scores in the intervention (spring) semester rose by two points from pretest to posttest.

Table 5: Student performance on the MTMA pre- and posttest in the traditional (fall) and 3D print terrain intervention (spring) semesters.

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Traditional Pretest	54	16.07	3.96	-.47	.33	.47	.64
Traditional Posttest	54	16.70	4.47	-.72	.33	.16	.64
3D Intervention Pretest	24	15.08	3.61	-.61	.47	-.23	.92
3D Intervention Posttest	24	17.04	3.74	-1.19	.47	1.43	.92

The traditional semester (n=54) pre- and posttest data had skewness and kurtosis values between 1 and -1 (Table 5), indicating that the traditional lab data are normally distributed within standard statistical limitations. The spring intervention semester (n=24) pretest had skewness and kurtosis values between 1 and -1, however, the posttest skewness and kurtosis both fell slightly outside of 1 and -1 values but were still within 2 and -2 (Table 5). For the spring intervention lab posttest this indicates that the distribution of data is slightly leptokurtic or sharp pointed and the negative skewness indicates that the distribution has a longer tail to the left. All data met the assumptions of normal distribution needed for parametric statistical tests. The distribution of data is displayed visually for the traditional lab in Figure 8 and the 3D print terrain lab in Figure 9.

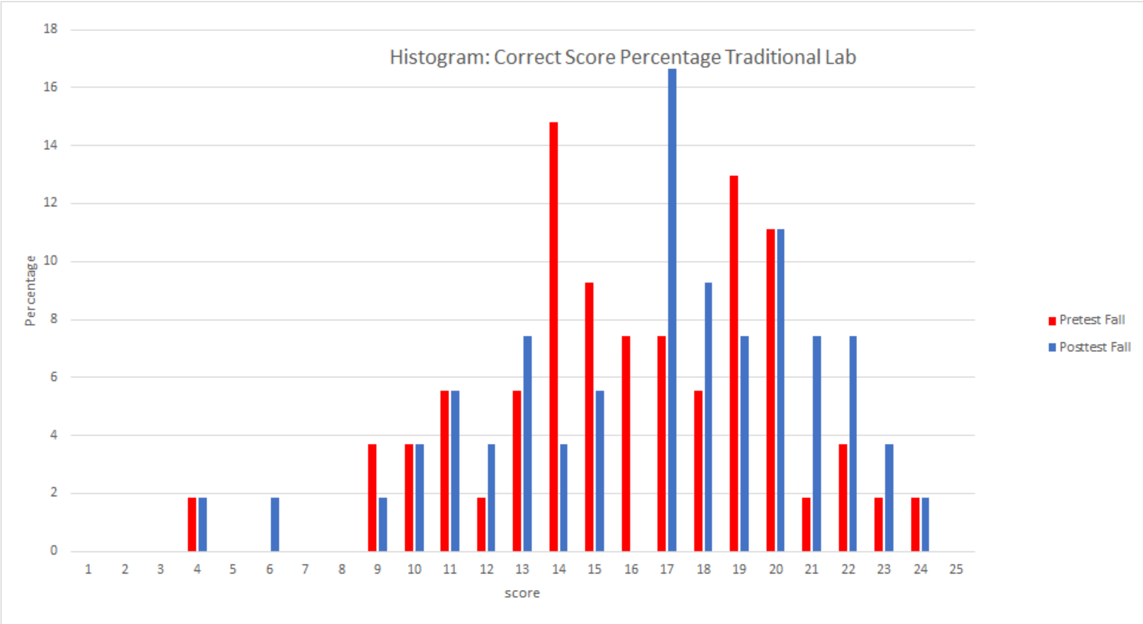


Figure 8: Histogram distribution of correct score percentages for the traditional (fall) semester.

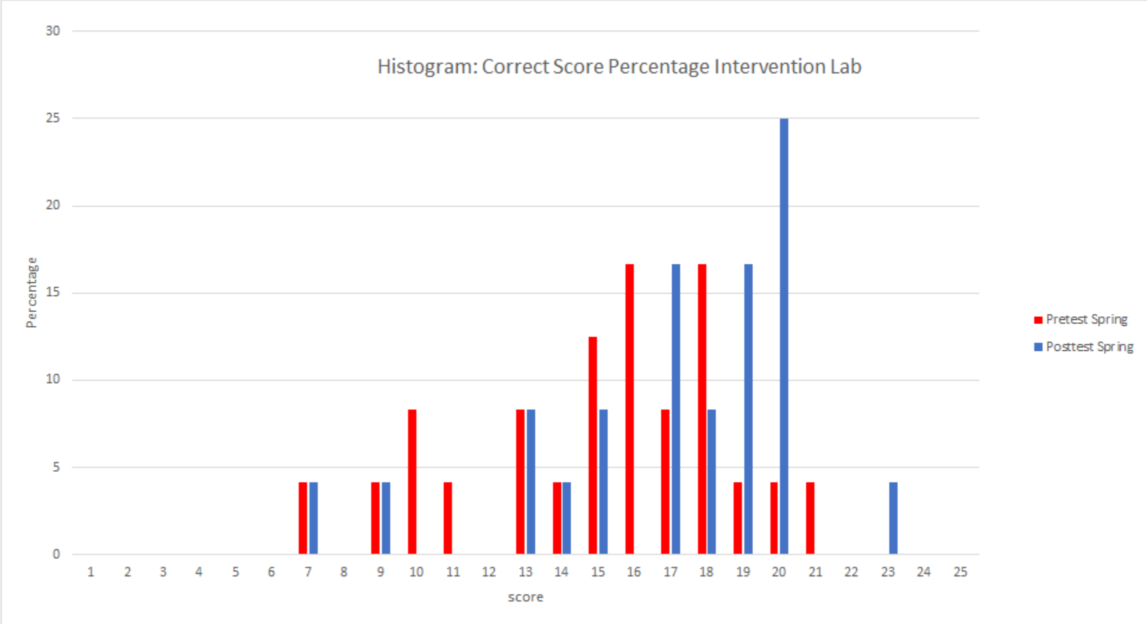


Figure 9: Histogram distribution of correct score percentages for the 3D print terrain intervention (spring) semester.

In order to examine student performance more closely, the pre- and posttest results are displayed side-by-side in Figure 10. Each point (Figure 10) represents the change in an individual student's MTMA score. In the traditional lab semester, almost half (48%) of students showed improvement from the pretest to the posttest, ranging from 1 to 7 points. Just over one-fifth (22%) of students had no change from pretest to posttest score as measured by the MTMA (the "line of no learning," Figure 10). Finally, approximately 30% of students performed more poorly on the posttest than on the pretest.

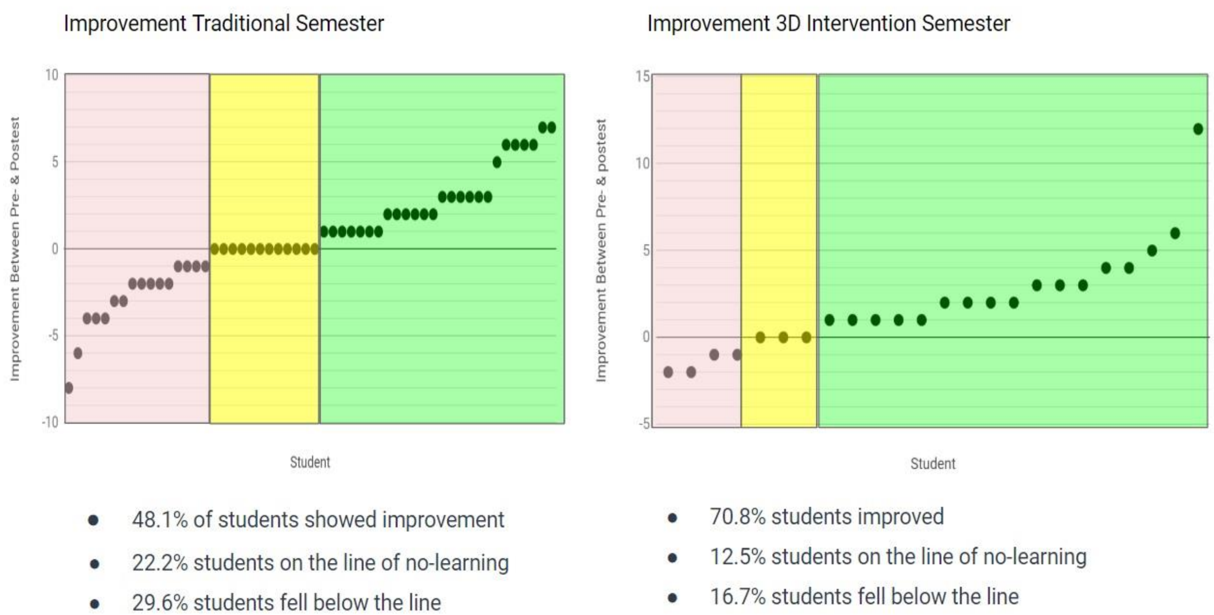


Figure 10: Comparison of MTMA score distribution for the traditional lab (fall semester) and 3D print terrain intervention lab (spring semester).

During the 3D printed terrain intervention semester, approximately 71% of students' MTMA scores improved from 1 to 12 points between the pretest and the posttest. The intervention semester had approximately 13% of students with no change in MTMA score, and about 17% of students with posttest scores lower than their pretest scores.

A paired samples t-test was performed in order to compare pre- to posttest scores within each semester (Table 6). Student scores on the MTMA posttest were not significantly different than scores on the pretest in the traditional lab semester at either the 95% or 99% level of confidence (Table 6). In the intervention semester, student scores were about two points higher on the MTMA posttest than on the pretest at the 95% level of confidence (Table 6).

Table 6: Comparison of MTMA pre- to posttest performance in the traditional (fall) and 3D print terrain intervention (spring) semesters.

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Traditional	.63	3.13	.43	-.23	1.48	1.48	53	.15
Intervention	1.96	2.97	.61	.70	3.21	3.23	23	.004*

* indicates significant difference with p < .05

An independent samples t-test was used to compare pretest scores between the two semesters. Incoming knowledge between the traditional lab semester (M = 16.07, SD = 3.96) and the intervention lab semesters (M = 15.08, SD = 3.61) were not significantly different (t(75) = .98, p = .33, Table 7). Results of the Levene’s test for equality of variances (Table 7) indicate a p-value greater than .05 (p = .57). The results of both tests indicate that there is no statistically significant difference between scores on the pretests between the two semesters.

Table 7: *Comparison of MTMA pretest performance between the traditional (fall) and 3D print terrain intervention (spring) semesters.*

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Equal variances assumed	.33	.57	.98	75	.33	.94	.95	-.96	2.83
Equal variances not assumed			1.02	49	.31	.94	.92	-.91	2.78

Although student performance on the MTMA did not statistically improve during the traditional topography lab (Table 6), student performance changed on several individual MTMA items (Figure 11). Students performed poorly on both the pre- and posttest on items 4 and 6, both of which required them to interpolate elevation between contour lines. Little to no change in performance was observed for items 3 (identifying which of two hills is higher elevation), 8 (cross section from topographic profile), 9 and 10 (perspective-taking), and 13, 14, and 15 (naming a landform) (Figure 11). A slight improvement was observed for items 1, 2, and 7, all of which require students to visualize the topography (Figure 11). A decline in performance was observed for items 5 (identifying a steeper slope) and 12 (naming a landform) (Figure 11).

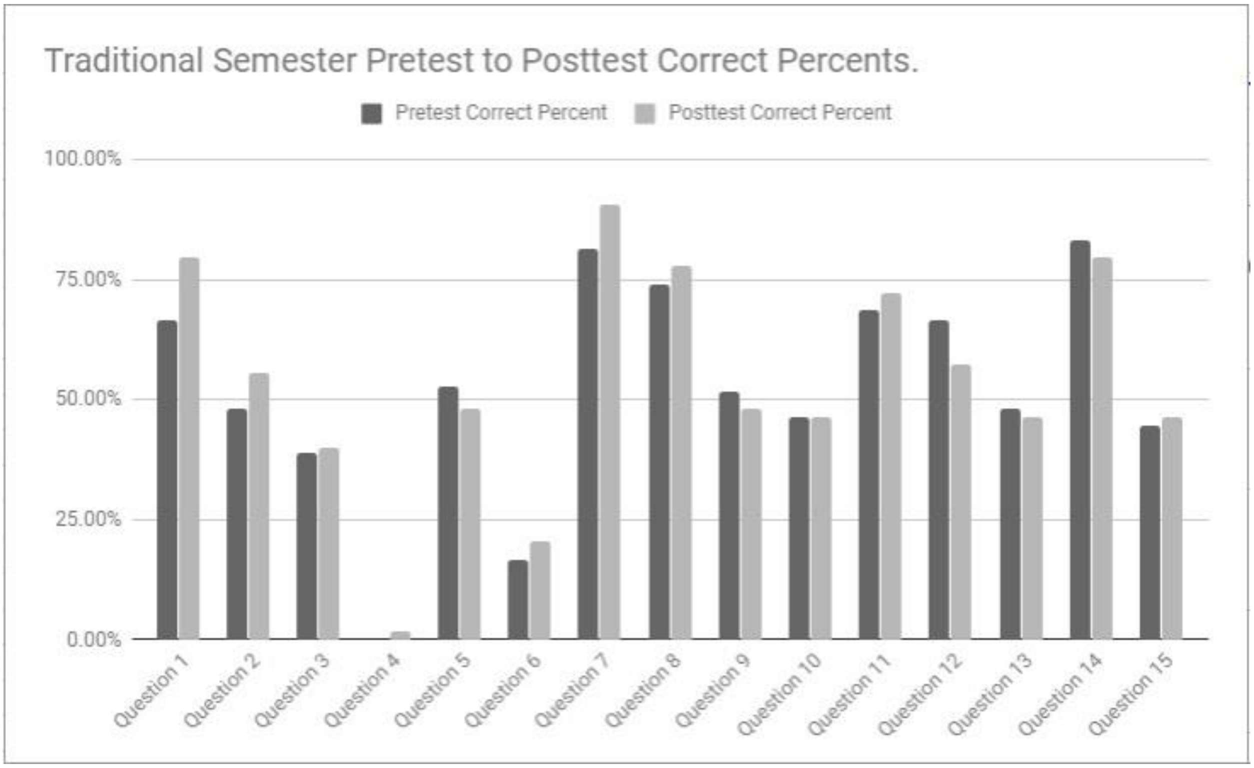


Figure 11: Student performance on individual MTMA items on the pre- and posttest during the traditional lab (fall semester).

In the intervention semester students also performed poorly on the two items that required them to interpolate elevation from contour lines (items 4 and 6) (Figure 12). Little to no change in performance was observed on the items measuring slope (item 5), cross sections (item 8), perspective-taking (items 9 and 10), and naming a landform (item 14) (Figure 12). Students preformed more poorly on the posttest than on the pretest on item 12, which asked them to name a landform (a valley). However, students improved on many items related to visualizing topography (items 1, 2, 3, 7, and 11) and on one item related to naming a landform (a valley; item 15) (Figure 12).

