USING HIGHER-LEVEL INQUIRY TO IMPROVE SPATIAL ABILITY IN AN INTRODUCTORY GEOLOGY COURSE

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ABSTRACT

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Visuo-spatial skills, the ability to visually take in information and create a mental image are crucial for success in fields involving science, technology, engineering, and math (STEM) as well as fine arts. Unfortunately, due to a lack of curriculum focused on developing spatial skills, students enrolled in introductory college-level science courses tend to have difficulty with spatially-related activities. One of the best ways to engage students in science activities is through a learning and teaching strategy called inquiry. There are lower levels of inquiry wherein learning and problem-solving are guided by instructions and higher levels of inquiry wherein students have a greater degree of autonomy in learning and creating their own problem-solving strategy. A study involving 112 participants was conducted during the fall semester in 2014 at Bowling Green State University (BGSU) in an 1040 Introductory Geology Lab to determine if a new, high-level, inquiry-based lab would increase participants’ spatial skills more than the traditional, low-level inquiry lab. The study also evaluated whether a higher level of inquiry differentially affected low versus high spatial ability participants. Participants were evaluated using a spatial ability assessment, and pre- and post-tests. The results of this study show that for 3-D to 2-D visualization, the higher-level inquiry lab increased participants’ spatial ability more than the lower-level inquiry lab. For spatial rotational skills, all participants’ spatial ability scores improved, regardless of the level of inquiry to which they were exposed. Low and high spatial ability participants were not differentially affected. This study demonstrates that a lab designed with a higher level of inquiry can increase students’ spatial ability more than a lab with a low level of inquiry. A lab with a higher level of inquiry helped all participants,
regardless of their initial spatial ability level. These findings show that curriculum that incorporates a high level of inquiry that integrates practice of spatial skills can increase students’ spatial abilities in Geology-related coursework.
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INTRODUCTION

Importance of spatial skills in education

The importance of spatial skills in an educational setting is well known. Spatial skills are used whenever a person must evaluate their location in space to execute behaviors, plan future motions, or assess events occurring in a location, such as in a physical education course (Tommasi and Laeng, 2012). A Geography course involves navigating one’s environment through identifying and remembering size and location of landmarks as well as the geometry of the surrounding areas (Tommasi and Laeng, 2012). Reading involves spatial skills when a person must envision detailed environments and scenarios described in the text (Tommasi and Laeng, 2012). Creative tasks in which a person must visualize a product to be created (Economics) or how layers of ceramic glaze will change when fired in a kiln (Art) involve spatial abilities as well (Coxon, 2012). Educators challenge students to take charge of their own learning by setting goals and spatial skills are crucial when students envision themselves achieving an invisible goal (Tommasi and Laeng, 2012).

Spatial ability plays a significant role in fields that are related to fine arts or STEM. A landmark study by Shea et al. (2001) followed high-achieving students throughout high school, undergraduate and graduate degree programs, and participants’ occupations at the age of 33. The results showed a strong correlation between high spatial ability and STEM-related fields of study and careers, while a reduced spatial ability was correlated to non-STEM related fields of study and careers (Shea et al., 2001). A follow-up study was conducted to test if the results of the previously mentioned study applied to students at all achievement levels (Wai et al., 2009). The results of this follow-up study showed that spatial ability plays a crucial role in whether a student pursues a degree or occupation in a STEM field (Wai et al., 2009). Additionally, the results of
the study indicated that the importance of spatial skills increases with successively higher levels of STEM-related educational programs (Wai et al., 2009). Spatial abilities are such an integral part of STEM-based programs that the National Science Foundation (NSF) considers spatial abilities part of the necessary skills for success in a STEM-related field (National Science Board, 2010).

Spatial visualization skills are especially important in the geosciences, with Geology considered as one of the most visually-intensive fields of science (Reynolds et al., 2006). Geologists must use data to interpret things on a small scale (e.g., studying mineral structure) and on a large scale (e.g., tectonic plate movement) (Kastens and Ishikawa, 2006). Imagining how a specific area would look if viewed from different reference points requires an individual to visualize spatial relationships (Kastens and Ishikawa, 2006). This skill is necessary for the fieldwork many geoscientists use to conduct their research. Geologists are often required to visualize structures in the subsurface based only on surface features and a topographic map. Not only are spatial skills needed to visualize one’s location on the map, they are also needed to interpret the underlying patterns and formations (Kastens and Ishikawa, 2006). A study at Southwest Missouri State University found that a higher spatial ability was linked with a higher score on the Earth Science Concepts Inventory test, further supporting the importance of spatial skills in the Geosciences (Black, 2005).

STEM subjects are not the only areas of education that can benefit from increasing students’ spatial abilities. For example, fine arts and creativity have been linked with higher spatial abilities (Colaianne and Powell, 2011; Coxon, 2012). Colaianne and Powell (2011) conducted a spatial assessment on 140 upper-level college students and found that students who have in-depth knowledge of the fine arts scored above the mean (Figure 1). The study also cites
that the overall fine arts scores were statistically the same as overall geology and physics scores (Colaianne and Powell, 2011). High spatial skills are also linked with creativity, which is a large component of fine arts subjects (Coxon, 2012).

The NSF recognizes that spatial abilities are consistently overlooked in today’s schools, leading to a deficit in national talent (National Science Board, 2010). Classes that have been developed to enhance visual-spatial skills are generally elective courses (art, graphic design), while the core courses (math, science) are more focused on acquisition of content knowledge through writing and reading about the subject matter (Mathewson, 1999). Also, most K-12 classrooms rely on textbooks to aid in learning. When the textbooks attempt to improve spatial skills by presenting information visually, such as in a diagram, the image may be out of scale, missing key information, or confusing to students (Matthewson, 1999). An additional reason that teachers in grade 9-12 classrooms may not focus on developing spatial skills is because State Standardized testing as well as the Scholastic Aptitude Test (SAT), a major component in college admissions, do not measure spatial ability (Kell and Lubinski, 2013). Rather, the state tests focus on content and processes and the SAT focuses on verbal and mathematical skills. Many state test and college preparatory classes will naturally favor these skills in order to best prepare students for success on the state assessments and college entrance exams (Kell and Lubinski, 2013).

Due to the lack of focus on developing spatial skills in K-12, students may struggle with spatially-related tasks at the college level (Reynolds et al., 2006; Titus and Horsman, 2009). For example, students studying topographic maps in an introductory geoscience course often struggle with taking a three-dimensional (3D) image and creating a two dimensional (2D) representation; students also struggle with using a 2D map and creating a 3D interpretation (Boardman, 1989,
Reynolds et al., 2006, Clark et al., 2008). Even if students can successfully visualize the landscape, they may have difficulty interpreting the topography from different viewpoints (Clark et al., 2008). In another example, students have a hard time visualizing cells as 3D structures, rather than 2D structures; this ideology can persist into the collegiate level, creating long-held misunderstandings that are difficult to change (Vijapurkar et al., 2014).

