PERFORMANCE ON THE GEOLOGIC SPATIAL VISUALIZATION SURVEY: A COMPARISON BETWEEN JUNIOR AND SENIOR UNDERGRADUATE STUDENTS

By

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ABSTRACT

Three components of students’ spatial visualization are tested (spatial relations, spatial manipulation, and visual penetrative ability) along with spatially intensive geology questions. The Geological Spatial Visualizations Survey (GSVS) was developed for four main purposes: (1) to quantify spatial visualization differences between a junior cohort (pre EOSC 223 and 323) and a senior cohort (post EOSC 223 and 323). (2) to determine which spatial visualization ability was the best correlate to spatially intensive geology question scores (3) to define the link between spatial visualization abilities and specific types of geology questions (4) and finally, to explore gender differences within each cohort.

Results from the GSVS include: (1) Senior students outperformed junior students in the geology and spatial visualization parts of the GSVS. (2) The best predictor of geology score was spatial manipulation which was also the spatial visualization ability that improved the most from junior to senior cohorts. (3) Although spatial visualization was correlated to geology score, the link between specific geology question types and specific visualization ability was not fully established. (4) There was no difference in geology score between gender and the only spatial visualization score that differed was spatial relations. Males outperformed females in spatial relations but that outcome had no bearing on geology score.

The GSVS can be used by instructors of spatially intensive geology courses as an assessment tool and as a skill development exercise because spatial visualization can be improved with practice.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE PAGE</td>
<td>i</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td>vii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>viii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>PREVIOUS WORK</td>
<td>4</td>
</tr>
<tr>
<td>1. Spatial Relations</td>
<td>4</td>
</tr>
<tr>
<td>2. Spatial Manipulation</td>
<td>5</td>
</tr>
<tr>
<td>3. Visual Penetrative Ability</td>
<td>5</td>
</tr>
<tr>
<td>4. The two-way relationship between Geology and Spatial Visualization</td>
<td>6</td>
</tr>
<tr>
<td>DEVELOPMENT OF THE GEOLOGICAL SPATIAL VISUALIZATIONS SURVEY</td>
<td>6</td>
</tr>
<tr>
<td>1. Step 1: Choosing questions based on instructor defined Key Geology Skills</td>
<td>8</td>
</tr>
<tr>
<td>2. Step 2: Develop Geology questions that utilize Key Skills</td>
<td>9</td>
</tr>
<tr>
<td>3. Step 3: Modify questions after correspondence with the Instructors of EOSC 223 and 323</td>
<td>10</td>
</tr>
<tr>
<td>4. Step 4: Validating the GSVS based on the results of the Think-Aloud Interviews</td>
<td>11</td>
</tr>
<tr>
<td>Administering the validated GSVS</td>
<td>12</td>
</tr>
<tr>
<td>RESULTS</td>
<td>14</td>
</tr>
<tr>
<td>1. Senior Students outperform Junior Students in both Geology and Spatial questions</td>
<td>14</td>
</tr>
<tr>
<td>2. Each Spatial Visualization Ability separately correlated with Geology Score</td>
<td>15</td>
</tr>
<tr>
<td>- Spatial Relations correlated with Geology Score</td>
<td>15</td>
</tr>
<tr>
<td>- Spatial Manipulation correlated with Geology Score</td>
<td>16</td>
</tr>
<tr>
<td>- Visual Penetrative Ability correlated with Geology Score</td>
<td>16</td>
</tr>
<tr>
<td>3. Geology Question Outcomes matched to specific Spatial Visualization Ability</td>
<td>17</td>
</tr>
<tr>
<td>4. Demographic Considerations</td>
<td>18</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1. shows the three spatial visualization abilities being studied: spatial relations, spatial manipulation, and visual penetrative ability (Titus and Horsman, 2009). .......................................................... 2

Figure 2. The steps involved in the development of the GSVS. ......................... 8

Figure 3. An example of a geology task that utilizes visual penetrative ability in the GSVS. .................................................. 9

Figure 4. An example from the GSVS showing what would be considered a geologic task utilizing spatial manipulation ability. ............... 10

Figure 5. Distribution of the geology score against the distribution of the spatial visualization score ........................................ 14

Figure 6. shows the senior and junior distribution of geology score plotted against spatial relations ........................................ 15

Figure 7. shows the senior and junior distribution of geology score plotted against spatial manipulation .................................... 16