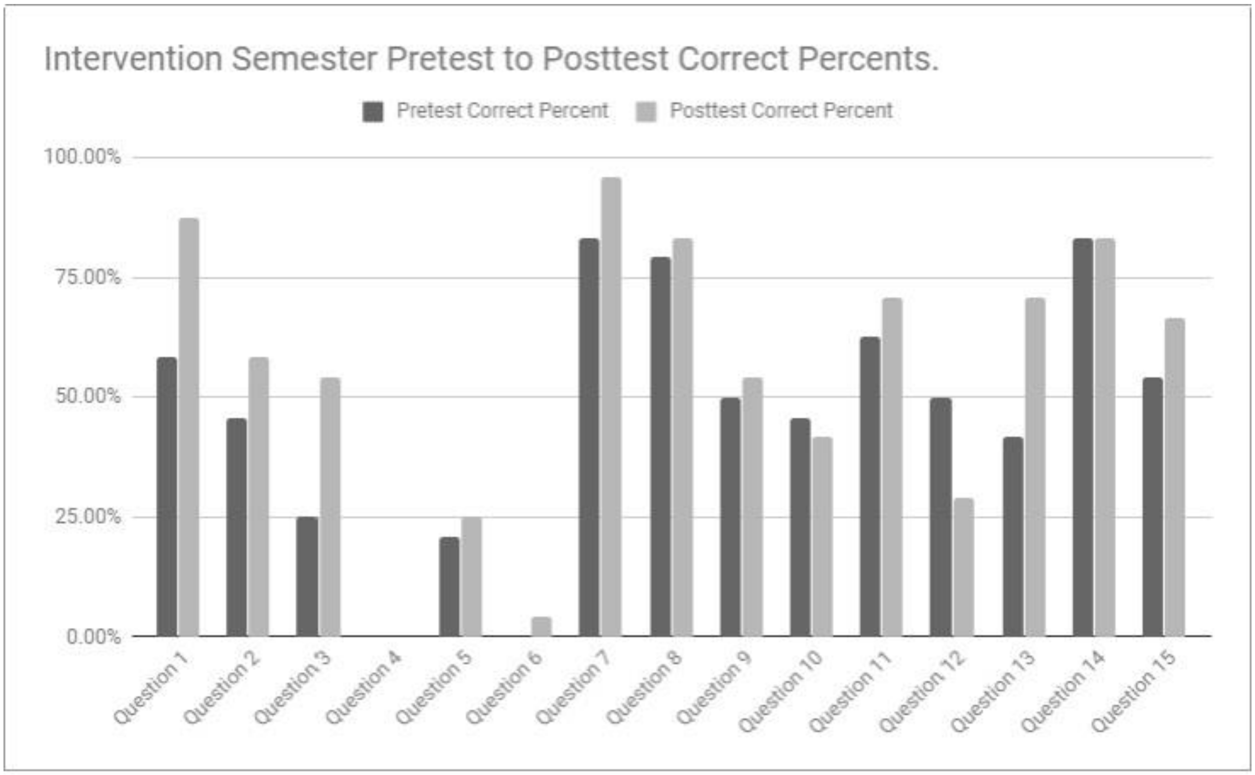


Figure 12: Student performance on individual MTMA items on the pre- and posttest during the 3D print terrain lab (spring semester).

Quantitative Discussion

In the traditional lab, scores on the MTMA improved from pre- to posttest from 16.07 (SD = 3.96) to 16.70 (SD = 4.47), and in the 3D print terrain lab they improved from 15.08 (SD = 3.61) to 17.04 (SD = 3.74). The comparison of pre- to posttest performance on the MTMA between the two semesters (Table 6) indicates a statistically significantly improvement in the intervention semester ($p = .004$) as compared to the traditional lab semester ($p = .15$).

Results of the independent samples t-test comparing pretest scores between the traditional and intervention lab groups (Table 7) suggest that students from both groups had comparable skills with topographic maps as measured by the MTMA. These results were confirmed with a lack of statistically significant results for the Levene's test for equality of variances ($p = .31$;

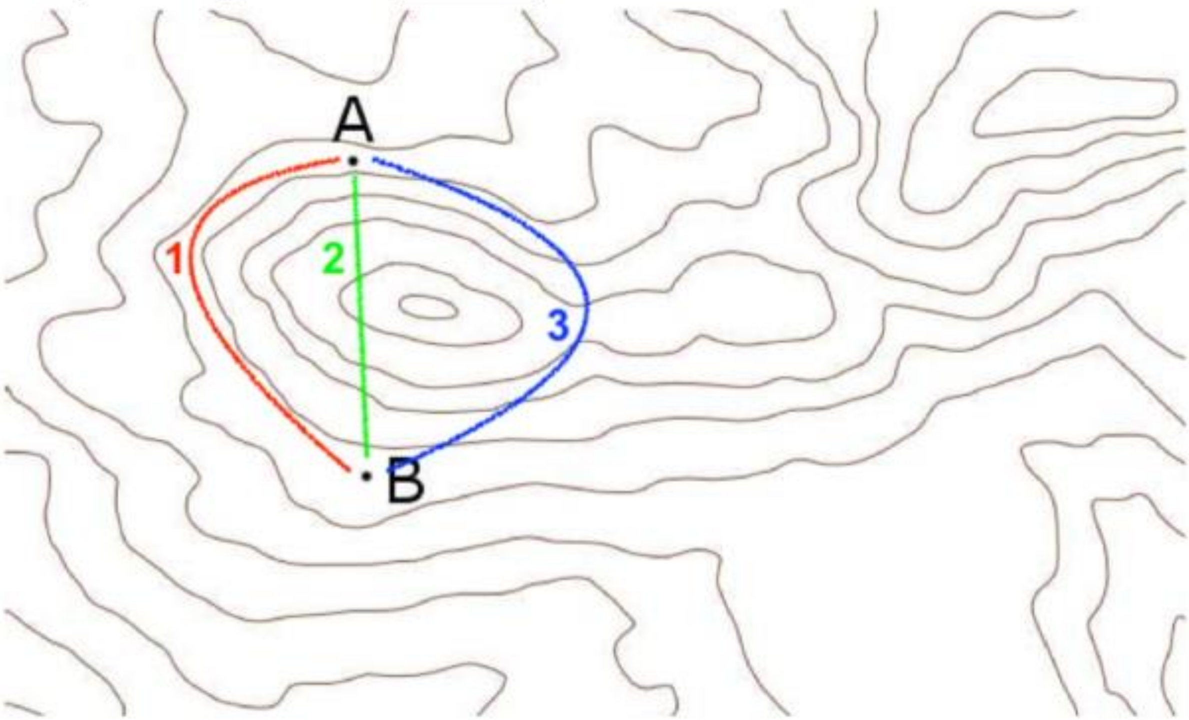
Table 7). Statistically, the two groups entered into the lab with comparable experience, according to the MTMA. A mean gain of 0.63 points was observed from pre- to posttest during the traditional lab semester and a mean gain of 1.96 points was observed during the intervention lab semester. This indicates that the 3D printed terrain intervention has promise for improved student learning as compared to the traditional lab. Although no statistical tests were done to evaluate student performance on individual MTMA items, students performed well on many items related to visualizing topography in the 3D print terrain lab, also suggesting that the intervention has promise.

Qualitative Results

The first, second, and fifth items of the MTMA also contained embedded qualitative questions in which students described the reasoning for their answer(s). Item 1 (Figure 13) has been selected to more deeply examine some sample responses for path choice because it assesses how well a student can visualize 3D topography from the 2D map. These qualitative responses were not scored and were used purely to gain insight into student thinking as they looked at the images and chose their response.

Q1) Imagine you had to walk from point A to point B and wanted to take the fastest path possible.

Which path would you choose? _________



Explain why you chose that particular path.

Figure 13: Item 1 of MTMA featuring embedded qualitative question.

Appendix Table F of raw data displays the traditional lab responses to the first question on the MTMA. For example, on the pretest, many student explanations indicate a desire to take the quickest route in order to get from point A to point B.

Table 8: Sample incorrect to incorrect responses on item 1 in the traditional (fall) semester.

Pretest Answer and Reason		Posttest Answer and Reason	
2	Because 2 is a straight shot to B	2	Straight shot to B
2	It seems the fastest	3	Because it's not super steep
2	Because a to b by 2 is a straight line and the other routes are longer	2	Straight line
2	The fastest way to a destination is a straight line	2	It's a shorter distance

As shown in Table 8, a small number of responses chose path 2 as both a "straight shot" and small elevation change. This result did not improve for the sample of students between the pretest and the posttest. Many of those students continued to choose the shortest distance, or travel in a "straight shot," suggesting that these students failed to visualize the 3D nature of the landform on which path 2 has the greatest elevation change.

Table 9: Sample correct to correct responses on item 1 in the traditional (fall) semester.

Pretest Answer and Reason		Posttest Answer and Reason	
1	With path one you go around the same level rather than having to go up or down levels	1	You stay on the same level as you go around the mountain
1	You're on the same level	1	It is equal elevation
1	I chose because there are no obstacles	1	It is a straight path to B
1	Because it's on an even path	1	Because it's on even ground

A subset of students answered correctly both in the pretest and the posttest (Table 9), presumably because they knew or could visualize that the "levels" should be the same between contour lines. A few of these responses in the posttests evolved to use more complex terms such as noticing the hill or mountain and stating elevation rather than "same level."

Finally, a sample of students who improved from incorrect to correct answers (Table 10) shows that these students entered the class with the idea that a straight line would create the fastest path. However, these students chose the correct answer on the posttest, beginning to explain that one would “miss having to go up and down” the mountain or hill feature. Responses indicate that these students were able to recognize or visualize the 3D nature of the landform during the posttest.

Table 10: Sample incorrect to correct responses on item 1 in the traditional (fall) semester.

Pretest Answer and Reason		Posttest Answer and Reason	
2	Because it’s the fastest path	1	Fastest path
2	It goes straight through the middle instead of around it	1	You miss having to go up and down the mountain
3	I assume that if you just went from a to b the smaller circles could mean elevation? Or a mountain/hill? If that’s true you’d be smart to go around	1	I would take 1 because the path goes around the hill, and also it remains around the same elevation
2	It’s the shortest path and goes straight	1	Shortest rout[e] and fastest way

Similar to the traditional lab semester, in the 3D print terrain intervention semester, a small number of students entered the lab thinking that a straight line is the fastest path between points A and B (Figure 8). These students did not change their responses on the posttest (Table 11), suggesting that they failed to recognize the 3D nature of the landform in Figure 8.

Table 11: Sample incorrect to incorrect responses on item 1 in the 3D print terrain intervention (spring) semester.

Pretest Answer and Reason		Posttest Answer and Reason	
2	Because it seems not as steep	2	Not as steep
2	Straight line is fastest way	2	Shortest path possible
2	It seems shorter and it’s just a straight path	2	It’s a straight shot

Another subset of students during the intervention semester answered item 1 of the MTMA correctly on both the pre- and posttest. This group of students entered the class using terms such as elevation and recognizing "topographic lines as same layers of land" (Table 12). These students may have been able to recognize or visualize the landform in item 1.

Table 12: Sample correct to correct responses for item 1 in the 3D print terrain intervention (spring) semester.

Pretest Answer and Reason		Posttest Answer and Reason	
1	I chose one because the line is going through the same layer of land	1	I chose 1 because the path has only 1 elevation
1	We stay on the same elevation	1	You don't climb any hills
1	The elevation doesn't change	1	Less up and down
1	Less elevation to cover so it will be faster	1	Path 1, because it doesn't change elevation

Table 13 shows intervention semester responses to the first question on the MTMA where students improved from incorrect to correct answers. Typically students responded on the pretest that Path 2 is fastest because it is a straight line or is the shortest path. However, a correct interpretation of the topographic image in this question shows that path 2 would be the most steep and least favorable.

Table 13: Sample incorrect to correct responses on item 1 in the 3D print terrain intervention (spring) semester.

Pretest Answer and Reason		Posttest Answer and Reason	
2	Shortest distance	1	Less elevation
2	The fastest way is a straight line?	1	Stay at the same elevation
2	It's straight through	1	It's the same elevation throughout
2	A straight line is the quickest [r]oute between 2 points	1	It has the least amount of elevation

The improvement from incorrect to correct answer is also associated with the use of terminology such as "same elevation." The students who showed no improvement from pretest to posttest typically held on to their idea that the fastest route would be the shortest distance, and did not include mention of elevation (only one response discussed steepness; Table 11). Finally, the responses of students who answered correctly on both the pre- and posttest suggest that these students were already thinking about elevation and topography. For example, one student wrote on the pretest that Path 1 is fastest because it is "... going through the same layer of land," suggesting that they were considering topography in planning the fastest route. This same student correctly applied the term "elevation" to their posttest response, suggesting that they could apply the correct term to their prior idea.

Qualitative Discussion

The qualitative responses to item 1 were not evaluated statistically, however, the answers were used to share a snapshot of the way students approached the questions in both pretests and posttests. These responses provide additional insight into how the use of terminology changed between pretest and posttests.

The students who showed no improvement from pretest to posttest typically held on to their idea that the fastest route would be the shortest distance. The responses do not mention elevation (only one response discussed steepness; Table 11), suggesting that these students failed to recognize the 3D nature of the landform in the map image. The responses of students who answered correctly on both the pretest and posttest suggest that these students were already thinking about 3D elevation and topography. For example, one student wrote on the pretest that Path 1 is fastest because it is "... going through the same layer of land," suggesting that they were considering topography in planning the fastest route. This same student correctly applied the term "elevation" to their posttest response, suggesting that following the intervention they could apply the correct term to their prior idea. As compared to the traditional lab, improvement from incorrect to correct answer on Item 1 in the 3D print intervention lab is more frequently associated with the use of terminology such as "same elevation." These results tentatively suggest that the 3D print terrain intervention helped students recognize the 3D nature of the topographic map and improved their understanding of contour lines as reflecting equal elevation.

CONCLUSIONS

The intention of this project was to develop and implement a lab activity in a general education earth systems course that uses 3D printed terrain to teach topography, and to evaluate the effect of the intervention on students' skills with topographic map interpretation. Using a quasi-experimental design, this study compared student learning gains on a test of topography skills (the MTMA) across two semesters. During the traditional lab semester, students took the MTMA as a pretest before the topography lab and as a posttest after the lab in order to gauge learning. During the intervention semester, 3D printed terrain, easily coded with the support of TouchTerrain and printed from 3D Hubs using a portion of the Kalamazoo, MI USGS 1:24,000 topographic map, was added as a support tool for students as they studied the topographic map. Observations of the lab in both semesters ensured that teaching was comparable across all sections. Students in the intervention semester also took the MTMA before and after the topography lab. Closed-response items on the MTMA were statistically analyzed and open-ended items were examined for changes in student thinking.

The results of the two semester study indicated statistically significant learning gains in the 3D print intervention semester, but not in the traditional lab semester. Results of two additional tests indicate that students had comparable incoming skills with topographic map interpretation across both semesters, as measured by the MTMA. While the results are promising, the pilot study was small, had small lab sizes, and is only a single trial. More research should be done to expand the potential use of 3D print terrain since it does show promise for future classroom implementations for its cost effectiveness and ease of implementation.

Implications for Education

The implications from the 3D terrain pilot study include the potential for 3D printed terrain to be used as a teaching resource beyond the introductory geoscience classroom. 3D terrain teaching resources could be developed for geography or geology major courses, used in conjunction with field courses, or used to teach other topic that require spatial understanding. The cost effective nature of 3D printed terrain could also make these resources accessible to K-12 earth and environmental science teachers. The United States Armed Services could use 3D terrain resources as a supplement for teaching land navigation and orienteering, or as a map reading tool.

3D terrain holds great promise for enabling visually impaired and blind students to engage in tactile learning about landforms. Anecdotally, in the intervention (spring 2019) semester, the student researcher worked with 3 visually other-abled students in a lab section using the 3D print terrain (this lab section was not included in the research study). These students expressed deep dissatisfaction with how visual so many of the labs were, including the topography lab. By adding 3d tactile surfaces superimposed over a topographic map, students can use other sensory features to learn topography more effectively than in traditional map labs. There are many directions that 3D printed terrain can go for further research opportunities beyond the pilot study that should be evaluated due to the promise the 3D printed terrain shows.

Limitations and Future Work

Limitations of Study. The design of this study has inherent limitations, which were minimized as described below. Laboratory sections were taught by four different graduate teaching assistants (TAs) in the fall and spring, who come from diverse backgrounds with different levels of teaching experience and even different primary languages. Although the same curricula was used in each of the labs and the TAs had the same preparation, observations revealed that the instruction varied across lab sections. Some TAs spent more time than others on the introductory lecture, and some were more skilled in responding to student questions during the lab. Furthermore, the TAs appeared more comfortable with the teaching materials in the second intervention semester. Observations confirmed that the TAs did use the 3D print terrain teaching materials comparably across sections. Due to the small number of students in the labs (most below 25 students) and even lower student participation in the study, no ANOVA tests could be run to determine if there was an instructor effect on student learning. With a much larger study population, statistical tests could reveal whether differences in the TAs contributed to learning gains.