*Improving students’ spatial abilities*

Although students may struggle with spatially-related tasks, spatial ability can be improved with practice (Lohman and Nichols, 1990; Titus and Horsman, 2009). Titus and Horsman (2009) conducted a study looking at students’ spatial abilities before and after taking a geology course and found improvement in spatial ability was noted for all courses. When they compared spatial abilities among non-Geology majors with potential Geology majors in the Introductory Geology class, they found both populations improved their spatial skills, while potential majors had a greater increase in improvement compared to non-majors (Figure 2).

Titus and Horsman conducted an additional study at the University of Wisconsin in an upper-level Geology course and looked into whether having students do a small visualization exercise each class period would increase students’ spatial abilities. Students who engaged in these exercises generally out-performed students who did not, but the sample size for the experiment was small (n=12), so more research would be needed to further support this study (Titus and Horsman, 2009).

Not only can spatial ability be improved with practice, but certain activities may differentially improve spatial abilities among students. Spatial ability can vary among individuals and is generally split into two categories: participants with high spatial ability and participants with low spatial ability. A study done by Klopfer et al. (2007) showed that
participants with low spatial ability may benefit from activities that are interactive and allow the participants to manipulate objects (Klopfer et al., 2007). The interactive and manipulable nature of the activities may help the participants with low spatial ability physically manipulate what they have difficulty mentally manipulating. This allows the participants with low spatial ability to make connections and further practice and develop their spatial skills.

Designing a curriculum to teach and enhance spatial skills will help students in Geology courses as well as other courses in fields relating to STEM and fine arts. Chiu and Linn (2014) have shown that a visualization-enhanced Chemistry unit increases students’ understanding of molecular concepts (Chiu and Linn, 2014). Although the study done by Chiu and Linn (2014) was conducted at the high-school level, targeting students enrolled in an introductory-level course (typically taken during the first year of college) allows students to gain critical spatial skills needed in higher-level university coursework. All students enrolled at Bowling Green State University must take at least two natural science courses, and Geology 1040, Earth Environments, satisfies one of these requirements. Students may also choose to take additional courses in Astronomy, Biology, Chemistry, Engineering Theory, Environmental Science, Geography, Geology, Materials Science, and Physics. Spatial skills are needed in all of these courses in order to visualize processes that occur at a small, atomic scale (Chiu and Linn, 2014) as well as ones that occur on a large, cosmic scale. Strengthening spatial abilities early in students’ university careers, such as in an introductory class, can lead to enhanced learning in other STEM- and fine arts-related courses (Milner-Bolotin and Nashon, 2012).

Inquiry

One of the best ways for instructors to engage students in science is through inquiry-based activities (NRC, 2000). Inquiry is defined as “the activities of students in which they
develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 2000, p. 1). Using inquiry as a form of instruction not only promotes science content knowledge acquisition, it teaches the processes involved in science as well (NRC, 2000). Using scientific inquiry as a teaching strategy is considered so essential in science classrooms that the National Science Education Standards (NSES) considers “…inquiry both as a learning goal and as a teaching method” (NRC, 2000, p. 18). Therefore, the NSES has included aspects of inquiry throughout the standards for all grade-levels (NRC, 2000). Although there are currently no inquiry standards at the university level, the K-12 inquiry standards are a good guideline when determining what students are expected to know and be able to do. Additionally, the National Science Teachers Association (NSTA) recommends that scientific inquiry be used as the focal point in K-16 science classrooms (NSTA, 2014).

Inquiry has several different levels of student engagement that can be used in the classroom. Figure 3 outlines the essential features of classroom inquiry. Banchi and Bell (2008), divided inquiry into four different levels based on the level of information given to students and teacher-guided instruction (Banchi and Bell, 2008). Features of low-level inquiry can be found on the right half of Figure 3. The lowest level of inquiry is confirmation inquiry, in which the students are given a question, provided with the method to solve the question, and know the solution beforehand (Banchi and Bell, 2008). This method is generally used when students are practicing previously learned skills. The next level of inquiry is structured inquiry, where the students are given a question and provided the method to solve the question, but the solution is derived from the students’ data and understanding. Structured inquiry is useful when teachers want students to discover relationships between the participants being studied. Both confirmation and structured inquiry are considered lower-level inquiry (Banchi and Bell, 2008).
Guided inquiry and open inquiry are considered higher-level inquiry methods (Banchi and Bell, 2008), and can be found on the left half of Figure 3. Guided inquiry is a level of inquiry in which students are given a question, but it is up to the students to determine their own method to find a solution to the question (Banchi and Bell, 2008). This type of inquiry allows for more student engagement in the activity because the students create their own problem-solving methods and causes the students to engage in more decision making throughout the activity. The highest level of inquiry is open inquiry, where the students create their own question, methods of solving the question, and solution (Banchi and Bell, 2008). This level of inquiry is generally used in student-created research projects.

**Objectives**

The lack of attention to spatially-focused curriculum allows for further exploration into the best teaching practices for spatially-related skills. Inquiry has been shown to have a high level of student engagement, which can lead to higher learning gains. The following study detailed in this thesis focused on determining if higher levels of inquiry increases students’ spatial abilities more than lower levels of inquiry. Additionally, this study explored whether students with a low spatial ability were differentially affected by the level of inquiry compared to students with a high spatial ability.
METHODS

Experimental Design

Students enrolled in an introductory Geology lab course (GEOL 1040, Earth Environments) at Bowling Green State University (BGSU) during the Fall semester of 2014 were chosen as research participants for this study due to the large sample size and the spatially-related activities taught in the lab. The total number of students enrolled in the Geology 1040 labs was 265 students, with 234 students consenting to the study. This project was approved by the local institutional review board (Appendix A). In order to participate in the study, students voluntarily signed a consent form and were informed that they may opt out at any time (Appendix A). Three professors taught the Geology 1040 lectures associated with the labs, with four lab sections for each lecture section, yielding a total of 12 lab sections. Figure 4 outlines the lab schedule and number of participants in each lab section. Labs were designated as either control or experimental by balancing differences in teaching styles, time of day, and lecture professor.

The Topographic Map Lab activity was selected for this experiment because participants must use spatial skills in order to visualize topography and to map topography. The lab activity currently in use (Appendix B) was chosen as the control lab because it exposed participants to spatial skills through a lower level of inquiry. The lab activities in the current lab trend towards the right half of Figure 3. Structured inquiry was used to teach the participants how to draw topographic maps and profiles as well as locate and recognize features on a topographic map. The participants were guided by the instructor on how to draw contour lines on a topographic map, following along as the instructor connected various elevation points to create the contour lines on an overhead projection. Afterwards, participants worked in small groups to locate
various features on a topographic map and answer questions about the map. The ending activity involved participants creating a topographic map from elevation data and constructing a topographic profile of a map.