Figure 8. shows the senior and junior distribution of geology score plotted against visual penetrative ability ........................................ 17

Figure 9. The distribution of average geology score percent by gender and cohort ........ 19

Figure 10. The distribution of average geology score percent by major and cohort ........ 20
LIST OF TABLES

Table 1. An example of the changes made to a question after correspondence with an instructor.................................................................11

Table 2. shows total percentage of students in each demographic category divided by senior and junior group.........................................................18
LIST OF APPENDICES

Appendix 1. Material referenced, used or modified in the creation of the GSVS…………34
Appendix 2. The rationale behind specific geology question development pertaining to respective spatial visualization ability………………………………………………………………………………………………………34
Appendix 3. Modifications and changes made to the GSVS during the student validation process and with instructor feedback…………………………………………………………………………………………………………………………36
Appendix 4. Validation Interview Consent Form……………………………………………40
Appendix 5. The final version of the Geologic Spatial Visualization Survey that was administered to the junior and senior cohorts…………………………………………………………………………………………………………………………….43
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INTRODUCTION

Spatial visualization is a fundamental ability that geoscientists must possess in order to represent, reproduce, manipulate, or reason about objects or processes in three dimensional space. This ability is used in rotating, translating or visualizing objects or shapes within a geological context. Geoscientists utilize this ability in a variety of field tasks such as mapping or creation of cross-sections (Kastens et al., 2009). Particular areas of study within geology that require spatial visualization are structural geology and field geology. Structural geologists study deformation and related structures on the surface of and within the earth’s crust. Field geologists map and produce cross sections characteristic of an area. To do these spatial visualization tasks, a geoscientist is required to visually translate surface features into an interpretation of what occurs at depth.

Although spatial visualization abilities are vital to geoscientists, many students struggle with spatial tasks. One factor that contributes to their difficulties is that not all students enter a geology degree program with the same “pre-program” abilities and as a result these abilities are unevenly distributed within a given student cohort (Kali and Orion, 1996). Pre-program ability describes the skill level that a student possesses as he or she enters a degree program. Students who have poor pre-program abilities may do poorly in courses or programs that require extensive spatial visualization abilities and subsequently transfer programs (Sorby, 2005). Titus and Horsman (2009) also note a correlation between those who score poorly on spatial visualization tests and those who have poor grades. These studies suggest that those spatial visualization abilities bear on students’ comprehension of spatially intensive geology questions.

Spatial visualization or reasoning is not a uniform or undifferentiated skill; there is more than one type of spatial ability. This thesis differentiates between three types of spatial visualization abilities: spatial relations, spatial manipulations and visual penetrative ability (Figure 1).
Figure 1. shows the three spatial visualization abilities being studied: spatial relations, spatial manipulation, and visual penetrative ability (Titus and Horsman, 2009).

Spatial relations, as tested by the Purdue Visualizations of Rotations Test (PVRT), refer to the ability to mentally rotate an object about its axis. Spatial relations is a skill that is relevant to geological problems such as crustal block rotation or moving fault hinges on a stereonet (Titus and Horsman, 2009). Secondly, spatial manipulation is the ability to mentally manipulate or transform an image into another arrangement (Ekstrom et al., 1976). Spatial manipulation is useful in structural geology to envision how a rock deforms or folds (Titus and Horsman, 2009). Finally, visual penetrative ability is the ability to mentally “penetrate” or visualize what is inside a solid object. This ability is typically used to examine cross sections, thin sections, or road cuts (Titus and Horsman, 2009).
In this thesis, I test three components of students’ spatial visualization abilities (spatial relations, spatial manipulation, and visual penetrative ability) along with geology questions that utilize these three spatial abilities. The geology questions are consistent with course learning goals specific to the Field Techniques (EOSC 223) or instructor defined key skills specific to Structural Geology I (EOSC 323) courses at The University of British Columbia. I developed a test, the Geological Spatial Visualizations Survey (GSVS), to quantify students’ spatial visualization abilities at two different points in their program: (1) before taking EOSC 223 and (2) after taking both EOSC 223 and EOSC 323. Not only is the students’ spatial visualization abilities (spatial relations, spatial manipulation and visual penetrative ability) tested, but it is tested at the same time that their “geologic” spatial reasoning is tested.