Another limitation of the study comes from the pre- and posttest data collection procedure. Due to a field trip during the weekly lab session prior to the topography lab, the pretest was deployed at the start of the topography lab. The posttest was then deployed in lecture after all of the lab sessions were finished for the week. Collecting data in this way means that students who had lab at the beginning of the week had a longer time between pre- and posttest as compared to students who had lab closer to the end of the week. Due to how the topography labs were scheduled, as little as a few hours and as long as four days elapsed between the pre- and posttest.

The pilot study was limited to a convenience sample of students enrolled in a single course at a single institution over a limited amount of time, and results therefore may not be transferable to other types of institutions, more diverse student populations, or other courses that teach topography. Furthermore, the study lasted a single academic year in order to accommodate the traditional lab (Fall 2018) and the 3D terrain intervention lab (Spring 2019), limiting the population of students who take the class. While the pilot study showed the promise of 3D printed terrain it is also worth noting that student learning was assessed using a single instrument, the MTMA. The original project design also included student and teaching assistant interviews but these were not able to be completed due to a lack of volunteers. It would be highly advantageous in a future project to also gather interviews in order to further probe what students may perceive that they learned from the 3D print terrain activity.

Future Research. Though only a single pilot study was completed, the results of using 3D terrain as a tool to help teach topographic map interpretation already shows promise. The promise of this curriculum development and evaluation project suggest both future research and practical implications for teaching. Testing 3D terrain as a topography teaching resource for a broader diversity of students, majors, and institution types is a key area for future work. Future research could replicate the current study using the Kalamazoo 3D terrain and accompanying topographic maps in other courses for both geoscience majors and non-majors at more diverse types of institutions. As .stl files can be created from USGS topographic maps in any region, the maps and 3D terrain can be adapted to maps already used in courses and can be directly relatable to student learning.

Expanding the 3D terrain activity to physical geography or testing the terrain in an upper division course, such as geomorphology, could inform researchers as to how 3D terrain helps to develop skills beyond a single lab. This also raises the potential uses for 3D terrain and its implementation into multiple courses along a student's career in a program of study. Testing the 3D terrain activity at more diverse institutions, including at two-year colleges and minority-serving institutions, would help determine whether the intervention improves topography skills among more diverse learners. A potential benefit to institutions with tight instructional budgets is the low cost to implement 3D terrain in the classroom, which could keep laboratory fees low for students from lower family incomes.

Another avenue of research could develop new 3D printed terrains using a variety of topographic features to better understand which types of 3D terrain models best impact student learning. This type of research could also look into how students could more effectively learn abstract subjects such as vertical exaggeration and what effect it may have on visual expectation versus the topographic reality in the field. Finally, the question of familiarity should be addressed; although many students in the test semesters were unlikely to be familiar with the topographic quadrangle and 3D terrain that they used in lab, the majority were likely familiar with the general topography of the region. Future research could examine how using an entirely unfamiliar region, or perhaps using an iconic region (like the Grand Canyon), impacts topography learning.

REFERENCES

Alvarez, A., Parra, B., & Tubio M., (2015). Assessment of 3D models used in contour studies. *Universal Journal of Educational Research* 3:11, 877-890.

Atit, K., Weisberg, S., Newcombe, N., & Shipley, T., (2016). Learning to interpret topographic maps: understanding layered spatial information. *Cognitive Research: Principles and Applications.* 2016;1(1):2. doi:10.1186/s41235-016-0002-y.

Clark, D., Reynolds, S., Lemanowski,V., Stiles, T., Yasar S., Proctor, S., Lewis, E., Stromfors C., & Corkins, J. (2008). University students' conceptualization and interpretation of topographic maps, *International Journal of Science Education*, 30:3, 377-408.

Coultant, B., & Westheimer, G., (1993). Population distribution of stereoscopic ability. *Ophthalmic & Physiological Optics*, 13:1, 3-7.

Draughtsman using stereoscope, (1949). Retrieved from https://www.alamy.com/114-queensland-state-archives-4261-draughtsman-using-stereoscope-in-topographical-mapping-c-1949-image215030355.html

Giorgis, S., Mahlen N., & Anne, K. (2017). Instructor-led approach to integrating an augmented reality sandbox into a large-enrollment introductory geoscience course for nonmajors produces no gains. *Journal of Geoscience Education*, 65, 283-291.

Goodcliff, A., Stowell, H., Students using Geowall. Virtual reality brings flat images into 3-D focus for UA geology students (2006). https://www.ua.edu/news/2006/06/virtual-reality-brings-flat-images-into-3-d-focus-for-ua-geology-students/

Harnapp, V., King, D., (1991). A new look at making raised-relief maps in classrooms. *Journal of Geography*, 90:5, 241-244

Hasiuk, F., Harding, C., Renner, A., & Winer, E., (2017). Touchterrain: A simple web-tool for creating 3d-printable topographic models. *Computers and Geoscience*, 109, 25-31.

Hausman, L., (1917). A simple rapid method for making relief models from contour maps. *Journal of Geography*, 16, 97-100

Ishikawa, T., & Kastens, K. (2005). Why some students have trouble with maps and other spatial representations. *Journal of Geoscience Education*, 53:2, 184-197.

Jacovina, M., Ormand, C., Shipley, T.F., & Weisberg, S. (2014). Topographic Map Assessment [Measurement instrument]. Retrieved from http://silcton.spatiallearning.org/index.php/resources/testsainstruments.

Logan, M. (2013). Islands – Topographic Model. Retrieved from https://mlogan1990.wordpress.com/2013/10/21/islands-topographic-model

McMenamin, P., Quayle, M., McHenry, C., & Adams, J., (2014). The production of anatomical teaching resources using 3-dimensional (3D) printing technology. *Anatomical Sciences Education*, Nov. 2014, 1-8.

Moore, J. W. (2018). Spatial feedback as a mechanism to improve topographic map literacy using the augmented reality sandbox (Order No. 10977912). Available from ProQuest Dissertations & Theses Global. (2183332523). Retrieved from http://libproxy.library.wmich.edu/login?url=https://search.proquest.com/docview/2183332523?accountid=15099

Nawaz, M., Sandeep, K., & Sattar, F. (2017). Augmented reality sandbox and constructivist approach for geoscience teaching and learning. *International Journal of Educational and Pedagogical Sciences*, 11, 1613-1616

Newcombe, N., Jacovina, M. E., Ormand, C., Atit, K., Shipley, T. F., & Weisberg, S. M. (2015). The lay of the land: sensing and representing topography. *The Baltic International Yearbook of Cognition*, Logic, and Communication. Dec. 2015, 10, 1-57.

Rapp, D., Culpepper, S., Kirkby, K., Morin, P., (2007). Fostering students' comprehension of topographic maps. *Journal of Geoscience Education*, 55, 5-16

Shadish, W., Cook, T., Campbell, D., (2002). Experimental and quasi-experimental designs for generalized causal inference. Boston, MA, US: Houghton, Mifflin and Company.

Slocum, T., Dunbar, M., & Egbert, S., (2007). Evaluating the potential of the geowall for geographic education. *The Journal of Geography*, May/June 2007. 91-102

Vaughan, K., Vaughan, R. & Seeley, J. (2017). Experiential learning in soil science: Use of an augmented reality sandbox. *Journal of Natural Sciences Education*, 46, 1-5.

Wilkerson, S., (2019). Augmented reality sandbox. Retrieved from https://www.depauw.edu/academics/departments-programs/geosciences/cool-geoscience-resources/augmented-reality-sandbox/

Woods, T., Reed, S., Hsi, S., Woods, J., & Woods, M. (2016). Pilot study using the augmented reality sandbox to teach topographic maps and surficial processes in introductory geology labs. *Journal of Geoscience Education*, 64, 199-214.

Appendix A

HSIRB Approval

WESTERN MICHIGAN UNIVERSITY

Institutional Review Board
FWA00007042
IRB00000254

Date: September 6, 2018

To: Heather Petcovic, Principal Investigator
Jay Cockrell, Student Investigator for thesis

From: Amy Naugle, Ph.D., Chair

Re: IRB Project Number 18-09-01

This letter will serve as confirmation that your research project titled "Assessing the Impact of 3D Printed Terrain on Teaching Topography in Introductory Earth Science Labs" has been **approved** under the **exempt** category of review by the Western Michigan University Institutional Review Board (IRB). The conditions and duration of this approval are specified in the policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may **only** be conducted exactly in the form it was approved. You must seek specific board approval for any changes to this project (e.g., ***you must request a post-approval change to enroll subjects beyond the number stated in your application under "Number of subjects you want to complete the study"***). Failure to obtain approval for changes will result in a protocol deviation. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the IRB for consultation.

Reapproval of the project is required if it extends beyond the termination date stated below.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: **September 5, 2019**

Office of the Vice President for Research
Research Compliance Office
1903 W. Michigan Ave., Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276
WEBSITE: wmich.edu/research/compliance/hsirb

CAMPUS SITE: Room 251 W. Walwood Hall

Appendix B

Student Instructions for the 3D Print Terrain Intervention Lab

3D Terrain Handout

Accompanied with each map a group will receive a 3D terrain piece. This terrain has been printed from the data presented on this map and is a 3D representation of a section of the map each group is looking at. In order to correctly use the terrain please follow the steps below.

1. **On the map, find the area in the upper right side of the map that has been outlined.**
2. **Find the + symbol in the upper right corner of the box.**
3. **Align the same symbol on the terrain piece so that the symbols are in the same corner.**
4. **Lay terrain piece on the map with symbols in the same corner.**

If you have any questions about if the terrain is aligned correctly your instructor can check for you if you ask.

You have now aligned the terrain so that the 3D terrain piece shows you the same data in 3D as the topography map is showing with contour lines. This terrain gives you an idea of what elevation may look like at a given contour line. Using the 3D terrain and your imagination you can use the contour lines to picture in your mind the elevation on the rest of the map.

Appendix C

MTMA Questionnaire

Name:

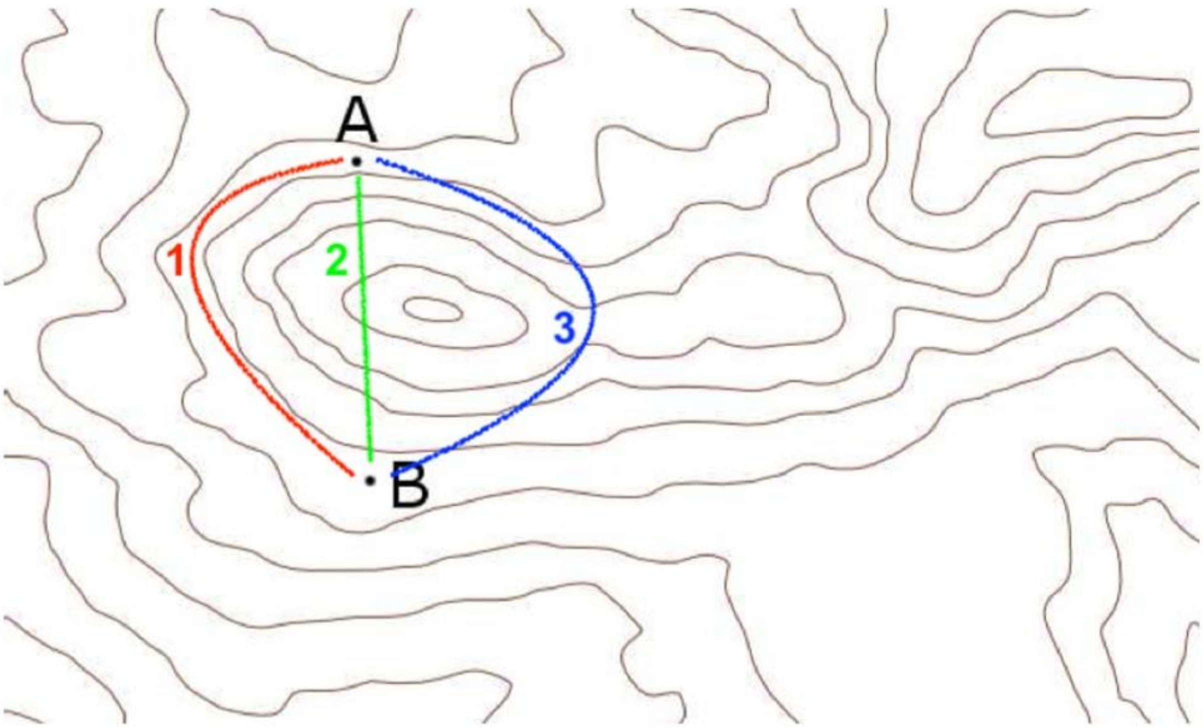
Modified Topographic Map Assessment

Adapted from Moore (2018); modified after Jacovina, Ormond, Shipley & Weisberg (2014)

Directions: Some of the questions on this assessment may be unfamiliar or challenging. Please try your best to answer each question.

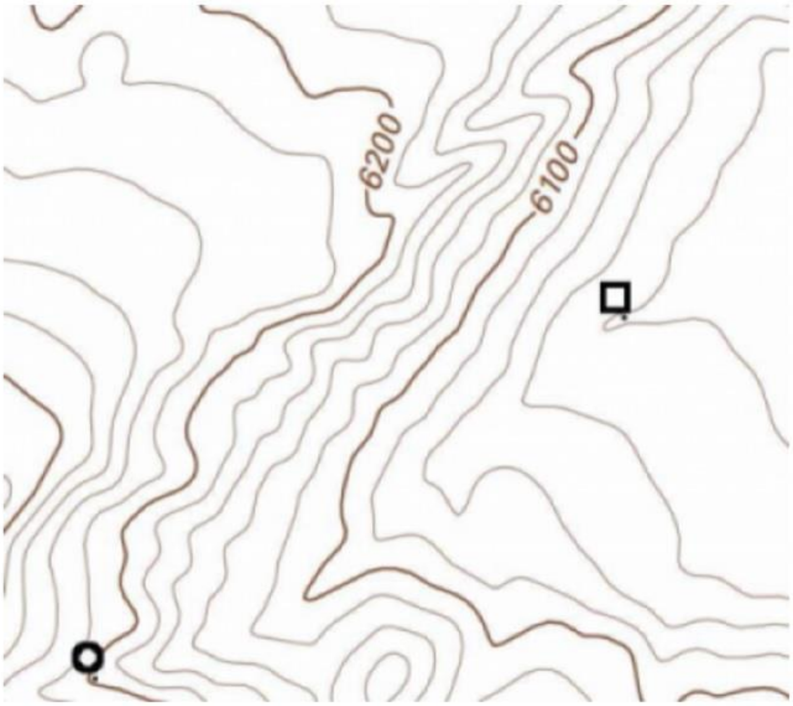
Q1) Imagine you had to walk from point A to point B and wanted to take the fastest path possible.

Which path would you choose? _________



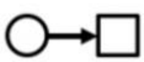
Explain why you chose that particular path.

Q2) Imagine there is a stream that connects the circle and the square.

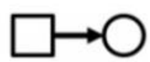


Which direction would the water flow?