A modified version of the Topographic Map Lab activity (Appendix C) was created for this study, which incorporates a higher level of inquiry. Activities were designed using Figure 3, in order to incorporate features on the left half of the figure. The majority (90%) of the new lab activity is based on guided inquiry activities focusing on the development of spatial skills, with a small amount (10%) of structured inquiry used to introduce the drawing of topographic map profiles. The participants worked in small groups (2-3 people) to encourage discussion and critical thinking. The first activity required the participants to analyze a 3D model of terrain and to create a 2D topographic representation of the elevation of the terrain. After completing the first activity, the students used a 2D topographic map to build a 3D terrain using Lego™ bricks, a process that has been shown to aid in student understanding (Boardman, 1989). These two activities incorporated guided inquiry and the practice of spatial skills. Using Lego bricks as an instructional aid was ideal due to their potential for strengthening spatial skills. By using the Lego™ bricks, the participants were able to explore orientations in space, manipulation, and development of structures (Tracy, 1987). Toys that allow the user to engage in these activities are related to the enhancement of spatial skills (Tracy, 1987), and may help students with low spatial ability physically model processes they have difficulty mentally visualizing (Klopfer et al., 2007). As stated previously, students typically struggle to create 2D images of 3D topography and also struggle with envisioning 3D terrain from a 2D image and the activities are specifically targeting these spatial skills.
In the next part of the lab, participants used the spatial skills gained in the previous activities to identify features on a topographic map. The participants then had to visualize the terrain between two points on the map and then sketch a profile of the terrain. These activities had a combination of structured and guided inquiry. Afterwards, participants were placed in a ‘survival’ scenario and had to visualize their route to safety based on slope and elevation in order to navigate the roadblocks along the way. This activity was adapted from the Survivor Island activity created by Ludman and Marshak (2012). However, for the study detailed in this thesis, the map was designed to allow for multiple ‘correct’ responses, promoting critical thinking and decision-making skills. This activity incorporates guided inquiry, engaging participants in a task that is not straightforward, causing students to use their problem-solving skills in addition to their spatial visualization skills to find a solution.

Assessment

In order to assess whether a higher level of inquiry improves spatial ability more than a lower level of inquiry, participants took a spatial ability assessment prior to and after being exposed to the control or experimental lab (Appendix D). The pre- and post-test design was adapted from Leventhal and Klopfer (2006). The pre-test was taken by participants four weeks prior to being exposed to the control or experimental lab. Participants had 10 minutes to answer 12 questions. The first six questions (Topo Portion) had a computer-generated shaded relief image of topography colored to indicate elevations and participants chose the 2D topographic image they believed best represented the 3D image (Appendix D). Images used in this portion of the test were modified from images from Leventhal and Klopfer (2006). This portion of the test focused on assessing participants’ ability to visualize a 2D image from a 3D image. The last six questions (Profile Portion) had a topographic map with a line drawn through it and participants
chose the profile they believed best represented the topography along the line (Appendix C). This portion of the test focused on assessing participants’ spatial rotation ability. Participants took the same test as a post-test four weeks after being exposed to the control or experimental lab.

Participants were also given an online version of two of the French Kit spatial assessments one week before the lab to determine each participant’s baseline spatial ability. Participants’ spatial orientation skills were tested using the Card Rotations assessment and participants’ spatial manipulation and visualization skills were tested using the Paper Folding assessment (Eckstrom et al., 1976). The resultant score of both tests determined if a participant initially had a low or high spatial ability.

Results of the pre-test and post-test were computed using non-penalty scoring. Non-penalty scoring was used in order to assess the number of answers participants answered correctly without punishing the participants for guessing an answer. The first six questions were weighted with correct answers scoring 1, close answers scoring 0.5, and wrong answers scoring 0. The last six questions were weighted with correct answers scoring 1, close answers scoring 0.5, and wrong answers scoring 0. Results from the French Kit were compiled and a Z-score (how far the student’s score deviates from the mean) calculated for the Cards Rotation assessment and the Paper Folding assessment. Students who scored above the mean composite Z-score were considered to have a high spatial ability and students who scored equal to or lower than the mean composite Z-score were considered to have a low spatial ability.

Using the Statistical Package for the Social Sciences (SPSS) software program, a 2x2 experimental design was used to compile the data from the pre-test, post-test, and French Kit. Using SPSS, the control and experimental conditions were analyzed to determine how each
condition affected participants’ performance on the post-test. Inherent spatial ability (calculated from the French Kit) was also assessed to determine how it may have affected participants’ performance on the pre-test and post-test. This model determines if the experimental condition yields a statistically meaningful effect on participants’ spatial ability, in addition to determining if the experimental condition differentially affected students with low inherent spatial ability compared to students with high inherent spatial ability.

**Trial Study**

A trial study was run on the introductory Geology lab course during the Spring 2014 semester. The trial study helped to identify potential problem areas within and potential outcomes of the study. A total of 53 participants were involved in the trial study. The experimental design was similar, however both the control and experimental labs contained the same final activity. It was also shown that there could be a potential ceiling effect of pre- and post-test scores. Classroom observations showed areas within the lab that had poor transitions and did not flow well. Despite the identified issues, results of the trial study showed that there was a statistically significant effect (p-value is less than 0.05) between the control and experimental group for the Topo Portion as well as a significant effect on the pre- and post-test scores for the Profile Portion. The identified problems, observations, and results were taken into consideration and appropriate modifications were made to the pre-test, post-test, control lab, and experimental lab.
RESULTS

Initially, 196 participants took the pre-test. A breakdown of scores for all participants who took the Topo and Profile portions is shown in Figures 5 and 6, respectively. However, only 112 participants completed all portions of the study and only these participants’ data were included in the analysis (Tables 1 and Table 2). There were 54 participants who received the control treatment and 58 participants who received the experimental treatment (Tables 1 and Table 2). The French Kit assessment determined that there were 28 participants with low spatial ability and 26 participants with high spatial ability receiving the control treatment (Tables 1 and Table 2). The French Kit assessment also determined that there were 29 participants with low spatial ability and 29 participants with high spatial ability receiving the experimental treatment (Tables 1 and Table 2).

A Repeated Measures Analysis of Variance (ANOVA) was performed on the data compiled from the Topo and Profile portions of the pre- and post-tests. An ANOVA was chosen because it enables the user to compare pre- and post-test effects between experimental groups and to determine if there are any interactions with spatial ability. The independent variables for each analysis were the pre- and post-test results, with treatment (control or experimental) and spatial ability (low or high) being the dependent variables. Significant effects for the Topo test and the Profile test can be found in Tables 3 and Table 4.

While the results of the ANOVA indicate whether there is a statistical difference between experimental groups, it is also useful to evaluate the size of any effect. Cohen’s $d$ effect size was also calculated (Cohen, 1988). The effect size provides a measure of the magnitude of difference in pre- and post-test scores (Tables 3 and 4). Following Cohen’s proposed designations, a small
effect was defined as equal to or less than 0.3, a medium effect was defined as between 0.4 to 0.7, and a large effect was defined as equal to or greater than 0.8.