Although there is a continuum between expert and novice abilities (Petcovic and Libarkin, 2007), I isolated the two groups (junior and senior) based on whether or not they had completed EOSC 223 and EOSC 323. My hypothesis is that the senior group will have more expert characteristics that do not rely on memorization and a greater aptitude in recognizing of geologic patterns (Petcovic and Libarkin, 2007). As a result, the senior cohort should be able to outperform the junior cohort on novel geology questions that have not been presented to them in course material.

The GSVS was administered to junior and senior cohorts to measure the differences in general spatial reasoning and geologic spatial reasoning within these two cohorts. I also determined whether or not there was a link between performance on spatial visualization and the respective geologic tasks that utilize spatial visualization with a focus on key differences between the junior and senior groups. The results of the GSVS were also analyzed to determine which spatial visualization ability could best predict the geology score outcome. Demographic factors such as gender or major were also accounted for in both cohorts and the results were analyzed for gender studies.
PREVIOUS WORK

Numerous investigations examine spatial visualization abilities within geology and other scientific fields. Many of these studies are used to evaluate possible reasons for underrepresentation of females in fields such as cartography, structural geology, engineering and architecture (Sorby, 2005; Petty and Rule, 2008). Many of these same studies also confirm a link between general spatial visualization performance and respective class performance in engineering and geology courses (Sorby, 2005; Petty and Rule, 2008; Titus and Horsman, 2009). Despite the evidence that spatial visualization is important for many scientific fields, spatial reasoning is commonly overlooked in the K-12 curriculum. As a result, undergraduate students may enter college or university unprepared for the visualization tasks they are given (Petty and Rule, 2008). To counter this problem, geoscience educators must identify the specific spatial visualization abilities that students utilize in geology problem solving and remedy these weaknesses.

Spatial Relations

The Purdue Visualizations of Rotations Test (PVRT) is the most established spatial reasoning test available. The PVRT tests spatial relations, which is the ability to mentally rotate an object about its central axis (Titus and Horsman, 2009). In comparison to the other spatial visualization components mentioned (spatial manipulation and visual penetrative ability), spatial relations shows the greatest gender disparity (Bodner and Guay, 1997; Black, 2005; Titus and Horsman, 2009). The PVRT is employed in a number of scientific disciplines to test general spatial reasoning which includes geology, chemistry and engineering (Black, 2005; Bodner and Guay, 1997; Sorby, 2005). Bodner and Guay (1997) argue that the PVRT measures Gestalt processing which is the key cognitive component of spatial ability while analytic processing is not. Gestalt processing occurs when an individual transforms a visual image as an organized whole in the same way people recognize faces. Analytic processing occurs when a whole object is broken into parts and subsequent relationships are mapped step by step on a one to one basis (Bodner and Guay, 1997). Although Bodner and Guay (1997) argue that the short time limit (10 minutes for 20
rotations) for the PVRT does not allow for a step by step analysis of a given rotation, it is possible that some students may still have the thinking skills to do the problem step by step within the time limit. Problems in geology do not necessarily require instant (gestalt) perceptions, and it is acceptable to work through problems step by step. One spatial reasoning task that can be done step by step is spatial manipulation.

Spatial Manipulation

Spatial manipulation is the ability to mentally manipulate or transform an image into another arrangement (Ekstrom et al., 1976). The spatial manipulation task within the GSVS uses the visualization of how a piece of paper can be folded to form a 3D object. Unlike the PVRT, this task can be done step by step by mentally folding one piece at a time in a series of operations or transformations (Lord, 1990). Spatial manipulation may also be described as a multistep manipulation of spatially processed information that is used in conjunction with spatial relations or spatial perception which is the ability to determine orientation with respect to one’s own body (Black, 2005). Poor spatial manipulation abilities have been correlated with poor academic performance in the sciences (Lord, 1990; Titus and Horsman, 2009). Spatial manipulation is the general spatial reasoning ability that is least correlated by gender differences (Black, 2005; Titus and Horsman, 2009). This ability can also be improved throughout the school year provided the curriculum involves spatially orientated geology questions (Baldwin and Hall-Wallace, 2005; Titus and Horsman, 2009).