From the circle to the square

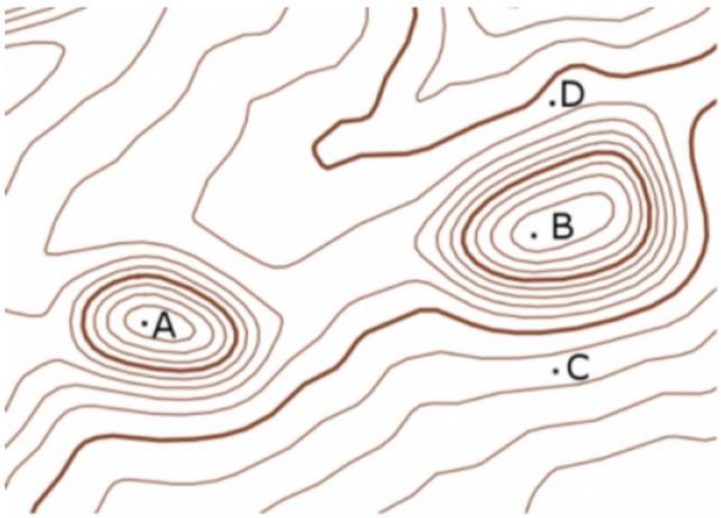


From the square to the circle



Explain why you chose that direction below.

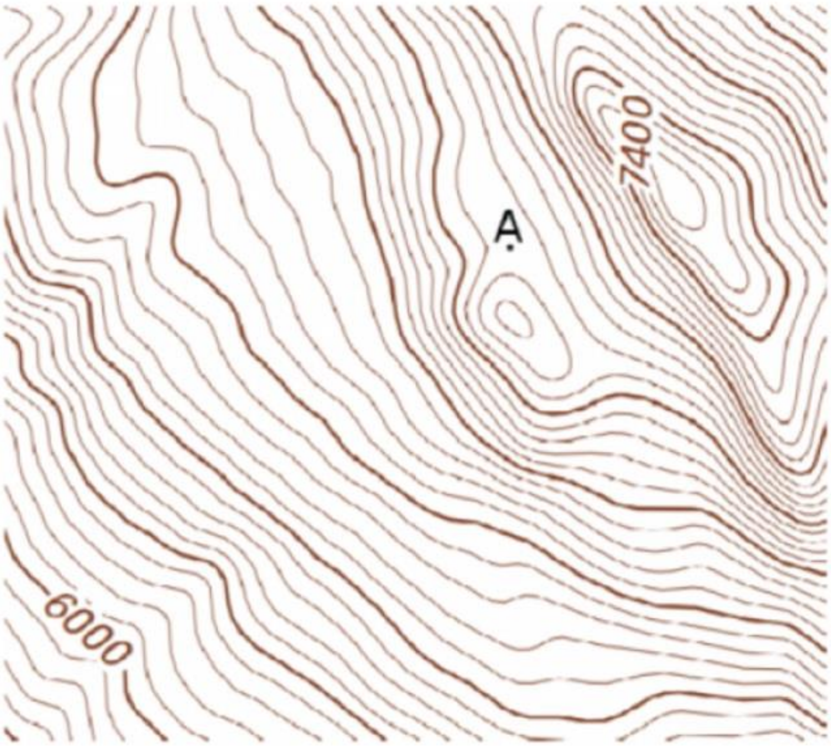
Q3) One person is standing at each point on the map labeled A, B, C, and D. Assume the people are able to use binoculars and there is no vegetation (such as trees, tall grass, etc.).



Can the people at each of these two points see each other?

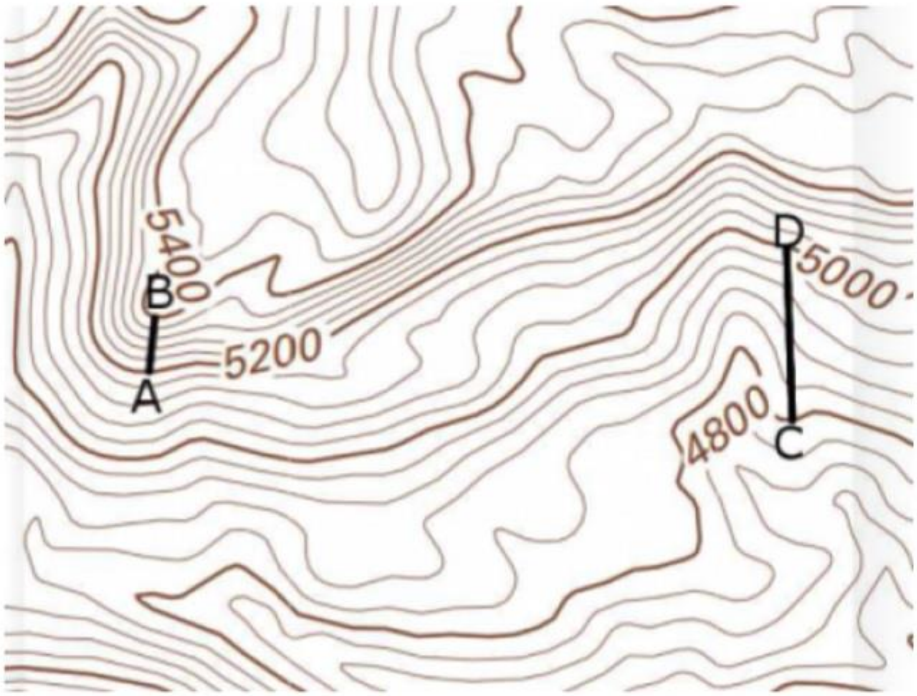
	Yes	No
A and B	○	○
A and D	○	○
B and C	○	○
C and D	○	○
B and D	○	○

Q4) What is the elevation at point A? ___________________



What is the elevation at point A?

Q5) Imagine Josh traveled on foot from point A to point B, and Amy traveled on foot from point C to point D.



Who walked up a steeper slope?

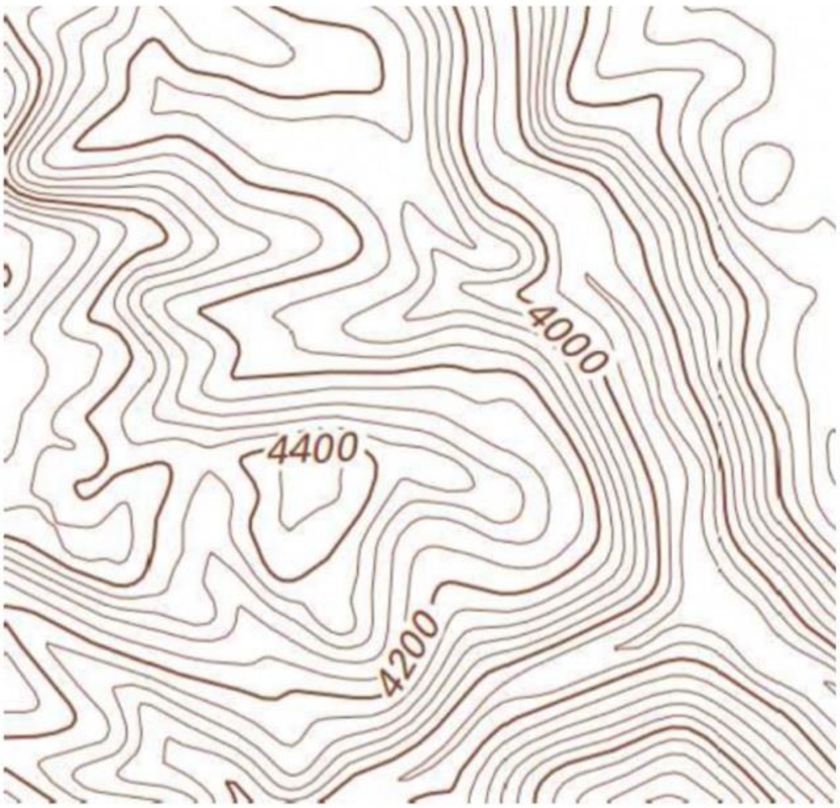
Josh from point A to point B
Amy from point C to point D
Both paths were the same steepness

How can you tell?

Who traveled a greater vertical distance?

Josh from point A to point B
Amy from point C to point D
Both paths were the same vertical distance

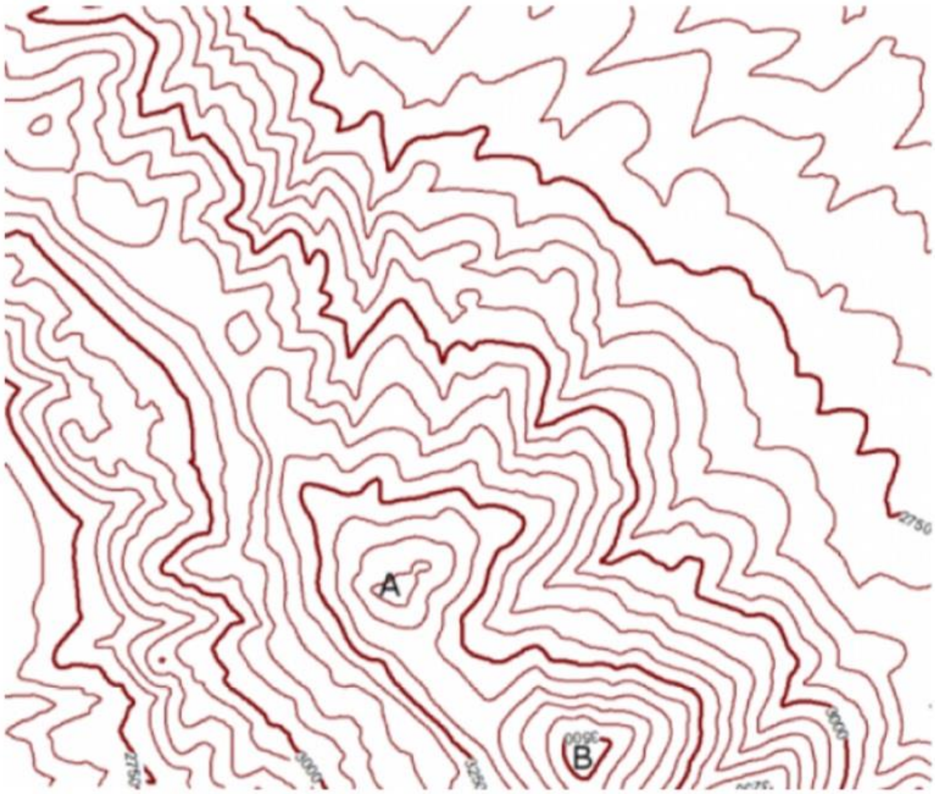
Q6) The lines on this map are contour lines. Answer the question below.



How much does the elevation change moving from one line to another on this map?

____

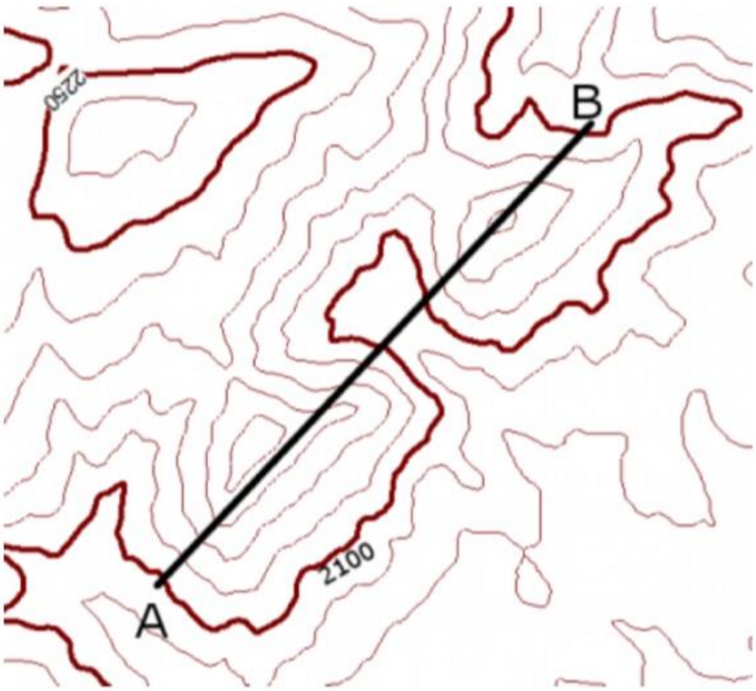
Q7)



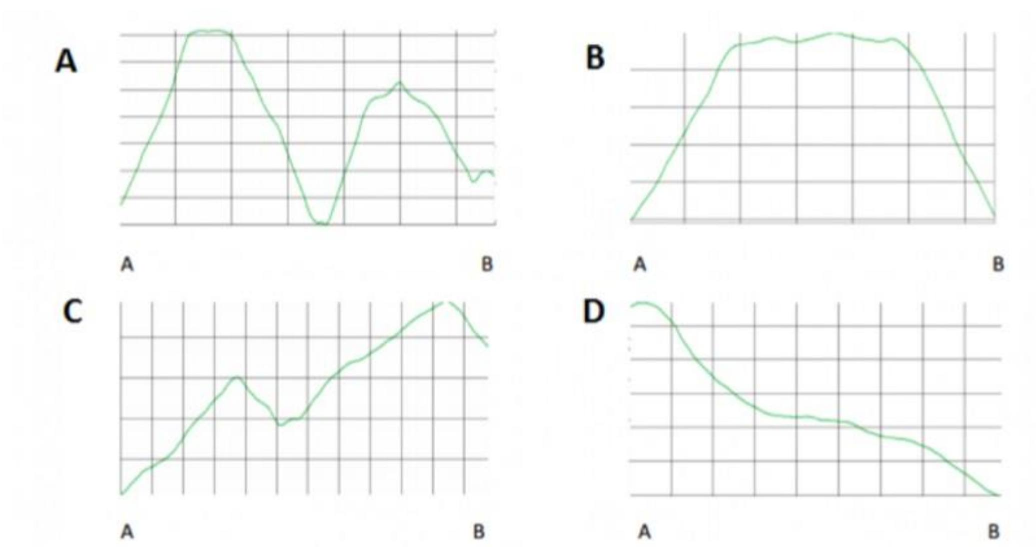
Which hill is higher?

Hill A
Hill B

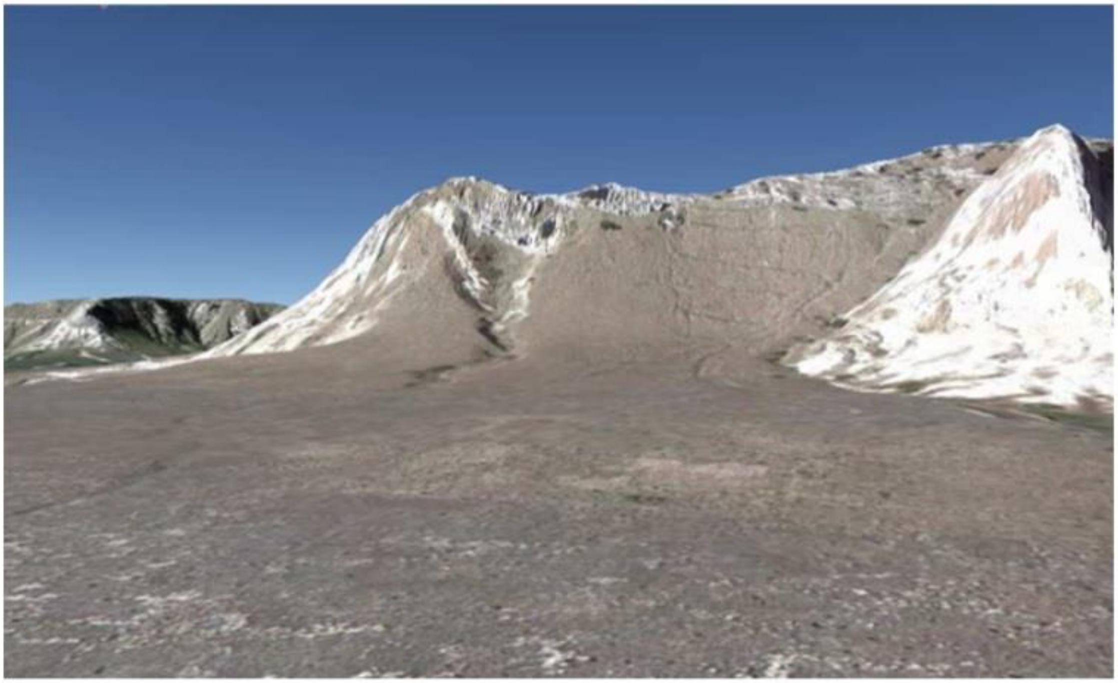
Q8)
The map shows a cross-section line from point A to point B.