Results of the Topo portion of the pre- and post-test were compiled (Table 1). A 95% confidence interval was chosen for this study, hence, if the treatment caused a significant effect on the post-test score, a p-value of less than 0.050 would be reported (Table 3). When comparing the overall pre- and post-test scores, there was an increase in the mean score (Figure 7). However, there was no significant effect (Table 3). When comparing the pre- and post-test scores of the control and experimental groups, one can see that the control group scores stayed relatively the same while the experimental group scores increased (Figure 8). In this case, there was a significant effect (Table 3). Overall scores of both spatial ability groups were compared (Figure 9). Participants with low spatial ability scored lower overall compared to participants with high spatial ability. The difference in low spatial ability scores and high spatial ability scores was statistically significant (Table 3). When comparing whether the control or experimental treatment differentially impacted students with low spatial ability or high spatial ability, one can see an increase in scores for students with low and high spatial abilities in the experimental group as well as students with high spatial ability in the control group; scores decreased for students with low spatial ability in the control group (Figure 10). There was no significant effect shown in this case (Table 3).

An ANOVA statistical analysis was also performed on the Profile portion of the pre- and post-test. Comparison of the overall pre- and post-test scores showed an increase in scores (Figure 11). This was shown to be a significant effect (Table 4). When comparing the pre- and post-test scores of the control and experimental groups, scores for both treatments increased (Figure 12). However, this was not shown to be a significant effect (Table 4). Overall scores of
both spatial ability groups were compared (Figure 13). Participants with low spatial ability scored lower overall compared to participants with high spatial ability. The difference in low spatial ability scores and high spatial ability scores was statistically significant (Table 4). When comparing whether the control or experimental treatment differentially impacted students with low spatial ability or high spatial ability, one can see that all scores increased (Figure 14). In this case, there was not a significant effect shown (Table 4).
DISCUSSION

Data Interpretation

Initially, 234 participants consented to the study, 194 participants took the pre-test, and 112 participants completed all portions of the study. The large attrition rate for the study may reflect that some participants dropped the course, were absent during the pre-test, post-test, or the lab, or did not complete the online spatial ability assessment. The average scores for all participants completing the Topo pre-test (4.1/6.0) and Profile pre-test (3.5/6.0) are comparable to the average Topo and Profile pre-test scores (4.1/6.0 and 3.6/6.0, respectively) for participants who completed all portions of the study. This shows that although 52% of participants initially consenting to the study did not complete the study, the remaining participants were representative of the overall lab population.

The Topo Portion results for the overall pre- and post-test scores did not show a significant interaction; however, the results can be interpreted as trending. This means that there is a trend for the scores to increase from the pre-test to post-test, but it is not statistically significant. This result suggests that participants did not significantly increase their spatial ability; however, the data are trending towards an increase in participants’ spatial ability.

The Topo results also showed that there was a significant 2-way interaction between the scores on the post-test and the treatment the participant received. Participants receiving the experimental treatment increased their post-test scores more than the participants receiving the control treatment. This means that participants were better able to visualize a 2D image from a 3D image after being exposed to the higher level of inquiry in the experimental treatment. The Cohen’s $d$ effect size value for this interaction ($d=0.41$) suggests that this effect is of medium practical significance (Cohen, 1988).
The results show that spatial ability does have a significant impact on participants’ scores. Participants with lower spatial ability received lower scores overall and participants with higher spatial ability received higher scores overall. This is a validation on why it is important to include spatial ability when evaluating performance on spatial tasks. The Cohen’s $d$ effect size value for this interaction ($d= 0.31$) suggests that this effect is of medium practical significance.

When comparing the Topo interaction between the type of treatment and the participants’ initial spatial ability, no significant effect was found. This means that the treatments did not differentially affect participants with high or low spatial ability. Taking into account the significant effect that the experimental treatment had on participants’ spatial ability, these results show that the higher level of inquiry helped participants regardless of their initial spatial ability. This is an encouraging result because it shows that a higher level of inquiry does not solely benefit participants with low spatial ability compared to participants with high spatial ability; it helps participants within all levels of spatial ability.

The Profile results for the overall pre- and post- test scores showed that there was a significant gain in the participants’ spatial ability. Overall, participants improved their ability to visually rotate objects in space after being exposed to the lab activity. This suggests that participating in a topographic map lab activity aids in developing participants’ visual rotation skills. The Cohen’s $d$ effect size value for this interaction ($d= 0.41$) suggests that this effect is of medium practical significance.

When comparing the results between the participants of the control and experimental labs, there was no significant 2-way interaction. This result, along with the previous result, shows that regardless of the treatment the participant was exposed to, their spatial abilities were improved. In reference to visual rotation, we find that a higher level of inquiry does not improve
spatial abilities more than a lower level of inquiry. In the control treatment, participants were taught a step-by-step process of plotting elevation points and connecting the points to form a profile (Appendix B). The experimental treatment had participants visualize the topography using contour lines and then had the participants sketch the profile of the island (Appendix C). It could be the case that the way participants were taught to visualize and draw profiles in each treatment used similar thought patterns, therefore either treatment would increase participants’ spatial abilities.

The results also showed that spatial ability has a significant effect on participants’ scores. Participants with low spatial ability scored lower overall and participants with high spatial ability scored higher overall. Again, this confirms the importance of including spatial ability when assessing performance on spatially-related tasks.

When comparing the type of Profile treatment the participants were exposed to and the participants’ initial spatial ability, there was no significant interaction found. This means that the treatment a participant received did not differentially impact participants with low or high spatial ability. When receiving either treatment, participants increased their spatial ability regardless of their initial spatial ability. This is encouraging because it shows that both interventions help all spatial abilities.

Observational Notes

In addition to the pre-test, French Kit assessment, and post-test data, observations were made in each classroom while the participants were being exposed to either treatment. The author sat in the back of the classroom for the first hour of lab and then moved to the middle during the second hour of lab, with observations recorded about the surrounding lab groups. Notes were taken on comments the students made specifically about the lab itself, comments
indicating struggle with the lab activities, behaviors (were they engaged in the lab or non-lab related activities), interactions between partners (were they working together as a team to complete the task or did they sit beside each other and work independently), and some control lab groups were timed on how long they took to complete the final activity.

In the control lab, participants seemed to struggle with identifying features on a topographic map. Specifically, participants struggled with finding the direction of the flow of a river and the length of a sinuous river. The last activity required participants to create their own contour map using elevation points labeled on the map; after the map was created, participants had to construct a profile from their contour map. This activity created the most confusion among the participants. In reference to this activity, one participant commented, “This doesn’t make any sense.” Many participants continually asked for guidance on the activity. Groups typically had difficulty on this task, sometimes struggling for up to 20 minutes before seeking further guidance. Overall, participant engagement in the lab was low, especially during the last activity: at least one third of the participants in each class were observed engaging in activities not directly related to the lab (checking cell phones, talking to other groups, staring off into the distance, playing with lab materials). It may be the case that the confusion during the second and third activity discouraged participants from actively participating in the lab, lowering engagement. Additionally, the lab did not encourage discussion and teamwork amongst the lab participants, which could have also lead to lower participant engagement.