Visual Penetrative Ability

Visual penetrative ability is the ability to mentally “penetrate” or visualize what is inside a solid object. Bisecting a three-dimensional geometric figure and envisioning the two dimensional slice or surface formed by the bisection is an example a visual penetrative task (Lord, 2006). This ability is utilized within a geologic context when a student translates surface features into features that occur at depth such as in a cross section or road cut. Visual penetrative ability coupled with other spatial abilities has been tied to students’ ability to answer questions pertaining to geologic cross sections (Kali and Orion, 1996; Titus and
Horsman, 2009). Lord (2006) and Titus and Horsman (2009) suggest that visual penetrative ability can be improved with repeated testing throughout a school year.

The two-way relationship between studying Geology and Spatial Visualization

Orion et al. (1997) suggest there is a two-way relationship between studying geology and spatial visualization skills. This two-way relationship shows the study of geology itself may improve general spatial visualization skills. As a result, this relationship may transfer to a variety of disciplines. The following questions asked in previous studies are also asked in this study. What is the link between general spatial reasoning and geologic spatial reasoning? How do the abilities of students to do general and geologic spatial reasoning tasks improve with education? In Titus and Horsman’s (2009) study, they administered a pre and post visualization test to a beginner geology class and an upper-level geology course (Structural Geology). The pre and post mean test scores for the senior students were higher than that of the junior students. This suggests that students at different points in their geology education have differing spatial visualization abilities. The p-values for the pre test compared to the post test were statistically significant (<0.05) for all three of the spatial visualization tasks in all three of the courses (Introductory Geology, Tectonics and Structural Geology) they administered the visualization test to. These p-values suggest that geology students’ spatial visualization abilities also improve from when they took the test initially at the start of the course compared to the scores of when they took it near the end of the course.

DEVELOPMENT OF THE GEOLOGICAL SPATIAL VISUALIZATIONS SURVEY

There were two phases in the development of the GSVS: (1) Spatial visualization question selection and (2) Development of geology questions that utilize spatial visualization abilities. In phase one of the development of the GSVS, spatial visualization tasks were examined to determine which ones were best suited to spatial reasoning tasks within a geologic context. During this process, I found studies involving spatial reasoning tasks related to other scientific fields such as chemistry or engineering (Bodner and Guay, 1997;
Sorby, 2005). To narrow down my question selection, I decided to focus on spatial visualization tasks that other geosciences educators had already considered (Kali and Orion, 1996; Black, 2005; Titus and Horsman, 2009). After considering several spatial visualization tasks in various studies, I decided to select the spatial visualization question kit used in the Titus and Horsman (2009) study. I choose this question kit because it had three different spatial visualization tasks specifically pertaining to key geologic abilities (Kali and Orion, 1996; Black, 2005; Titus and Horsman, 2009). Another reason I chose this question kit is because it provides more spatial visualization skill variables to consider since it tests three different components of spatial visualization (spatial relations, spatial manipulation and visual penetrative ability). Using this question kit also allows me to compare my study results with other geosciences education researchers.

The spatial visualization section of the GSVS was used with permission from Titus and Horsman (2009). This spatial visualization question kit is composed of ten spatial relations multiple-choice questions, twenty “fill in the blank” spatial manipulation questions and fifteen visual penetrative ability multiple-choice questions. I validate the spatial visualization kit that Titus and Horsman (2009) have provided and also develop the geology specific section. The references for any material used or adapted to create the GSVS are shown in Appendix 1.

Phase two of the development of the GSVS is the process of selecting, modifying or creating geology questions that utilized particular spatial visualization abilities. This phase can be summarized in four steps: (1) Chose questions based on instructor defined key skills, (2) Develop and select geology questions that use spatial visualization abilities, (3) Modify questions after correspondence with instructors of EOSC 223 and 323, and finally, (4) Validate questions based on analysis of think-aloud interviews with students (Figure 2). Step 4 was an iterative process and there were ten versions of the GSVS and three versions of the answer key before it was considered finalized. Not all components of the test were completed in the outlined step order. These steps were taken after considering the precedent set by other geosciences education researchers (Charters, 2003; S. Harris, personal communication, 2010).
Step 1: Choosing questions based on instructor-defined Key Geology Skills

To ensure that the GSVS was relevant to the geologic curriculum at UBC, the course-level learning goals for EOSC 223 were consulted to develop appropriate questions that address key course goals and involve spatial abilities (Bevier, 2010). One of the course learning goals of EOSC 223 is to develop a student’s ability to create geologic maps and cross sections. Questions pertaining to geologic cross sections were added to the GSVS in Part IV question 4, and in Part V questions 1, 2, 3, and 4 (Appendix 2).