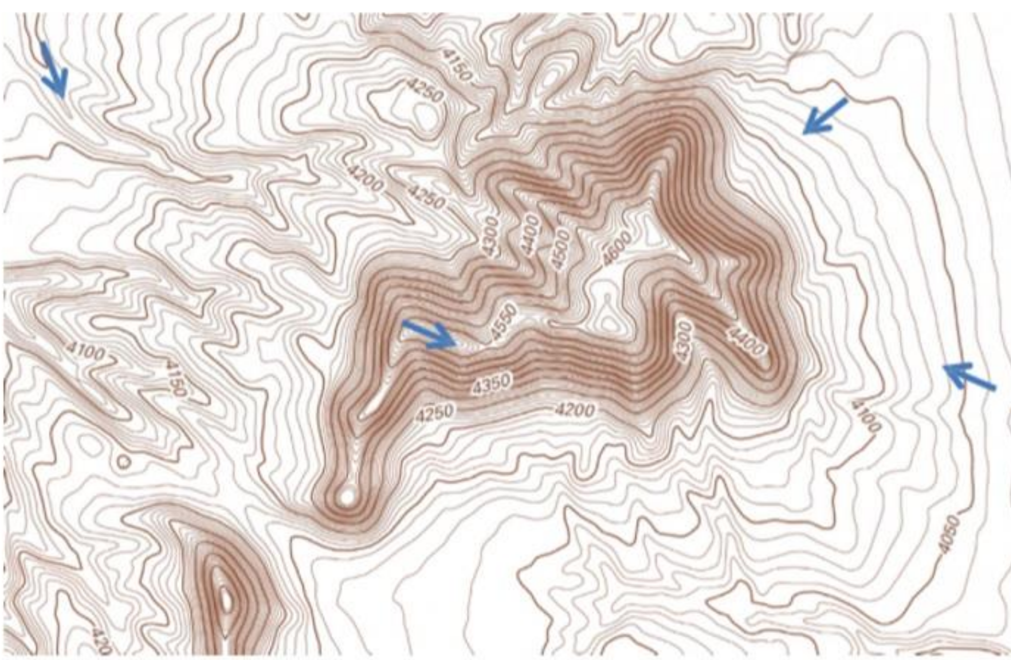
Which elevation profile (below) matches the cross-section of the line AB (above)?



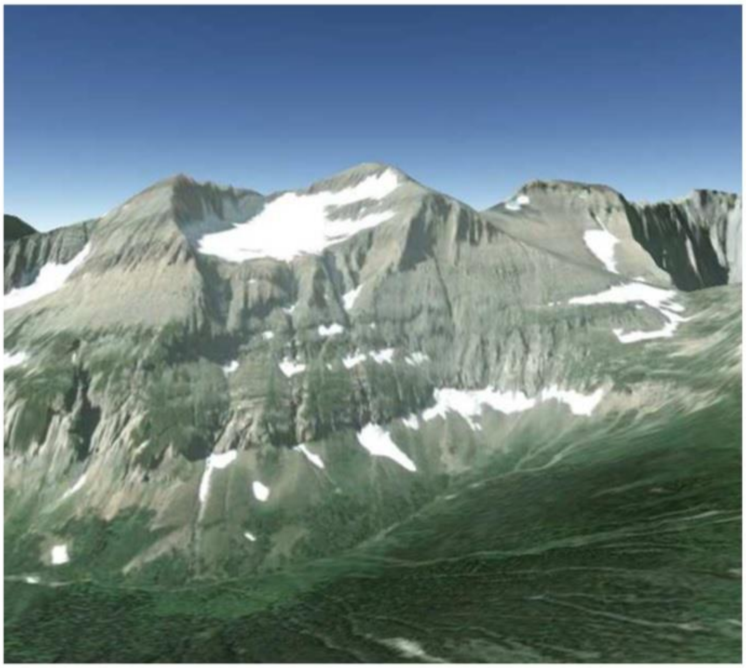
Q9)



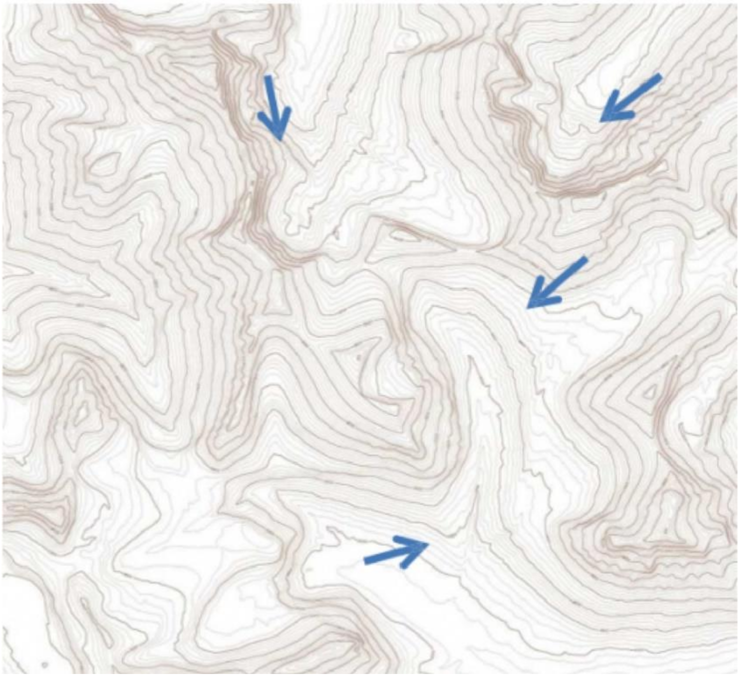
Imagine you see the view in the picture above. Select the arrow on the map below that indicates where and which direction you think you are facing.



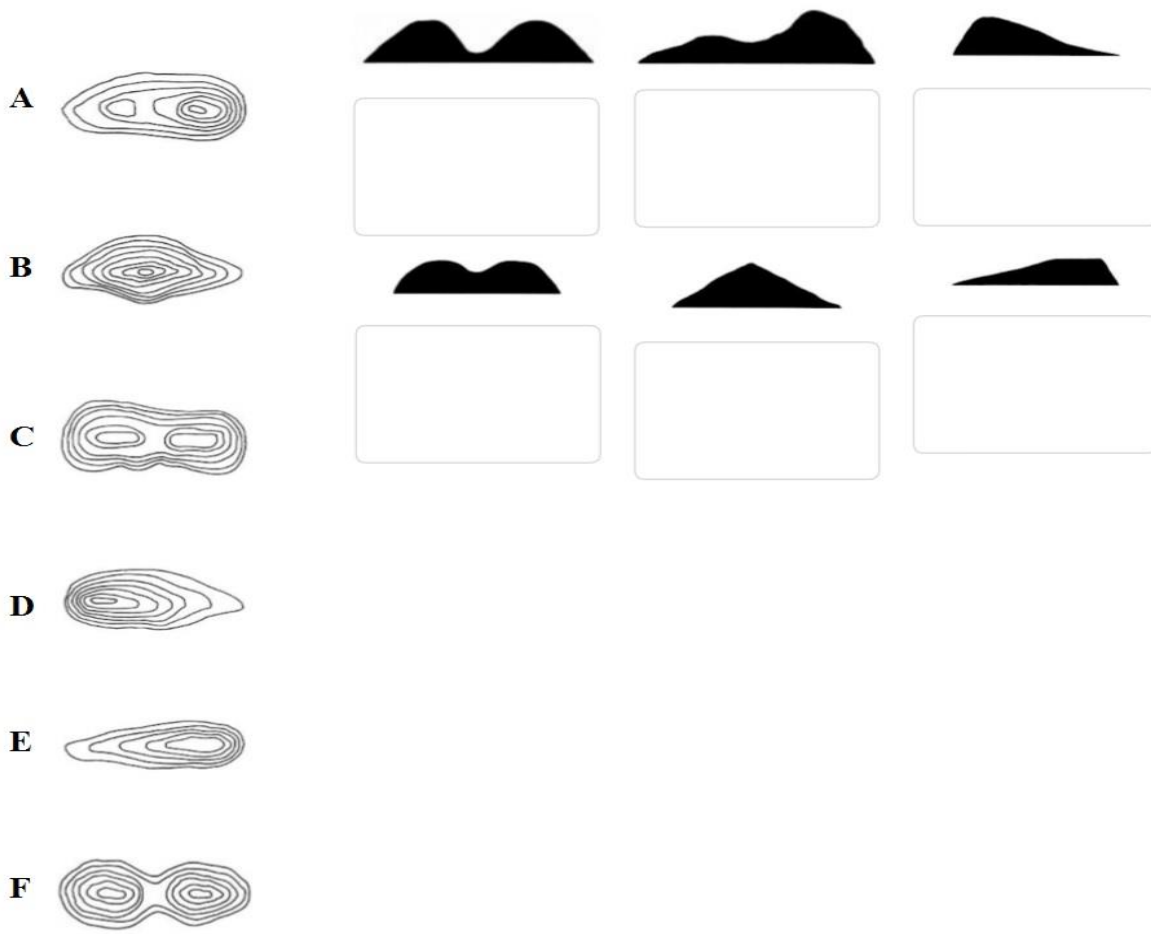
Q10)



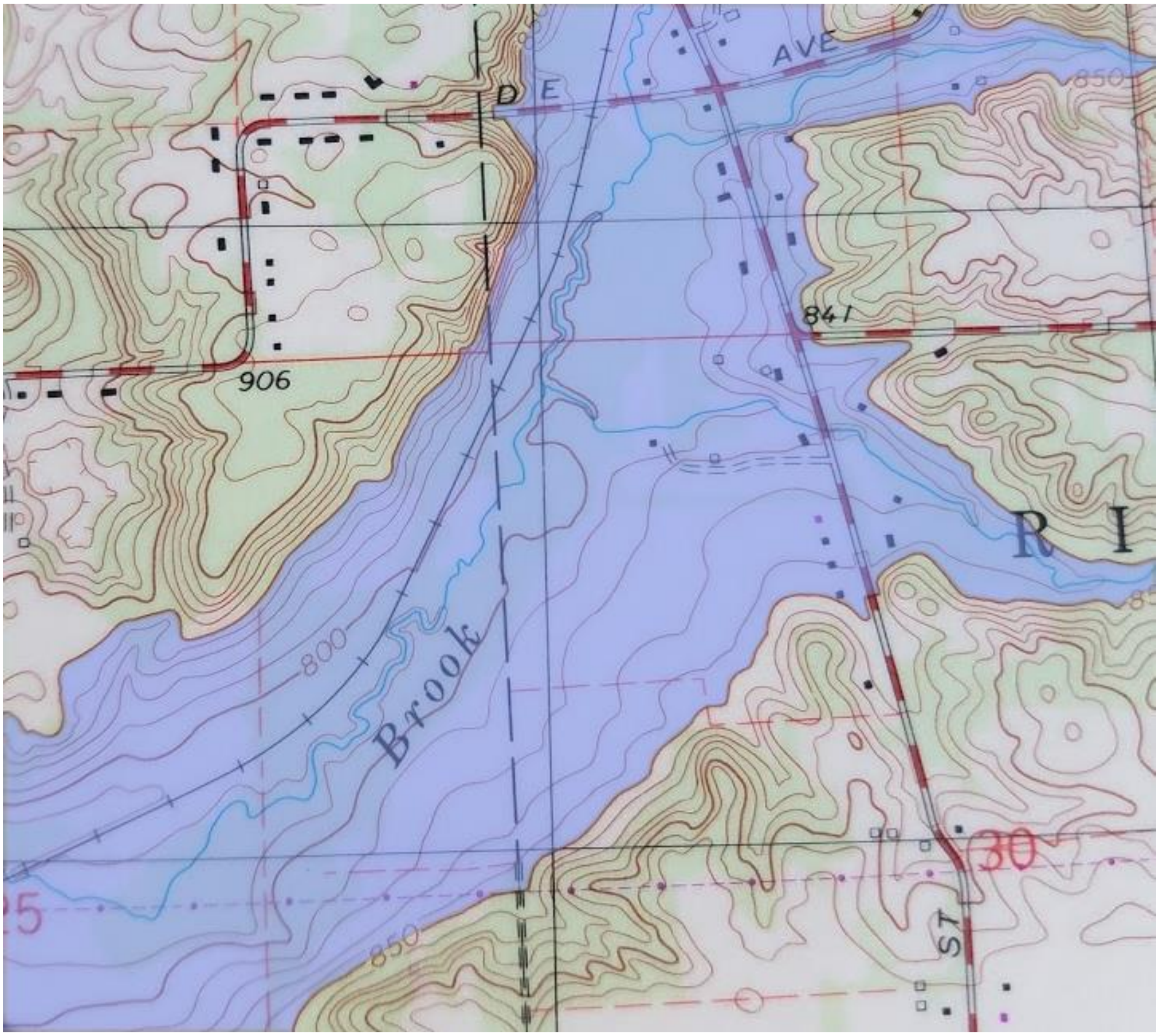
Imagine you see the view in the picture above. Select the arrow on the map below that indicates where and which direction you think you are facing.



Q11) Match each topographic map letter (left) to it's matching profile in space below (right)



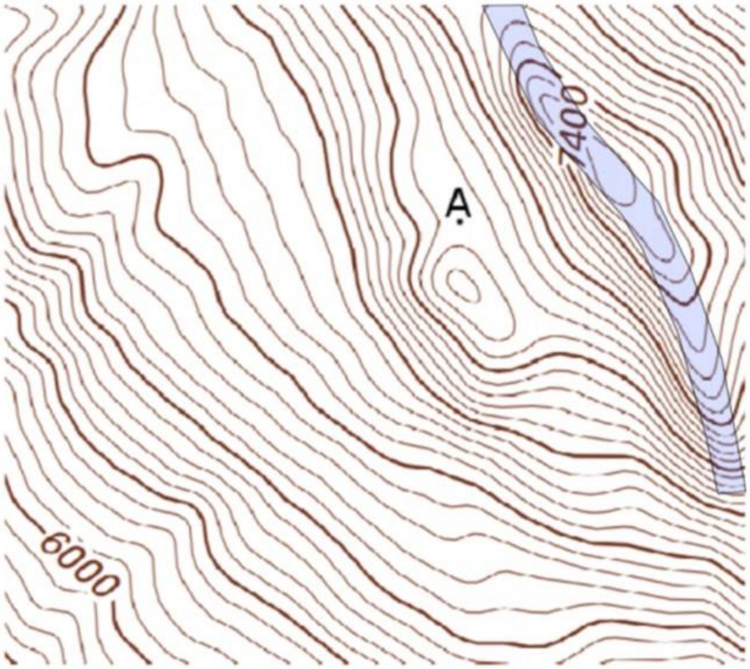
Q12) The shaded section on the map highlights a type of landform.



What landform is highlighted on the map?

Hill Saddle Ridge Valley

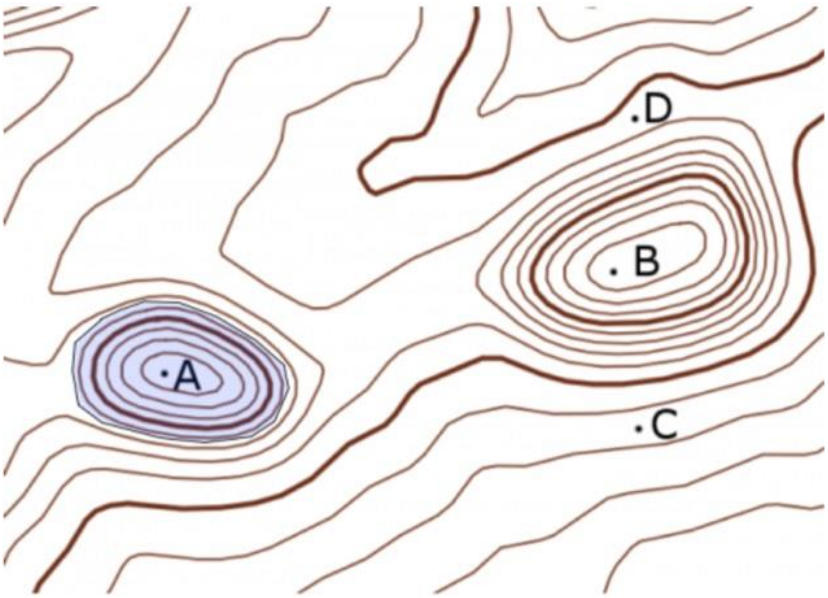
Q13) The shaded section on the map highlights a type of landform.