Observations of the experimental lab showed higher levels of participant enthusiasm and engagement. Many participants were excited to use the Legos during the first two activities in the experimental lab: many participants commented on how they had played with Legos as a child or how they were excited to play with toys in a science lab. However, some participants
were distracted by the Lego pieces and used them to build structures other than the one related to the lab activity. After making a 3D model of the 2D topographic map, one participant remarked, “I’m proud of this thing.” Several participants were also observed taking pictures of their 3D models. The last half of the lab required participants to analyze and identify features on a topographic map, create a profile, and navigate the topographic map. There was a lot of discussion within participant groups on how to analyze topographic features and draw a profile. Additionally, groups had to choose between walking or using a raft to navigate obstacles on the island in order to travel to one of two possible rescue sites. The most discussion between group members occurred during this portion of the lab. Typically, groups took several minutes to analyze the advantages and consequences of traversing the island obstacles with and without the raft. Overall, participant confusion was lower and participant engagement was higher than in the control group. These observations are supported by Xu and Talanquer (2013), who did a study comparing student interactions during labs with varying levels of inquiry. They found that labs with higher levels of inquiry encouraged students to suggest more ideas about solutions to problems (instead of just ask other group members the answer to the question) and to approach problem solving with a more exploratory method instead of just a procedural method (Xu and Talanquer, 2013).

The results are comparable with a study conducted by Chiu and Linn (2014) wherein student performance was compared between groups receiving traditional textbook and lecture-based instruction with groups receiving a visualization-enhanced online inquiry unit. Students who participated in the visualization-enhanced online inquiry unit had higher post-test scores and were able to create more connections to concepts than students who participated in the traditional
instruction (Chiu and Linn, 2014). The study detailed in this thesis further supports the need for inquiry-based curriculum that focuses on increasing visualization skills.

The results of this study also support the findings by Leventhal and Klopfer (2006) who, in their second study, showed that spatial ability plays an important role in performance on spatially-related tasks. In their study, participants with high spatial ability performed better on tasks than participants with low spatial ability. Their results also showed that practice with spatially-related tasks can improve performance as well.

However, results from the current study contrasted with those from the first study done by Leventhal and Klopfer (2006), in that, they found that participants with low spatial ability and participants with high spatial ability were differentially affected by an interactive manipulation. The 3D computer-based manipulable activity increased the spatial ability of participants with low spatial ability, but did not affect spatial ability of participants with high spatial ability. It could be the case that computer-based manipulable activities differentially aid participants compared to the physically manipulable activities used in this study.

The data compiled from the pre-test, French Kit analysis, post-test data, and the classroom observations shows that participating in a lab with a higher level of inquiry increases participants’ spatial ability more than a lab with a lower level of inquiry. Interactive participant-guided activities that require critical thinking and discussion foster a higher level of participant engagement and can lead to greater gains in spatial abilities. The experimental lab placed participants in a “survival scenario” and encouraged participants to discuss and determine a route to rescue. It may be the case that allowing participants to figure out their own problem solving method (higher levels of inquiry) rather than solving a problem using pre-determined steps (lower levels of inquiry) allows participants to create a problem-solving method more
meaningful to themselves, and thus, the participants learn more from the lab. Making the lab more meaningful to participants and encouraging them to problem-solve in small groups increases participant engagement in the lab, which could be the reason for the increase in spatial ability.

Although the study has shown that a higher level of inquiry can improve participants’ spatial abilities, there are some limitations. The study contained 112 participants, with about half receiving the control treatment and about half receiving the experimental treatment. Each treatment contained similar quantities of participants with low or high spatial ability. This proportion was ideal; however, more participants would be needed in the study to allow for analysis of additional factors and their impact on spatial ability, such as age, college major, progress towards completion of a college major, and prior spatial ability training. This study allotted 10 minutes to answer 12 questions in the pre- and post-test due to time constraints. Adding a greater number of questions involving a greater degree of difficulty would provide a more in-depth analysis of participants’ spatial skills after receiving the control or experimental treatment; however, the length must be balanced with students’ motivation and attention spans. Another limitation was that the treatments were administered by several different instructors. Prior to administering the control or experimental treatment, instructors were taught how to present the material and answer participants’ questions. It could be the case that differences in individual teaching styles may have had an impact on the post-test results. In order to minimize this effect, the author moderated and observed each lab in order to maintain consistency and intervene if necessary.
CONCLUSION

The results of this study demonstrate that lab activities with a higher level of inquiry can lead to higher gains in spatial ability. Participants in the study outlined in this thesis significantly improved their spatial ability through just one lab, and multiple labs created with a focus on developing spatial skills through higher levels of inquiry would be predicted to make an even greater impact. Also, higher gains in spatial ability are shown to lead to greater success in STEM and arts-related fields. A follow-up study tracking participants over long-term periods of time (semesterly throughout their degree program and at five year intervals after graduation from the program) would be ideal to determine spatial skill retention trends over time.

Another potential impact of this study is that student enthusiasm and engagement in the lab was observed to increase with a higher level of inquiry. A challenge of introductory Geology labs is to get all students interested in the subject matter. Designing an entire lab course with a higher level of inquiry could lead to more involvement in the subject matter and a greater understanding of STEM-related concepts. One of the challenges society faces today is a lack of understanding and interest in STEM subject matter. Engaging labs that challenge participants to problem-solve and think critically create a personal connection to the subject matter. This, in turn, would aid in combating a cultural aversion and skepticism relating to STEM fields.

This study shows that there is a benefit of incorporating higher levels of inquiry in STEM curriculum. Spatial ability is one of the key skills necessary for success in these fields and can be enhanced through labs designed with higher levels of inquiry. Labs with higher levels of inquiry promote spatial skill acquisition and foster greater enthusiasm and engagement of participants and curriculum. When students are engaged and creating meaningful connections to
the subject matter, it could aid in greater scientific literacy and foster a long-lasting connection to STEM-related concepts.
REFERENCES CITED


Figure 1: Results of a spatial ability test when corrected for gender and GPA. Sciences and the fine arts, score above the mean (Colaianne and Powell, 2011).