There were no existing explicit learning goals for EOSC 323, but after personal communication with the instructor, Bram van Straaten (2010), questions that were relevant to key concepts in the course were established. For example: Part IV Question 6 was derived from the 2008 EOSC 323 final exam and Part IV Question 7 was derived from the 2009 midterm exam (B. van Straaten, personal communication, 2010).
Step 2: Develop Geology questions that utilize Key Skills

Since one of the purposes of the GSVS was to measure how spatial visualization tasks are tied to specific geology related spatial reasoning tasks, the geology questions I could chose were restricted. For example, one geology task related to visual penetrative ability is sketching a cross-section of a slice through a geologic block. Visual penetrative ability questions were chosen because it is an ability that allows students to utilize the skills required to visualize slices in a geologic context (Figure 3).

2. The following block diagram shows folded stratigraphy that is plunging downwards. Please sketch in the box to the right a slice through the block indicated by the dotted line. Don’t forget to sketch the textures in the different layers.

![Diagram](image.png)

Figure 3. An example of a geology task that utilizes visual penetrative ability in the GSVS.

Spatial manipulation is the ability to fold, bend or manipulate an image into another arrangement and within the GSVS, structural geology questions utilize this spatial visualization ability (Figure 4). Lastly, some questions involving rotational rock deformation were used in the geology section of the GSVS to correspond to spatial relations. A list of the geological spatial reasoning questions with their corresponding spatial visualizations task is in Appendix 2.
5. In the diagram on the left, a rigid geological layer is folded by a neutral surface folding mechanism. Where does stretching and compression occur in the fold? The locations are indicated by x and y.
   a) Features at point x experience compression while features at point y experience stretching.
   b) Features at point x and y both experience compression
   c) Features at point x and y both experience stretching
   Features at point x experience stretching while features at point y experience compression.

Figure 4. An example from the GSVS showing what would be considered a geologic task utilizing spatial manipulation ability.

Step 3: Modify questions after correspondence with the Instructors of EOSC 223 and 323

It was vital that my questions were related to the curriculum being taught because one of the questions being asked is how education improves geologic spatial reasoning.

Feedback from the instructors led me to modify several questions in the GSVS (Appendix 3). The following table (Table 1) shows an example of the changes made after correspondence.

<table>
<thead>
<tr>
<th>Before Correspondence:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress (shear) to the right</td>
</tr>
<tr>
<td>body of rock</td>
</tr>
<tr>
<td>Stress (shear) to the left</td>
</tr>
<tr>
<td>?</td>
</tr>
</tbody>
</table>

7. In the diagram above, a body of rock deforms plastically. Stress (to the right) is applied to the upper part of the body and stress (to the left) is applied to the bottom part of the body. How does this body of rock deform?
   a) The body of rock is stretched and elongated
   b) The body of rock is shortened and compressed
   c) The body of rock is first shortened and compressed then stretched and elongated
   d) The body of rock is first stretched and elongated then shortened and compressed

Instructor Feedback on Question:
“Certain material lines in this body of rock will get shorter during instantaneous
deformation, whereas other material lines will get longer. This obviously changes as deformation proceeds, resulting in some lines that are first shortened and then elongated. If you would draw a line along the long axis of the rock body and change your question to how the LINE is deformed, your question would be correct. However, if you would draw a line along the short axis of the body of rock then this line would first get extended, then shortened.” (B. van Straaten, personal communication, 2010).

<table>
<thead>
<tr>
<th>Change made to Question:</th>
</tr>
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<tbody>
<tr>
<td>I added a material line (a vein) to correct my question.</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>After Correspondence:</th>
</tr>
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<tbody>
<tr>
<td>7. In the diagram above, a body of rock deforms plastically. Stress (to the right) is applied to the upper part of the body and stress (to the left) is applied to the bottom part of the body. How does the vein in this body of rock deform?</td>
</tr>
<tr>
<td>a) The vein is stretched and elongated</td>
</tr>
<tr>
<td>b) The vein is shortened and compressed</td>
</tr>
<tr>
<td>c) The vein is first shortened and compressed then stretched and elongated</td>
</tr>
<tr>
<td>d) The vein is first stretched and elongated then shortened and compressed</td>
</tr>
</tbody>
</table>

Table 1. An example of the changes made to a question after correspondence with an instructor.