What landform is highlighted on the map?

Hill Saddle Ridge Valley

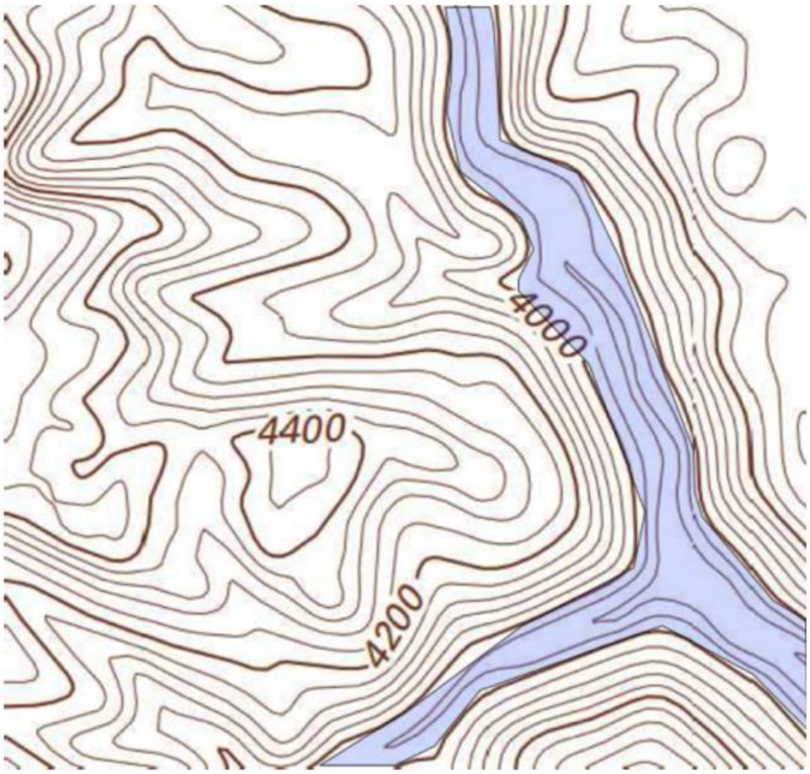
Q14) The shaded section on the map highlights a type of landform.



What landform is highlighted on the map?

Hill   Saddle   Ridge   Valley

Q15) The shaded section on the map highlights a type of landform.



What landform is highlighted on the map?

Hill Saddle Ridge Valley

Appendix D

Demographic Questionnaire

Demographic Questionnaire:

Q1) What is/are your major(s)?

Q2) What is your age?

Q3) What is your gender?

Female Male Other Prefer not to answer

Q4) What is your race/ethnicity?

Asian/Pacific Islander	African American/Black	Caucasian
Hispanic/Latinx	Two or more races	Prefer not to answer

Q5) What is your class standing at WMU?

Freshmen Sophomore Junior Senior "Super" 5+yr Senior

Q6) How many total years have you attended college (including community college, WMU, or other institutions)?

Less than one	One	Two	Three
Four	Five	Six or more	

Appendix E

Compiled MTMA Pre- and Posttest Responses

Code	MTMA Items Pretest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AB	1	SC	1,2,3	7100	A to B, Both	40	B	A	BR	UR	C,A,D,F,B,E	V	R	H	V
AC	1	SC	1,2	7000	A to B, Both	50	B	A	UR	MR	F,A,D,C,B,E	V	V	H	R
AD	1	CS	1,2,5	7000	A to B, C to D	40	B	A	UR	UR	F,A,D,C,B,E	V	R	H	V
AE	1	SC	1,3,5	7400	Both, C to D	200	B	A	UR	UR	F,A,D,C,B,E	V	S	H	R
AF	1	CS	1,2,3,5	7400	A to B, Both	25	B	A	UL	MR	F,A,D,C,B,E	V	S	H	R
AG	1	CS	1,2,3,5	7200	A to B, Both	200	B	A	BR	UL	F,A,D,C,B,E	V	R	H	S
AH	1	CS	1,2,3,5	7400	A to B, Both	33.33	B	B	UR	UR	F,A,D,C,B,E	R	S	H	v
AI	1	CS	1,2,3,5	7400	A to B, Both	40	B	A	UR	UR	F,A,D,C,B,E	V	R	H	v
AK	1	CS	1,2,3,5	6000	A to B, Both	I Don't Know	B	C	BR	BC	A,B,C,D,E,F	V	R	H	v
AL	1	SC	2,5	6300	A to B, C to D	200	B	A	UR	MR	C,A,D,F,B,E	R	H	H	V
AM	1	SC	1,2,3,5	7400	A to B, Both	75	B	A	UR	UR	F,A,D,C,B,E	V	R	H	v
AN	1	CS	3,4,5	8700	A to B, Both	40	B	A	BR	UR	F,A,D,C,B,E	V	R	H	V
AO	2	CS	1,2,3,5	6900	A to B, Both	40	B	A	BR	MR	F,A,D,C,B,E	V	R	H	S

Code	MTMA Items Pretest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AP	1	SC	2,4	-	Both, A to B	-	B	C	UL	UR	F,A,D,C,B,E	V	R	H	S
AQ	1	SC	1,2	7000	Both, A to B	200	B	A	BR	UR	F,A,D,C,B,E	V	S	H	R
AR	2	SC	1,3,4,5	7120	C to D, C to D	200	B	A	UR	BC	F,A,D,C,B,E	R	V	s	v
AS	1	SC	2,3,5	2000	C to D, C to D	200	B	B	UL	UR	C,A,D,F,B,E	V	R	H	S
AU	1	CS	1,2,3,5	7100	C to D, Same	25	B	A	UL	UR	C,A,D,F,B,E	R	V	H	S
AV	2	CS	0	I Don't Know	A to B, C to D	I Don't Know	A	A	UR	UL	C,A,D,F,B,E	V	R	S	R
AW	1	CS	1,4	7000	A to B, C to D	50	A	C	UR	UR	C,A,D,F,B,E	R	H	V	S
AX	1	CS	1,2,5	7400	A to B, Both	50	B	A	UL	UR	F,A,D,C,B,E	S	R	H	S
AY	1	SC	1,2,3,5	5500	A to B, C to D	200	B	A	UR	UL	F,A,D,C,B,E	V	S	H	R
AZ	2	SC	0	1400	A to B, C to D	200	B	C	UL	MR	F,A,D,C,B,E	R	V	H	S
BA	1	CS	1,5	6280	C to D, A to B	-	B	A	UL	UR	F,A,D,C,B,E	V	S	H	R
BB	2	SC	1,2,3,5	The Middle	C to D, C to D	200	A	C	BR	BC	C,A,D,F,B,E	S	H	R	H
BC	2	CS	1,2,3,4,5	7000	C to D, C to D	200	A	B	UR	MR	F,B,A,C,D,E	H	V	R	S
BD	2	SC	1,2,3,5	6000	A to B, A to B	200	B	A	UR	UR	F,A,D,C,B,E	V	R	H	S

Code	MTMA Items Pretest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BF	3	CS	1	7400	C to D, A to B	50	B	A	UR	UL	F,A,D,C,B,E	V	R	H	S
BG	2	CS	1,2,3,5	7400	Both, C to D	40	B	A	UR	UR	C,A,D,F,B,E	R	V	H	S
BH	2	CS	1,2,3,5	7400	A to B, C to D	200	A	D	UR	BC	C,A,D,B,F,E	V	S	H	R
BI	1	CS	1,2	7400	A to B, A to B	50	B	A	UR	UR	F,A,D,C,B,E	V	R	H	V
BJ	1	CS	1,2,3,5	7200	Both, C to D	40	B	A	BR	UR	C,A,D,F,B,E	V	R	H	V
BK	1	CS	3,4	-	A to B, Both	-	B	C	UR	UL	F,A,D,C,B,E	V	R	H	V
BL	2	SC	2,3,4,5	1400	A to B, C to D	200	B	A	UL	MR	F,A,D,C,B,E	H	S	V	R
BM	1	SC	1,2,3,5	7000	Both, C to D	-	B	A	BR	MR	C,A,D,F,B,E	V	H	H	S
BN	2	SC	1,2,4	7400	A to B, A to B	200	B	A	UR	UL	F,A,D,C,B,E	R	H	H	V
BO	2	SC	1,3,5	7400	C to D, C to D	Get Wider and Some space out	A	A	UR	BC	C,A,D,F,B,E	V	H	S	R
BQ	2	SC	1,3,5	7000	Both, C to D	200	A	C	UR	BC	C,A,D,F,B,E	R	H	R	V
BR	1	SC	1,2,3	7250	C to D, A to B	75	B	A	UR	UR	F,A,D,C,B,E	V	R	H	S
BS	2	SC	1,2,3,5	1,2,3,5	A to B, C to D	6-8	A	B	UL	MR	F,A,D,C,B,E	V	R	S	H

Code	MTMA Items Pretest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BT	1	SC	1,2,3,5	7000	A to B, C to D	50	B	A	UR	UR	F,A,D,C,B,E	V	H	H	R
BU	2	CS	1,2,3,5	7400	A to B, Both	50	B	A	BR	MR	F,A,D,C,B,E	H	R	H	V
BV	1	CS	1	Pretty High	A to B, Both	Elevation increases and decreases	B	A	BR	-	C,A,D,F,B,E	V	R	H	S
BX	1	CS	1,2,3,5	No Idea	Both, C to D	200	B	A	BR	UR	F,A,D,C,B,E	V	R	H	V
BY	1	SC	1,2	7000	A to B, Both	20	B	A	UR	MR	C,A,D,F,B,E	S	V	H	V
BZ	2	SC	1,3,5	7200	A to B, C to D	?	B	A	-	-	F,A,D,C,B,E	V	R	H	S
CA	1	CS	1,3,5	7000	A to B, Both	40	B	A	UL	MR	C,A,D,F,B,E	V	R	H	S
CB	1	SC	3,5	1400	A to B, C to D	200	B	C	UR	UL	F,A,D,C,B,E	R	H	H	V
CC	1	SC	1,3,5	7200	A to B, Both	50	B	A	M	MR	C,E,D,F,B,A	V	H	H	V

Code	MTMA Items Posttest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AB	1	CS	1,2,3,5	7040	A to B, Both	?	B	A	BR	UL	F,A,D,C,B,E	V	R	H	V
AC	1	CS	1,2	7100	A to B, Both	50	B	A	UR	MR	F,A,D,C,B,E	V	H	H	V
AD	1	CS	1,2,3,5	7000	A to B, C to D	25	B	A	UR	UR	F,A,D,C,B,E	V	R	H	S
AE	1	CS	1,2,3,5	7010	A to B, Both	200	B	A	UR	UR	F,A,D,C,B,E	V	R	H	V
AF	1	CS	1,2,3,5	7400	A to B, Both	25	B	A	UR	UR	F,A,D,C,B,E	V	S	H	R
AG	3	CS	1,2,3,5	650	A to B, Both	200	B	A	BR	UR	F,A,D,C,B,E	V	R	H	S
AH	1	CS	1,2,3,5	6010	A to B, Both	40	B	B	BR	UR	F,A,D,C,B,E	V	s	H	R
AI	1	SC	1,2,3,5	7400	A to B, Both	50	B	A	UR	UR	C,A,D,F,B,E	-	-	H	V
AJ	A	CS	1,2,3,5	7480	A to B, Both	40	B	A	UR	UR	F,A,D,C,B,E	S	R	H	V
AK	1	CS	0	6000	A to B, C to D	2000	B	A	UR	BC	C,A,D,F,B,E	V	R	H	V
AL	1	SC	1,2	6270	A to B, A to B	200	B	A	BR	TL	F,A,D,C,B,E	H	V	H	v
AN	1	CS	3,4,5	7140	A to B, Both	40	B	A	UR	UR	F,A,D,C,B,E	V	R	H	S
AO	1	CS	1,2,3,5	6800	A to B, C to D	40	B	A	BR	BC	F,A,D,C,B,E	S	R	H	V
AP	1	SC	1,2	-	A to B, Both	-	B	A	UR	UR	F,A,D,C,B,E	V	R	H	S

Code	MTMA Items Posttest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AQ	1	SC	1,2	7430	A to B, Both	40	B	A	TL	UR	F,A,D,C,B,E	V	S	H	R
AR	1	SC	1,3,5	7000	Both, C to D	200-400	B	B	UL	UL	C,A,D,F,B,E	V	R	H	H
AS	1	SC	1,4	8000	A to B, C to D	200	B	A	BR	MR	C,A,D,F,B,E	V	H	R	S
AT	1	CS	1,2,3,5	7400	A to B, C to D	40	B	A	BR	BC	F,A,D,C,B,E	V	H	H	V
AU	1	SC	1,2	7100	C to D, Both	250	B	A	TL	UR	F,A,D,C,B,E	S	R	H	v
AV	1	CS	1,2,4	7400	A to B, Both	200	B	A	BR	BC	F,A,D,C,B,E	V	R	H	S
AW	1	CS	4	7480	A to B, C to D	40	B	A	UR	UR	C,A,D,F,B,E	V	H	V	R
AX	1	SC	1,2,3,5	7200	A to B, Both	40	B	A	UR	UR	F,A,D,C,B,E	S	R	H	v
AZ	2	SC	1	7400	A to B, C to D	200	B	A	BR	MR	F,A,D,C,B,E	H	H	S	R
BA	1	CS	1,2,3,5	-	A to B, A to B	-	B	A	UR	UL	f	-	-	-	-
BB	2	SC	1,2,3,5	7400	A to B, A to B	200	B	C	UR	MR	B,D,A,C,D,F	V	H	S	R
BC	2	SC	2,3,5	7000	C to D, Both	50	A	A	UR	UR	F,C,D,A,B,E	R	V	H	S
BD	2	SC	1,2	7400	A to B, A to B	200	B	A	UR	UR	F,A,D,C,B,E	V	R	H	S
BE	1	SC	3,4	1400	Both, Both	200	A	B	-	-	A,C,B,D,F,E	R	S	V	S

Code	MTMA Items Posttest Traditional Lab (Fall 2018)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BF	1	SC	2	7400	A to B, C to D	200	B	C	BR	UR	C,A,D,F,B,E	V	S	H	R
BG	1	CS	1	6000	A to B, Both	40	B	A	BR	UR	F,A,D,C,B,E	S	V	H	R
BH	1	CS	1,3,4	7400	A to B, C to D	200	A	C	UR	UR	F,B,D,E,C,A	H	V	V	S
BI	1	CS	1,2	7400	A to B, Both	200	B	A	UR	UR	F,A,D,C,B,E	-	-	-	-
BJ	1	CS	1,2,3,5	7100	A to B, Both	50	B	A	BR	UL	F,A,D,C,B,E	V	H	H	-
BL	1	CS	1,2	7000	A to B, A to B	200	B	A	BR	BC	F,A,D,C,B,E	S	R	H	v
BM	1	CS	1,2	7000	A to B, A to B	200	B	A	BR	BC	F,A,D,C,B,E	S	R	H	V
BN	1	CS	1,2	7000	A to B, A to B	200	B	A	BR	BC	F,A,D,C,B,E	S	R	H	v
BO	1	SC	1,3,5	7400	A to B, C to D	200	A	D	UL	BC	F,A,D,C,B,E	R	V	S	V
BP	1	CS	1,2,3,5	6500	A to B, Both	17	B	A	UR	UR	F,A,D,C,B,E	V	R	H	V
BQ	3	SC	3,5	7200	Both, C to D	200	B	C	UR	UL	C,A,D,F,B,E	S	V	H	R
BR	1	CS	1,5	7000	A to B, C to D	50	B	A	UR	UL	F,A,D,C,B,E	V	R	H	S
BS	A	SC	1,2,3,5	7200	A to B, C to D	60	A	D	BR	UL	-	R	H	V	S
BT	1	SC	1,3	7400	A to B, Both	No idea	B	A	BR	UR	F,A,D,C,B,E	V	H	H	R