Figure 2. Outcomes from Carleton College Study of Introductory Geology Students’ Spatial Abilities. Non-majors are students who have taken one Geology course and potential majors are students who have enrolled or taken two or more Geology courses (Titus and Horsman, 2009).
<table>
<thead>
<tr>
<th>Essential Feature</th>
<th>Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Learner engages in scientifically oriented questions</td>
<td>Learner poses a question Learner selects among questions, poses new questions Learner sharpens or clarifies question provided by teacher, materials, or other source Learner engages in question provided by teacher, materials, or other source</td>
</tr>
<tr>
<td>2. Learner gives priority to evidence in responding to questions</td>
<td>Learner determines what constitutes evidence and collects it Learner directed to collect certain data Learner given data and asked to analyze Learner given data and told how to analyze</td>
</tr>
<tr>
<td>3. Learner formulates explanations from evidence</td>
<td>Learner formulates explanation after summarizing evidence Learner guided in process of formulating explanations from evidence Learner given possible ways to use evidence to formulate explanation Learner provided with evidence and how to use evidence to formulate explanation</td>
</tr>
<tr>
<td>4. Learner connects explanations to scientific knowledge</td>
<td>Learner independently examines other resources and forms the links to explanations Learner directed toward areas and sources of scientific knowledge Learner given possible connections</td>
</tr>
<tr>
<td>5. Learner communicates and justifies explanations</td>
<td>Learner forms reasonable and logical argument to communicate explanations Learner coached in development of communication Learner provided broad guidelines to use sharpen communication Learner given steps and procedures for communication</td>
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Figure 3: Variations of Essential Features of Inquiry (NRC, 2000).
### Schedule of Control and Experimental Labs

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![Color Legend]
- **Red**: Professor 1 Experimental
- **Green**: Professor 2 Experimental
- **Blue**: Professor 3 Experimental
- **Pink**: Professor 1 Control
- **Yellow**: Professor 2 Control
- **Blue**: Professor 3 Control

**Figure 4**: A weekly schedule detailing the control and experimental labs. Numbers on lab groups denote the number of students consenting to take part in the study. Initially, there were a total of 117 students participating in the control labs and 117 students participating in the experimental labs.
Figure 5: Participants’ Topo pre-test scores, mean score is 4.1 out of 6.

Figure 6: Participants’ Profile pre-test scores, mean score is 3.5 out of 6.
Figure 7: Pre- and post-test mean scores, $p<0.053$ (data from Table 3).

Figure 8: Pre- and post-test mean scores for the control and experimental treatments $p<0.035$ (data from Table 3).
Figure 9: Overall Topo test scores of participants with low spatial ability (3.86) and participants with high spatial ability (4.53), $p<0.001$ (data from Table 3).

Figure 10: Pre- and post-test scores for spatial ability in the control and experimental treatment, $p<0.393$ (data from Table 3).
Figure 11: Pre- and post-test mean scores, $p<0.000$ (data from Table 4).

Figure 12: Pre- and post-test mean scores for the control and experimental treatments, $p<0.067$ (data from Table 4).
Figure 13: Overall Profile test scores of participants with low spatial ability (3.24) and participants with high spatial ability (3.86), \( p < 0.000 \) (data from Table 4).

Figure 14: Pre- and post-test scores for spatial ability in the control and experimental treatment, \( p < 0.730 \) (data from Table 4).
Table 1: Participant Scoring Data for all treatments for the Topo Test

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean (Out of 6)</th>
<th>Standard Deviation</th>
<th>Number of Participants</th>
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<tbody>
<tr>
<td>Pre-Test (All participants)</td>
<td>4.1</td>
<td>1.247</td>
<td>112</td>
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<td>Control Pre-Test (All spatial abilities)</td>
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<td>Control Pre-Test, High spatial ability</td>
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<td>Experimental Pre-Test (All spatial abilities)</td>
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<td>Experimental Pre-Test, Low spatial ability</td>
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<td>Experimental Pre-Test, High spatial ability</td>
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<td>Post-Test (All participants)</td>
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<td>Control Post-Test (All spatial abilities)</td>
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Table 2: Participant Scoring Data for all treatments for the Profile Test

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<td>Pre-Test (All participants)</td>
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### Table 3: Statistical Analysis for significant effects of Topo Portion

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<tr>
<th>Treatment</th>
<th>Significant Effects</th>
<th>Cohen’s Effect Size (d)</th>
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<td>Pre- and Post-Test</td>
<td>$ggF(1.000, 108.000) = 3.843, p&lt;0.053$</td>
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<td>Pre- and Post-Test, Control and Experimental</td>
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<tr>
<td>Pre- and Post-Test, Control and Experimental, High and Low Spatial Ability</td>
<td>$ggF(1.000, 108.000) = 0.737, p&lt;0.393$</td>
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<tr>
<td>High Spatial Ability and Low Spatial Ability</td>
<td>$ggF(1.000, 108.000) = 11.249, p&lt;0.001$</td>
<td>0.31</td>
</tr>
</tbody>
</table>

### Table 4: Statistical Analysis for significant effects of Profile Portion

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Significant Effects</th>
<th>Cohen’s Effect Size (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre- and Post-Test</td>
<td>$ggF(1.000, 108.000) = 21.354, p&lt;0.000$</td>
<td>0.41</td>
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<tr>
<td>Pre- and Post-Test, Control and Experimental</td>
<td>$ggF(1.000, 108.000) = 3.427, p&lt;0.067$</td>
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<tr>
<td>Pre- and Post-Test, Control and Experimental, High and Low Spatial Ability</td>
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APPENDIX A: HUMAN SUBJECTS REVIEW BOARD CONSENT FORM.
APPENDIX B: CONTROL LAB (RICH, 1980).

Topographic Maps

Purpose
The purpose of this lab is to illustrate the types of information presented on maps and to develop your skill in constructing and interpreting topographic maps.

Introduction
A map is a representation of a portion of the earth’s surface drawn to some scale, usually on a flat two-dimensional surface. Maps are used to show the spatial distribution of features in a particular region, ranging from political boundaries, roads, cities, population density, annual precipitation, mineral resources, to hundreds of other features.

Every map is created for a specific purpose. A biologist, for instance, may use a vegetation map to document changes occurring in a forest. A geologist may consult gravity, magnetic, or geologic maps in his search for an oil reservoir. Almost everyone has consulted a roadmap at some point in their lives for navigation from one place to another.

Elements of a Map
To create a valuable map, no matter what type, there are six essential pieces of information that must be included.

1. **Location**
   This element, most commonly included in the title, indicates what portion of the Earth’s surface is portrayed on the map. In addition to the written location, many maps include a coordinate system for locating places plotted on the map.

2. **Direction**
   Direction indicates the orientation of the map, commonly shown by a north arrow. By convention, north is toward the top of the map unless a different orientation is indicated.

3. **Scale**
   Scale indicates how much of the Earth’s surface is portrayed on the map, or the ratio of the distance on the map to the corresponding distance on the ground (e.g., 1 cm on the map is equivalent to 10 km on the earth’s surface). Scale may be displayed in one of three ways:

   - **Graphic Scale** – visually shows the distance on the map corresponding to the distance on the ground
   
   ![Graphic Scale Example](image)

   - **Verbal Scale** – distance ratio is expressed in words
   
   *Example:* 1 cm = 10 km

   - **Ratio Scale** – distance ratio is expressed as a ratio
   
   *Example:* 1:24,000 (1 unit on the map = 24,000 units on the earth’s surface, whether the units are feet, meters, miles, etc.)
4. Date
   Features shown on a map can change through time. Therefore, the date that data were collected to produce a map can be important.

5. Legend
   A legend explains the symbols on the map.

6. Source
   The source indicates what individual, group, or agency produced the map.

Topographic Maps
One of the most useful types of maps is a topographic map, which is used to show the three-dimensional geometry of the Earth’s surface (topography) in two-dimensions. Topographic maps are beneficial for analyzing the Earth’s surface, geographic planning, architecture, mining projects, recreational use, and many other purposes.

Topographic maps, along with several other types of maps will be used in many of the upcoming labs, and your ability to read them is an essential part of this course.

Topography on a map is represented by elevation, or the distance above or below sea level, which has an elevation defined as 0 feet or meters. Elevation is depicted with contour lines, or lines of equal elevation. To build your skill in interpreting topographic maps, you will learn how to read the patterns of contour lines, to draw contour lines, and to construct a topographic profile.

Reading Contour Line Patterns
By looking at the shape, spacing and location of contour lines, you can interpret the shape of the land surface. The following is a list of rules that will help you to understand the topography:

1. By definition, every point on a contour line represents the exact same elevation. As a result, every contour line must eventually close on itself to form an irregular loop. Contour lines may not appear to close on your map if they are the edge of map, but if you attached the adjacent map you would see that eventually the contour will close.

2. The difference in elevation between two contour lines is given by the contour interval.

3. Contour lines can never cross one another.

4. Moving from one contour line to another always indicates a change in elevation, either positive (uphill) or negative (downhill).

5. Contour lines closer to one another indicate a steeper slope (change in elevation over a given distance).

6. If contour lines are evenly spaced, the slope is constant.
7. A series of closed contours in a bull’s-eye pattern with the highest elevation at the center is a hill. A series of elongated v-shaped closed contours with the highest elevation at the center is a ridge.

8. A series of closed contours in a bull’s-eye pattern with the lowest elevation in the center and hachure marks is a depression. A series of elongated v-shaped closed contours with the lowest elevation at the center is a valley.

9. Contour lines crossing a stream valley will form a "V" shape pointing in the uphill (and upstream) direction. This is known as the rule of v’s.

Lab Activity One
Demonstrate your ability to read and interpret a topographic map by answering the following questions about the Paw Paw, MD/WV topographic map provided by your instructor.

1. What is the contour interval of this map?

2. Look at the topographic feature labeled The Devils Nose in the SW corner of the map. What type of feature is this? How did you know?

3. What is the highest elevation along Purslane Mountain?
4. Look at Rockwell Run, a stream on the East boundary of the map. What type of topographic feature does Rockwell Run cut through? How did you know?

According to the rule of v’s, which direction is the stream flowing?

How does the elevation change from the start of the stream to the end?

Describe the topography on either side (NW and SE) of Rockwell Run.

5. Look at the Potomac River cutting through the middle of the map, which direction is the river flowing?

Using a string, estimate the slope (in feet/mile) of the Potomac River from the Morgan Co./Hampshire Co. Line to Campbells (in NE of map area).

6. Describe the general topography of the area using specific topographic features as examples.
Drawing Contour Lines

Another valuable way to gain an understanding of topographic maps is to draw your own contour lines from a series of spot elevations, or specific locations on a map where the elevation is known or measured. There are four simple rules to follow in order to contour your own topographic map:

1. Choose a contour interval, or set difference in elevation between adjacent contour lines (e.g., 20 meters between each contour line). Use the smallest interval possible without overcrowding the map.

2. Begin contouring by choosing a beginning contour value, usually the highest or lowest value contour line, and connecting points that are equal to that value.

3. When drawing connecting points of equal value, use other spot elevations to guide your contour line. For instance, when connecting two points with known elevation of 500, if your line passes between the spot elevations of 400 and 600, your 500 contour line should be and equal distance from both of those spot elevations since 500 is exactly halfway between 400 and 600, as shown below.

4. Complete the other contour lines on the map using your initial contour as a guide for the general shape of the topography.

Based on the rules provided, try contouring the simple map below. Start by drawing the 500 m contour, then draw a contour line every 50 m.

Question: Using your understanding of contour lines, describe the topography of the map you just drew.
**Drawing Topographic Profiles**

*Topographic profiles*, or cross sections of the topography along a specified line, are a useful way of visualizing the topography and verifying your interpretations from the contour line patterns.

Just as with drawing contour lines, there is another simple set of rules required for drawing topographic profiles:

1. Draw a profile line across the area of interest on the contour map.
2. Lay a piece of paper along the line and mark where each contour line or spot elevation crosses the profile line. Make sure you record the elevation value for each mark you make as well. Also label the beginning and end points of your profile line.
3. Transfer your markings to a scaled piece of graph paper with elevation on the y-axis and the length of the profile line as the x-axis.
4. Connect all of your points.

Following the steps provided, construct a topographic profile from X-X' of the simplified topographic map on the previous page on the graph below.

![Graph with labeled axes](image)

**Question:** Does your topographic profile confirm your previous description of the topography?
Lab Activity Two
Demonstrate your ability to construct a topographic map and profile by contouring and drawing a topographic profile along A-A' on the map below. Using a contour interval of 100 feet, draw contour lines connecting all points of equal elevation above sea level in even 100's of feet (e.g., 100, 200, 300...). Sketch lightly so you can make adjustments easily. When sketching is complete, darken the contour lines and label each line with numbers to indicate its elevation.

Note: The dashed lines represent streams (remember the rule of V's).
APPENDIX C: EXPERIMENTAL LAB.

Topographic Maps

Purpose

The purpose of this lab is to develop 3D spatial visualization skills using topographic maps. This lab also supports the BG Perspective Student Learning Outcome: [students] will learn how to solve problems through using the logical approach of science, and the University Learning Outcome: [students will gain] intellectual and practical skills through critical and constructive thinking.

Introduction

Have you ever gotten lost due to your GPS or phone losing signal? Chances are, you have, and it was probably very frustrating. Paper maps don’t lose signal, but can be equally frustrating to understand. This lab is designed to allow you to learn how to use a topographic map (ground surface elevation map) to navigate terrain.

Topographic maps are different than your car or phone GPS maps because they show the elevation (height of land above sea level). They take 3D landscapes (such as mountain chains, steep slopes, or valleys known as topography) and represent them on a 2D surface (the flat, paper map). These maps are extremely useful for navigating terrain.

Important Elements of a Topographic Map

Topographic maps show elevation using contour lines. These lines represent equal elevation; each point along one line is exactly the same height above sea level. For example, if you have a contour line representing 200m, every point the line touches on the hill is exactly 200 m in elevation.

![Topographic Map Diagram]

Figure 1: A mountain showing different levels of elevation.

Typically, there are several different elevations on topographic maps. Depending on your location and the size of the map, it can be tricky to put many contour lines and their elevations on the map. A way to simplify the map is to use contour intervals: this tells you the difference in height between contour lines. The contour interval in the picture above would be 100 m because there is 100 m between each contour line.
Contour Line Rules

By looking at the shape, spacing and location of contour lines, you can interpret the shape of the land surface. The following is a list of rules that will help you to understand the topography:

1. Every point on a contour line represents the exact same elevation. As a result, every contour line must close to form an irregular loop. Contour lines may not close if they are at the edge of a map, but if you attached another map to continue the land in that direction, you would eventually see the contour line close.