Code	MTMA Items Posttest Traditional Lab (Fall 2018)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
BU	2	CS	1,2,3,5	7400	A to B, Both	50	B	A	BR	MR	F,C,D,A,B,E	V	R	H	V
BV	1	CS	1,2	7400	A to B, Both	100	B	A	BR	UL	F,A,D,C,B,E	S	R	H	v
BX	1	CS	1,2,3,5 *no 4	6000	A to B, Both	100	B	A	UR	UR	F,A,D,C,B,E	V	S	H	V
BY	1	SC	4	6290	A to B, C to D	200	B	A	UR	b	F,A,D,C,B,E	V	V	H	V
BZ	2	SC	1,2,3,5	7000	A to B, C to D	200	B	A	-	-	C,A,D,F,B,E	R	H	H	V
CA	1	CS	1,3,5	7100	A to B, Both	40	B	A	BR	MR	F,A,D,C,B,E	R	S	H	V
CB	1	SC	1,2,3,5	7400	A to B, C to D	200	B	C	BR	UL	F,A,D,C,B,E	R	H	h	R
CC	1	CS	1,2,3,5	7300	A to B, Both	20	B	A	UL	UR	F,A,D,C,B,E	V	S	H	V

Code	**MTMA Items** Pretest 3D Print Terrain Intervention Lab (Spring 2019)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DB	1	SC	1,2,3,5	7200	A to B, C to D	200	B	A	UL	UC	F,A,D,C,B,E	R	V	S	V
DC	1	CS	1,2,3,5	1350	A to B, Same	50	B	A	UR	UC	C,A,D,F,B,E	v	R	H	V
DD	2	CS	4	No Idea	A to B, C to D	No Idea	B	C	UR	UC	B,F,E,C,D,A	R	V	H	V
DE	1	SC	2,3,4,5	7400	A to B, C to D	4100	B	B	UR	BC	C,E,D,F,B,A	R	V	H	S
DF	2	CS	1	7400	Both, Both	200-400	A	A	LR	UR	F,A,D,C,B,E	V	H	H	S
DG	2	SC	1,2,3,5	7000	Both, C to D	400	A	A	UR	UR	F,A,D,C,B,E	S	R	H	V
DH	1	SC	3,4	7400	A to B, Same	-	B	A	UR	UR	F,A,D,C,B,E	-	R	H	V
DI	1	SC	1,2,3, 4,5	7100	C to D, C to D	200	B	D	-	-	C,A,D,F,B,E	H	V	R	s
DJ	1	CS	1,2	7300	Both, C to D	800	B	A	UR	UR	F,A,D,C,B,E	R	H	H	R
DL	1	CS	1,2,3	7000	A to B, Same	50	B	A	MR	UR	F,A,D,C,B,E	H	R	H	R

Code	MTMA Items Pretest 3D Print Terrain Intervention Lab (Spring 2019)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DM	1	CS	1,2,3,4,5	7200	A to B, C to D	50	B	C	UR	UR	F,A,D,C,B,E	R	V	H	V
DN	1	SC	1,2,3,4,5	7400	A to B, C to D	50	B	A	UR	UL	C,A,D,F,B,E	R	V	H	V
DO	1	CS	1,2,3,5	7000	A to B, Same	50	B	A	UR	BC	F,A,D,C,B,E	V	R	H	S
DP	3	CS	1,2,3,5	7400	Both, C to D	50	B	A	UR	BC	F,A,E,C,D,B	V	R	H	V
DQ	1	SC	1,3,5	6000	A to B, C to D	200	B	A	MR	UR	F,A,D,C,B,E	V	V	H	V
DR	2	SC	1,3,5	7000	A to B, A to B	50	B	A	MR	UR	C,A,D,F,B,E	V	R	H	R
DT	2	SC	3,4,5	7100	A to B, C to D	100	B	A	MR	UR	F,A,D,C,B,E	V	R	H	S
DU	1	CS	3,5	7000	Both, Both	25	B	A	MR	UR	F,A,D,C,B,E	V	H	H	V
DV	2	SC	1,2,3,5	7100	Both, C to D	50	A	A	UR	MR	-	R	R	H	S

Code	**MTMA Items** Pretest 3D Print Terrain Intervention Lab (Spring 2019)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DW	1	CS	1,2,3,4,5	7000	A to B, Both	50	B	A	MR	MR	C,A,D,F,B,E	V	R	H	V
DX	2	CS	1,2	7400	Both, C to D	25	B	B	MR	BC	F,A,D,C,B,E	V	H	H	V
DY	2	-	1,2	7400	A to B, C to D	200	B	A	UL	BC	F,A,D,C,B,E	H	V	R	V

Code	**MTMA Items** Posttest 3D Print Terrain Intervention Lab (Spring 2019)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DB	1	CS	1,2,3,5	7200	A to B, C to D	200	B	A	UR	UL	F,A,D,C,B,E	S	R	H	V
DC	1	CS	1,2,3,5	7200	A to B, Same	50	B	A	UR	MR	C,A,D,F,B,E	V	R	H	V
DD	1	CS	1,2,3,5	6000	A to B, C to D	200	B	A	UR	MR	F,A,D,C,B,E	H	V	H	V
DE	1	SC	3,4,5	7480	A to B, C to D	200	B	A	UL	MR	F,A,D,C,B,E	V	H	R	S
DF	1	CS	1	7400	Both, Both	200-400	B	A	MR	UR	C,A,D,F,B,E	S	R	H	V
DG	1	SC	1,2,3,5	7300	A to B, C to D	50	B	B	MR	UL	F,A,D,C,B,E	S	R	H	V
DH	1	CS	1,2,3,5	6000	A to B, Both	200	B	A	UR	UR	F,A,D,C,B,E	V	R	H	V
DI	1	CS	1	1400	C to D, C to D	200	B	-	-	-	C,A,D,F,B,E	H	R	V	S
DJ	1	CS	2	6990	Both, A to B	60	B	A	UR	UR	F,A,D,C,B,E	R	H	H	R
DL	1	SC	1,2,3,5	6270	A to B, Both	50	B	A	UR	UL	F,A,D,C,B,E	V	R	H	R

Code	MTMA Items Posttest 3D Print Terrain Intervention Lab (Spring 2019)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DM	1	CS	4	7200	A to B, C to D	25	B	C	UR	UR	F,A,D,C,B,E	H	R	H	V
DN	1	SC	4	7000	A to B, C to D	50	B	A	UR	BC	F,A,D,C,B,E	H	R	H	V
DO	1	SC	1,2,3,5	7500	A to B, Both	50	B	A	UR	UL	F,A,D,C,B,E	R	H	H	V
DP	3	CS	1,2,3,5	7400	A to B, C to D	50	B	A	MR	BC	F,A,D,C,B,E	R	R	H	V
DQ	1	SC	1,2,3,5	7000	A to B, C to D	200	B	A	UR	UR	F,A,D,C,B,E	R	S	H	V
DR	1	SC	1,2,3,5	7300	A to B, C to D	50	B	B	MR	UL	F,A,D,C,B,E	S	R	H	V
DT	1	CS	1,2,3,5	7280	A to B, Both	40	B	A	MR	UR	C,A,D,C,B,E	ALL	R	H	R
DU	1	CS	1,2,3,5	6800	A to B, Both	45	B	A	UR	UR	C,A,D,F,B,E	H	R	H	V
DV	2	SC	4	7000	C to D, A to B	100	A	A	MR	MR	A,B,C,D,E,F	S	R	R	V

Code	**MTMA Items** Posttest 3D Print Terrain Intervention Lab (Spring 2019)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DW	1	CS	1,2,3,5	7480	A to B, C to D	10	B	A	MR	UL	F,A,D,C,B,E	V	R	H	V
DX	1	CS	3	7000	Both, C to D	50	B	A	UR	UR	F,A,D,C,B,E	V	H	H	R
DY	2	CS	3	6300	A to B, C to D	200	B	A	MR	UL	F,A,E,C,B,D	R	H	H	V

Abbreviations: CS= Circle-Square, SC= Square-Circle, MR= Middle Right, UR= Upper Right, LR= Lower Right, ML= Middle Left, UL= Upper Left, LL= Lower Left, UC= Upper Center, BC= Bottom Center, H= Hill, R= Ridge, S= Saddle, V= Valley

Appendix F

Open-ended MTMA Responses

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
AB	1) Path 1 remains on one elevation. being the least strenuous path to take	1) The area between 2 contour lines is about the same elevation/ the farther spaced the more gentle slope	Square-circle: when topography lines bend/flex the outside of the flex is down in elevation placing the square higher.	Circle-Square: The height goes circle to square as the contour lines show	A to B - the lines are closer together	A to B - Closer lines
AC	1) With path one you go around the same level instead of having to go up or down levels	1) You stay the same elevation as you go around the mountain	Square-circle: It seems like the stream would be going down since the square is higher up than the circle.	Circle-Square: The elevation gets lower as you head towards the square	A to B - Levels are closer together for Josh than for Amy.	A to B - Different elevations are closer together
AD	1) Walking uphill sucks... and I think 1 is staying the same elevation.	1) I would be staying at the same elevation	Circle-Square: Because that direction is downhill	Circle-Square: Because it's the opposite way of the triangles	A to B - Lines are closer together	A to B - The lines are closer toether
AE	1) By taking path 1, I avoid having to ascend and clear a mountain. the terrain is level, in other words.	1) Because the terrain is level, I wouldnt have to clear a ridge or mountain	Square-circle: Water runs downstream from a higher point of elevation, I perceive the square to be at higher elevation based on the map.	Circle-Square: Because the pointed parts of the contours point up stream, water flows from high elevations to lower and betwoeen the circle and triangle elevation goes down from 6200 ft	Both - Because elevation gained only 200 ft for each person. Point A (5200) to B (5400) 5400-5200=200 Point c (4800) point D(5000) 5000-4800 = 200.	A to B- The contours are closer together
AF	1) Path 1 has the most consistent elevation os it would be easiest.	1) Its all the same elevation	Circle-Square: The circle looks like it's at higher elevation than the square.	Circle to Square: the elevation is declining in that direction	A to B - The lines are closer together on Josh's path.	A to B- lines are closer together

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
AG	1) Because it is the most direct but does not have an incredible steep climb	3) Least steep path	Circle-Square: The circle is at higher elevation. It would flow downhill	Circle to Square: Higher to lower elevation	A to B He went up 2000 ft in a much shorter distance than Amy making his journey steeper	A to B Steepest slow in shortest distance.
AH	1) There doesn't appear to be any changes in elevation.	1) No change in elevation	Circle-Squre: The elevation decreases from 6200 ft to 6100 ft.	Circle to square: The V points the opposite way of flow	A to B - the lines are closer to each other.	A to B- The lines are closer to each other
AI	1) Tighter the circles get the higher the slope.	1) You go around the hill	Circle-Square: Circle is higher	Square to circle: V's point to circle	A to B - tight lines	A to B- Close lines
AJ	1) Same elevation, don't have to walk uphill.	A) Same elevation - easier time *not a correct answer...*	Circle-Square: Circle is at a higher position so the water would flow down the hill	Circle to square: Water starts at higher elevation and flows downhill	A to B - Closer the lines were	A to B- The lines are closer together meaning steeper slope.
AK	1) It seem[s] like the strai[ghtest] path to b[e] from A	1) Seems like the straig[ht]est of the three paths	Circle-Square: Because you['re] going from circle to square.	Circle to square: Because it looks like it's flowing from up to down	A to B - The elevation was higher from A to B	A to B- More lines which means more elevation
AL	1) Because the path is at the same level	1) Because its the same elevation	Square-Circle: Higher on the photo	Square to circle: the direction of the lines	A to B - more lines	A to B- c to d is only 200 ft different
AM	1) Because there is no change in elevation so the walk would be easier.	1) Because the elevation doesn't change so even though the path isn't straight, the walk is easier	Square-Circle: Because the lines are showing a flow to left	Square to circle: be the elevation is angled towards the circle	A to B - The elevation lines are closer together from point A to point B rather than from point C to point D.	A to B- The lines of elevation are closer together on point A to point B

MTMA Open-Ended Items
Traditional Semester (Fall 2018)

Code	Pretest Q1	Posttest Q1	Pretest Q2	Posttest Q2	Pretest Q5	Posttest Q5
AN	1) Cause its at the same level throughout	1) Same elevation throughout	Circle-Square: Because it goes downhill	Circle to square: goes down in elevation	A to B - Shorter distance between	A to B- shorter line same distance
AO	2) Because it's the fastest path	1) Fastest path	Circle-Square: Because the slope of the hill goes downward towards the square.	Circle to square: down hill slopes	A to B - The lines are more together to signify a steeper slope.	A to B- lines are closer
AP	1) It doesn’t involve change in elevation	1) There is no change in the slope of the hill	Square-Circle lines are pointing that way	Square to circle: the stream would go downhill	Both 5400-5200=200 5000-4800=200	A to B- The distance between the lines is smaller from A to B
AQ	1) You're on the same level	1) It is equal elevation	Square-Circle: *nothing*	Square to circle: the contours are pointing down stream	Both - each differ by 200	A to B- The contours are close together
AR	2) It goes straight through the middle instead of around it	1) You miss having to go up and down the mountain	Square-Circle: The ridges are moving in that direction with it.	Square to circle: the ridge moves in that direction	C to D - It's a deeper drop.	Same- the numbers both equal to the same distance
AS	1) *nothing*	1) Because the other paths were hills	Square-Circle: I chose this direction because it seems like the terrain is moving in to the direction of the circle. So water flow would move towards that direction	Square to circle: because the terrain moves that way	C to D - The direction of the terrain	A to B- The contour lines
AT	1) It doesn't intersect with any lines. possilby ignoring obsticles making it the fastest and most efficent path.	1) Keeping the same elevation	Square-Circle: It looks though that would be correct	circle to square: the stream is going towards square	A to B - The lines are closer together	A to B- The lines are closer together making it ste[e]per

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
AU	1) I chose because there are no obstacles.	1) it is a straight path to b	Circle-Square: It will flow from the square to the circle because the stream starts from the squares end.	Square to circle: Since the circle has a higher elevation point it flows from square	C to D - Amy took longer to reach point D	C to D- Hills were longer
AV	2) I would chose path 2 because if you extend path 1 and 3 its longer than path 2	1) The 2nd path is going through water	Circle-Square: I chose this direction because it looks as though the water is already flowing that way.	Circle to square: no answer	A to B - *no answer*	A to B- The lines are closer together
AW	1) I chose path 1 because that path has less hills than path 2 and 3	1) Path 1 has less elevation	Circle-Square: Because the elevation is going downhill, therefore the water will flow that direction.	Circle to Square: Rivers flow downhill	A to B - The lines on the map are closer together, therefore it is steeper.	A to B- Shorter distance with same slope
AX	1) It appears you wouldn't need to change elevation to make this journey.	1) Because it follows the same elevation and would require little effort	Circle-Square: The square appears to on a loner plain than the O	Square to circle: the lines pinch of in the direction water is flowing when travelling over a stream	A to B - They travelled the same elevation 200, but Josh had a shorter trajectory, meaning his route was steeper.	A to B- Shorter path, more radical distance covered
AY	1) because I think the lines are elevation and it takes longer to walk on different elevations. 1 is level.	1) Because there isnt a change in elevation this is easer and faster to walk	Square-Circle: because the lines look to be going in that direction.	Square to circle: Because the stream is in the direction that the lines point	A to B - the lines are closer together.	A to B- More lines closer together
AZ	2) Because 2 is a straight shot to B	2) Straight shot to B	Square-Circle: Square to circle because it looks like that's the	Square to circle: the water flow is flowing to the left	A to B - his paths shorter but looks more steep.	A to B- the lines are closer over there making it steeper