2. The difference in elevation between two contour lines is given by the contour interval.

3. Contour lines never cross one another.

4. Moving from one contour line to another shows a change in elevation, going either uphill (the elevation numbers increase) or downhill (the elevation numbers decrease).

5. Contour lines close to one another indicate a steep slope (change in elevation over a given distance). Contour lines spaced far apart, indicate a more gentle slope. Contour lines that are evenly spaced show the slope is constant.

6. A series of closed contours in a bull’s-eye pattern with the highest elevation at the center depicts a round hill. A series of elongated v-shaped closed contours with the highest elevation at the center is a ridge.
7. A series of closed contours in a bull’s-eye pattern with the lowest elevation in the center and hachure marks is a **depression**. A series of elongated v-shaped closed contours with the lowest elevation at the center is a **valley**. The contour line directly adjacent to the first hachure mark is the same height as the hachure mark.

![Depression and Valley Diagram](image)

8. Contour lines crossing a stream valley will form a "V" shape pointing in the uphill (and upstream) direction. This is known as the rule of v’s.

![River Diagram](image)

**Topographic Profiles**

Another way you can use a topographic map is to help you construct a **topographic profile** or **cross section**. This is what a selected area of the map would look like from a side-view. Usually a portion of the map is selected (generally, a line running through the map) and, using the contour lines as a guide, one can draw the increases and/or decreases in elevation along the line.
Lab Activity One: Mt. Lego-My-Eggo

You will need to pick up the raised-terrain baseplate and large map for this activity. Your job is to create a topographic map of the baseplate.
- The small island is located in the southeast corner.
- Outline the base of the mountain and island with a 0-brick contour line.
- Use 3-brick contour intervals (the elevation between the contours you create will be 3 bricks high).
- A colored pencil might be helpful in making your contour lines stand out on the map.
- Label each contour line with its associated height (0-brick, 3-brick, or 6-brick).

Lab Activity 2: U-Breccia Mountain

In the previous activity, you took a 3-D image and created a 2-D image. Using the U-Breccia Mountain map provided by the TA, you’re going to create a 3D representation. Re-create the terrain shown on the map with the small baseplate and Legos.

TA’s signature of completion: ____________________________

Lab Activity 3: Endurance Island

Your 1040 Geology Lab was on the BGSU Boat Cruise when a storm caused the ship to crash into Endurance Island. Luckily, your group has survived and your TA has found a map among the wreckage. The best thing to do would be to analyze your surroundings using the map.

1. The outer border of the island is at sea level (0 ft). Where is the highest point on the island and what is the elevation?

2. According to the rule of v’s, which direction does the river connected to Parched Pond flow?

3. Which direction does the river connected to Listless Lagoon flow?
4. In general, how does the elevation change from the start of the stream to the end?

5. Look at the $\vee$‘s the contour lines make along the stream. Why do the contour lines point upstream?

6. What is the lowest elevation of Dead Slug Quagmire?

7. What side of Mt. Last Chance is the steepest? How can you tell?

8. How does the island topography change as you go from point B to point A? Make sure to note the general steepness and any features you may come across.

9. Draw a line from point B to point A. In general, which side of the island is more like a gently-rolling plain? How can you tell?

Imagine you are standing at the crash site and looking at the island. On the appropriate graph, each partner needs to sketch a profile of the island from point A to point B. A sketch is an approximate representation that contains some details, but is not an in-depth drawing. It may be helpful if you orient your map accordingly.

10. Does your initial assessment in question 8 match the profile you created? Explain.
Unfortunately, you both have been injured in the crash and infection has begun to set in. In order to save yourselves, you and your partner need to find the quickest route to a rescue site. Note: there are two rescue sites. Amongst the rubble, you find a raft. But, before you leave the crash site, you need to decide if you’re going to carry the raft or leave it behind. Listed below are the benefits and consequences of choosing to carry the raft.

**Raft**
- Can cross water (but *cannot* travel up or down rivers due to rapids)
- Raft has built-in water filter (can drink from any water source)
- You *must* carry the raft all the way to the rescue site
- Can only carry 3 days of water
- Can only ascend/descend 300 ft total in one day
- Can *only* travel 4 miles in one day

**No Raft**
- *Cannot* cross water
- Can *only* drink from freshwater ponds and lakes (rapids prevent you from drinking from the river and the water surrounding the island is too salty)
- Can only carry 3 days of water
- Can only ascend/descend 300 ft total in one day
- Can *only* travel 10 miles in one day

11. Circle your decision above and briefly explain why you chose this option.

*** Beware: there are several dangers lurking on Endurance Island***
- Cape Kraken is impassable due to the monster that lives beneath its waters.
- Dead Slug Quagmire will cause you to become stuck for 1 day.
- Do not venture into Jaundice Jungle, unless you want to die at the hands of a ferocious beast.

**Your task:**
- Using the appropriately-sized string as a way to measure your distance, trace the quickest path to a rescue site following all applicable rules and avoiding dangers.
- A different partner will decide the path for each day.
- Make sure to trace your path and place an X where you spend each night.

12. How many days did your trip take?

13. Did you have to stop for water? If so, where?
14. What was the total distance of your trip?

15. Using the appropriate graph, each partner needs to sketch a general profile of your route.

16. Compare your results with a group that made the opposite raft choice and/or rescue site choice. Which way was quicker? Why?

Student has completed online assessment (10 points) __________________________

Handouts (Originally each printed on 11x17 paper)
Mt. Lego-My-Eggo

Contour Interval = 3 Bricks
APPENDIX D: PRE- AND POST-TEST.

DO NOT WRITE ON TEST PACKET

The Geology 1040 labs have been selected to participate in a research study analyzing spatial abilities of students enrolled in beginning-level Geology courses. The results of this test will not have an impact on your grade in the class and will be used to evaluate the effectiveness of the current labs in developing students’ spatial abilities.

1. Fill out the information section on your Scantron© sheet using your student ID number as your Identification number. Also fill in whether you identify as male or female. If you do not identify as male or female, or prefer not to answer, leave it blank.

2. For questions 1-6 you will be finding the topographic map that best matches the terrain shown. Select the one map (a-d) that best matches the colored picture shown, and mark your answer on the Scantron© sheet.

   *The numbers on the map correspond to the elevation along the contour of that portion of land.*

3. For questions 7-12 you will be shown a topographic map. Again, the numbers correspond to the elevation along the contour of that portion of land. You are to select the topographic profile that best fits the line A-B.

   *A topographic profile is the cross section of the map along a certain line and is useful for visualizing the way a section of land looks from a side-view.*

4. Use the General Purpose section of your Scantron© sheet to answer the test questions. Question 1 will correspond to number 1, etc… on your Scantron© sheet.

   You may not have worked with topographic maps before, but do your best to answer the questions in the time given.

   DO NOT WRITE ON TEST PACKET