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
			way the water is flowing.			
BA	1) because the height is less at number 1	1) The height of the 1 way is the lowest so I don't have to climb up to reach A	Circle-Square: because the height is more at the line of circle so the water flows from circle to square	Circle to Square: the height at circle is higher than the height at square so that water flows direction would be circle to square	C to D - *No Answer*	A to B- If the lines are clos to each other, it means it's getting very higher
BB	2) The fastest way to a destination is a straight line.	2) It's a shorter distance	Square-Circle: From high to low	Square to Circle: *no answer	C to D - *No Answer*	A to B- The lines are close together
BC	2) Because it's the fastest path to point B	2) Fastest path	Circle-Square: Because the river looks like it flows that way.	Square to circle: The patterns show flowing that way	C to D - the curve is going up	C to D- the lines tell you it's steeper
BD	2) It would be quicker to cut through rather than going around to the other paths. Path 2 has less area to cover	2) Quickest route	Square-Circle: The stram would flow downhill	Square to circle: It forms a V	A to B - The lines for Josh show a quicker incline	A to B- A quicker rise in elevation
BE	1) go around, same path	1) Go around, fastest	Square-Circle: The square starts at the top, meaning the water will flow down.	Square to circle: 6100 is less than 6200	Same - 5400-5200=200 5000-4800=200	Same- Subtract both is the same
BF	3) I assume that if you just went from a to be the smaller circles could mean elevation? or a mountain/hill? If thats true you'd be smart to go around.	1) I would take 1 because that path goes around the hill, and also it remains around the same elevation	Circle-Square: Water circle-square because the elevation is higher at the circle.	*NO ANSWER* It's flowing upstream because of the "v" lines are indicating that	C to D - Amy walked a steeper slope, I believe because the steepness was the same but her	A to B- Because Josh had higher elevation

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
					direction was longer.	
BG	2) Its a straight shot to the destination that appears closer distance than 1 or 3	1) You can walk around any elevation	Circle-Square: The stream goes from cirlce to square because the 6200 is greater than 6100 maybe the height of something in which the stream would flow "down" (up right) bc the lower height of land.	Circle-Square: The "v" shows the direction which is moving when *image*	Both - 5400-5200=200 5000-4800=200	A to B- more elevation differences with the # of lines
BH	2) It is a straight shot going straight ahead	1) Because I can walk around the water rising	Circle-Square: It will flow downard because they are elevated differently. The square sits higher than the circle.	Square-Circle: I choose this direction because the elevation moves up going from square to circle	A to B - the lines going down in between point a and b	A to B- More steeper the lines closely together
BI	1) Because this has the least elevational change, which is easier on my legs.	1) Because its the same elevation	Circle-Square: Elevation changed over 100 ft from circle to square, so gravity would have water flowing downhill.	Circle-Square: The elevation change is 100 foot downhill water can't flow downhill	A to B - Its a shorter distance, while climbing the same height of 200 ft.	A to B- The quick elevation change with not much distance
BJ	1) It would be easier to walk on level ground than steep incline	1) Because its easier to walk/run on leveled ground than a steep incline or decline	Circle-Square: The circle is at higher elevation than the box and water always flows downward	Circle-Square: b/c the circle is at a higher elevation than the box and water always runs downhill and the	Same- they both went down by 200 ft	A to B- Josh walked a shorter distance w/ the same incline

MTMA Open-Ended Items
Traditional Semester (Fall 2018)

Code	Pretest Q1	Posttest Q1	Pretest Q2	Posttest Q2	Pretest Q5	Posttest Q5
				contour lines form a "v" pointing up stream.		
BK	1) because it is on an even path	1) Because it is on even ground	Circle-Square: circle seems higher than the square	Circle-Square: Circle is higher and "v"s in the lines point upstream	A to B - geography changes more frequently	A to B- topography changes more often
BL	2) It's the shortest path and goes straight	1) Shortest rout[e] and fastest way	Square-Circle: the way that the land flows shows direction	Circle-Square: goes down hill	A to B - Lines are closer	A to B- Lines closer together
BM	1) It looks shorter than the others because it's a direct shot.	1) Using path 1 you avoid elevatoin	Square-Circle: Square to circle because the downward rush of the water.	Circle-Square: Because of the downward elevation	Both - Upward elevation	A to B- The lines are closer together
BN	2) It is a straight shot with no boundaries you have to go through	1) It wouldn't be 2 because of the elevation so 1 is shorter than 3 so it is 2	Square-Circle: The lines look like they are going that way.	Circle-Square: The elevation goes down so the river does too	A to B - Shorter but same distance	A to B- The lines are same length distance- wise but its steeper for Josh based on the close lines
BO	2) I pick 2 because it's a straight path to B instead of going outwards to get to the B	1) Seem move faster way	Square-Circle: Because the square is by 6100 and that carries first in a way so square will lead down to the circle	Square-Circle: Because it travel down to get to the circle	C to D - I can tell by the distance and how long it was	A to B- *No answer*
BP	1) It is on flat ground.	1) less elevation change	Circle-Square: IT is dropping elevation going that direction	Circle-Square: the elevation is dropping	A to B - Same elevation increase shorter distance	A to B- Lines are much closer
BQ	2) It seems the fastest	3) Because it's not super steep	Square-Circle: It looks like waves flowing	Square-Circle: By the looks of the "v" on the map	Same - Both paths went up 200	Both- By the elevation levels

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
			downward from square to circle			
BR	1) Goes around the hills	1) Go around the steep hills, in the more of a valley area	Square-Circle: Flows downstream	Circle-Square: *image* goes above the V's	C to D - 5200 vs 4800	A to B: The lines are closer together
BS	2/A?) Straight shot rather than curves	*2* A) Straight shot	Square-Circle: Square is higher than the circle	Square-Circle: South	A to B - The lines across are closer together	A to B: *no answer*
BT	1) I picked path 1 because it's avoids elevation	1) This path has the flatest path from point A to B	Square-Circle: The square to the circle because the lines are curving that direction	Square-Circle: The water is curving that way	A to B - They are both 2000 differences but a to be is shorter making it steeper	A to B: Although they are the same elevation difference (200) Point A to be is shorter, making it steeper
BU	2) Because a to b by 2 is a straight line and the other routes are longer	2) Stright line	Circle-Square: Because of the elevation listed on the map	Circle-Square: El[e]vation	A to B - Because Josh has a shorter walk, yet they both climb 200 elevation	A to B: Shorter distance, same el[e]vatoin
BV	1) this would be the fastest becaus it is all on one level and I could avoid any uphill or downhill obstacles. I'm really lazy so path 1 is ideal for me	1) 1 you stay on the same level	Circle-Square: It just seems right to me that the water flows this way, the water would be going downhill I think	Circle-Square: that's the way the water flows	A to B - It's shorter, but the same distance as Amy so it must be steeper	A to B: More lines closer together
BW	2) It's direct and right to where I want to go.	2) It's direct	Square-Circle: It looks like it's downhill	Square-Circle: It's downhill	A to B - His distane isnt as far but he is at a higher elevation	A to B: High number means higher elevation

MTMA Open-Ended Items Traditional Semester (Fall 2018)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
BX	1) It has the least elevation change	1) Less change in elevation	Circle-Square: 6200 is higher than 6100	Circle-Squrae: down stream	Both - the amount of rings	A to B: Short yet his change in elevation
BY	1) It goes around and you avoid any weird obstacles	1)Because if you took 2 or 3, it would be deeper path when if you take 1, its the most level	Square-Circle: From the square to the circle the lines are going toward the circle so if there was a stream. I feel as though it would go towards the circle.	Square-Circle: That's the direction of the lines	A to B - At point D there is elevation so that indicates steepness	A to B: D to C is a long path but A to the lines are closer together
BZ	2) Looks the fastest way from B to A	2) It is more direct	Square-Circle: The lines are angled square to circle	Square-Circle: The direction the lines are pointing	A to B - The lines are closer	A to B: Lines are closer together
CA	1) Because it is a plain f[ie]ld, no climbing hills	1) I would choose 1 because it is at the same level, no climbing up and down hills	Circle-Square: Water flow would g[o] from circle to square because elevation goes down	Circle-Square: The water would flow that way because the elevation is going down	A to B - the lines are closer together	A to B: The lines are closer together
CB	1) Doesn't have any obstacles there is a straight line which would be quicker if ther wasn't "Blockage"	1) Most even ground	Square-Circle: Rivers go into a larger area.	Square-Circle: The water leads into a pond	A to B - more lines	A to B: More lines (elevation)
CC	1) 2 goes over mountains/hills/variou s levels 1 is all on level, 1 height, easierst	1) One single level of land you stay on and need to cross	Square-Circle: water flows south except the nile?	Circle-Square: The circle is at higher elevation it goes	A to B - It's shorter, have to walk at a steeper angle to get there, not a gradual change.	A to B: More lines= steeper, more elevation

MTMA Open-Ended Items
3D Print Terrain Intervention Lab (Spring 2019)

Code	Pretest Q1	Posttest Q1	Pretest Q2	Posttest Q2	Pretest Q5	Posttest Q5
DB	1) I chose one because the line is going through the same layer of land	1) I chose 1 because that path has only 1 elevation	Square-Circle: I chose this because the circle is below the square which means the water must come from where the square is.	Circle-Square: I chose this direction because the elevation is higher on the side of the circle	A-B the layers of land are very close together	A-B You can tell because the contour lines are clothes together
DC	1) Because 2 would force you to go straight over the hill/mountain. And 3 would be going out and around but you would still have to climb and then go back down. 1 doesn't change elevation, just a walk around.	1) No change in elevation, just have to walk around	Circle-Square: because the circle is higher up (on the 6200 line) and the square is even further down than 6100.	Circle-Square: because the circle is at 6200 and the square is below 6100	A-B Lines are closer together which means more rapid change in elevation.	A-B closer lines means more rapid elevation change
DD	2) Because its a straight shot	1) you dont have to go up hills	Circle-Square: I think by looking @ the numbers the "O" is higher up	Circle-Square: its higher than the square	A-B Because the lines are closer together	A-B lines are closer
DE	1) taking path 1 isnt as spread out and is just a small turn	1) Quicker and shorter	Square-Circle: Square to circle because it starts skinner at the top.	Square-Circle: the mouth of the river	A-B the smaller the lines the more steep	A-B the contours are closer
DF	2) Shortest distance	1) less elevation	Circle-Square: Higher elevation	Circle-Square: flows high to low	***Nothing written but math for second question***	Both *nothing written*
DG	2) It's a direct path	1) around the mountains	Square-Circle: Down stream	Square-Circle: Down stream	Same both 200 in difference of elevation	A-B closer together = steeper
DH	1) because 2 you go down and then back up the rocks. This is the same with 3. with 1	1) because 2 you need to walk over hill and 3 is longer	Square-Circle: because the lines look like there flowing toward the circle	Circle-Square: because the circle is higher and would	A-B because he traveled a shorter distance and the	A-B because the lines are closer together

MTMA Open-Ended Items

3D Print Terrain Intervention Lab (Spring 2019)

Code	Pretest Q1	Posttest Q1	Pretest Q2	Posttest Q2	Pretest Q5	Posttest Q5
	you stay on the same level	and you have to walk up a smaller hill		lead the water down to square	lines were closer together	
DI	1) The water current will move your body	1) flat land, straight path	Square-Circle: the wave created a current that pushes the water in the direction of the circle. I gathered this from the waves in the picture.	Circle-Square: going down in elevation	C-D the elevation increased.	C-D increase in elevation
DJ	1) If you went directly from straight from A to B, then the terrain would slow you down	1) There's not much elevation from 1-B	Circle-Square: The elevation is higher from O->Square	Circle-Square: the elevation is higher starting at O	Same the elevation from both go up by 200	Both They're both the same lengths. (they go up by 200)
DK	2) path 2 looks like the wrong path but the fastest and that is what the question is asking so I chose 2	1) 2 and 3 are both uphill	Square-Circle: because thats how the lines look like theyre flowing	Square-Circle: because it is downstream	C-D the lines kinda go up so it looks steep	A-B lines are closer together
DL	1) I chose 1 because all the other paths require me to climb up mountain peaks. path 1 takes me around the mountain, shortening the time.	1) Because you don't have to climb a steep path	Circle-Square: the circle is on higher ground	Square-Circle: It has a "V" shape where the direction of river would flow	A-B shorter line, same elevation	A-B lines are closer together
DM	1) we stay on the same elevation	1) you dont have to climb any hills	Circle-Square: Thats going down hill	Circle-Square: water flows downhill	A-B same height rise shoter distance	A-B same height raise shorter distance
DN	1) because the land is flat	1) Because 1 wouldn't be walking over any hills	Square-Circle: Thats the way of the wind-current or whatever.	Square-Circle: That's just the motion it goes	A-B the lines are closer together	A-B The lines are close together

MTMA Open-Ended Items 3D Print Terrain Intervention Lab (Spring 2019)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
DO	1) Less elevation to cover so it will be faster	1) Path 1, because it doesnt change elevation	Circle-Square: The elevation is lowering from the Circle to Square so thats how the water should flow	Square-Circle: Because that is where the v's in the lines are pointing	A-B seperation of the lines	A-B The lines are closer together
DP	3) Because it seems not as steep	3) Not as steep	Circle-Square: Because I think the circle is by a hill	Circle-Square: O is higher up	Same the difference in numbers seems the same	A-B lines are closer together
DQ	1) It seems the lines on the map are obstables* like hills but path one doesn't intersect with any lines	1) because you say at the same elevation	Square-Circle: I don't know exactly it just seems the lines are flowing towards the circle	Square-Circle: The contour lines are pointing towards the circle	A-B the lines are closer together	A-B The countour* lines are pointing together
DR	2) the fastest way is a straight line?	1) Stay at the same elevation	Square-Circle: less elevation	Square-Circle: Downstream	A-B closer lines higher slope?	A-B more elevation
DS	1) is the shortest distance at the elevation you're on. Closer lines means mountains	1) Shortest path at same elevation	Square-Circle: the lines of the ridge are pointing that way	Square-Circle: Cliffside is pointing that way	A-B the lines are closer together	A-B lines are closer
DT	2) It's straight through	1) It's the same elevation throughout	Square-Circle: the circle may be a lake	Circle-Square: because its going downhill	A-B more lines	A-B have to go up more
DU	1) the elevation doesn't change	1) Less up and down	Circle-Square: I think the elevation is going down	Circle-Square: There is a hill going down towards the square	Same the lines	A-B the lines are closer
DV	2) straight line is fastest way	2) Shortest path possible	Square-Circle: looks downhill	Square-Circle: Downhill	Same each is 200 feet apart	C-D steepness
DW	1) Both 2 and 3 have inclines. path 1 stays the same	1) no incline. further distance but less difficulty	Circle-Square: I believe the circle is at higher elevation	Circle-Square: The circle is higher elevation	A-B the lines are closer together	A-B higher elevation

MTMA Open-Ended Items 3D Print Terrain Intervention Lab (Spring 2019)						
Code	**Pretest Q1**	**Posttest Q1**	**Pretest Q2**	**Posttest Q2**	**Pretest Q5**	**Posttest Q5**
DX	2) a straight line is the quickest loute* between 2 points	1) It has the least amount of elevation	Circle-Square: It goes down hill/stream	Circle-Square: It would be going downhill	Same both paths are 200 feet	Same they both change by 200
DY	2) It seems shorter and it's just a straight path	2) It's a straight shot	- I'm not sure	Circle-Square: The water would be flowing to a higher elevation	A-B there are more lines	A-B the contour lines are thinner