Step 4: Validating the GSVS based on the results of the Think-Aloud Interviews

Think-aloud interviews provide crucial information about participants’ thinking during a language based activity or test (Charters, 2003). These interviews are conducted to observe the inner dialogue of the validation participants to determine how they reason through any particular question (Charters, 2003). During a think-aloud interview, a student is asked to vocalize their thought process while completing the questions. These interviews help validate any given assessment because it is a way of ensuring that the questions in the assessment were understood by the students for the intended purposes (Sireci, 2007). A common problem with assessments that are not validated is that the question may be misinterpreted by the student and as a result, the assessment does not accurately evaluate the students’ knowledge or skills (Messick, 1989). Some examples of problems with unvalidated tests are wording problems in grammar or vocabulary or uncertainty in what the
question itself is asking (Messick, 1989). Since the GSVS has been validated, any results from the test can be interpreted without the problems outlined above and interpreted with little concern about miscommunication issues (Sireci, 2007).

Ten students participated in the validation process. Seven were recruited by the instructor emailing the students of EOSC 110 and three were recruited through personal correspondence through the department. The seven students in EOSC 110 were chosen because they had enough of a background in geology to understand the most basic geological terminology because the validation process was occurring near the end of that course. Only one first year geology course is required as a prerequisite for taking EOSC 223 so it was comparable to students just entering EOSC 223 (comparable to my beginner level study group). The three students chosen through department correspondence were chosen because they were fourth year students close to completing their earth and ocean science degrees. These three students are comparable to the senior level study group who wrote the GSVS. More beginner students were chosen for this process because they are more likely to have difficulties in comprehension in the geology-specific portion of the survey. Senior students were chosen because they are more likely to notice errors or ambiguities in the geology questions because they have taken more geology courses. By including students of both levels (junior and senior) in the validation process, I have ensured that students at both levels interpret the questions in the same way.

The spatial visualization section of the GSVS used the same questions and timing as used by Titus and Horsman (2009). The GSVS was designed to take 30 minutes to minimize class time needed for test administration. The validation process also helped me to gauge how much time I should allow the students to take the geology sections (Part VI and V). The finalized GSVS has a total of five timed sections: 3 minutes for parts I, II and III (the spatial visualization kit), 4 minutes for part IV (multiple choice) and 10 minutes for part V (sketching). Some time was allotted for reading instructions on how to complete the spatial visualization tasks since some students had trouble understanding the spatial visualization tasks during the validation process.

This survey was conducted in accordance with the Tri-Council Policy for the Ethical Conduct for Research Involving Humans (TCPS) within the Carl Wieman Science Education
Initiative (CWSEI). Each student signed a standard consent form (Appendix 4) and received $15.00 compensation for their time. Each interview was conducted in private and lasted 25 to 45 minutes. These interviews were recorded and the audio files were kept with the guarantee any personally identifiable information would be kept in confidence.

Step four of the development of the GSVS was an iterative process with questions being added and deleted throughout (Figure 2). The test changes that occurred during Steps 2 through 4 are documented in Appendix 3.

Administering the validated GSVS

The finalized GSVS (Appendix 5) was administered to a junior level class (EOSC 223, n=62) and to two senior level classes (EOSC 332 and 328, combined n=31). These two groups were selected for formal administration of the test in order to compare and contrast a group of students that had already taken EOSC 223 and 323 (the “senior” group) with a group of students that had not yet completed EOSC 223 and 323 (the “junior” group). Students in EOSC 332 and 328 were selected because the prerequisite courses were EOSC 223 and 323.

Students in EOSC 223 and EOSC 328 were given a paper copy of the GSVS (Appendix 5) and were asked to complete it in class time as part of the participation marks for the course. Students in EOSC 332 took the GSVS outside of class time for a bonus percent in that course. Each part of the GSVS was timed. Tests were filled out by hand, each particular answer was entered into a dataset and the marks were tallied digitally.

Demographic information collected included gender, major, specific EOSC courses taken in the past, and whether or not they were a transfer or exchange student. Students were asked to mark boxes next to all those courses that they had taken in the past: EOSC 110, 111, 112, 114, 116, 223, 323, 328 and 332. These courses were listed to obtain a general overview of a student’s background in geology along with the courses presumed to improve student’s spatial visualization abilities. This demographic survey was placed on the last page of the GSVS as to prevent any chance of stereotype threat (Stone and McWhinnie, 2008; J. Caulkins, personal communication, 2010). Even asking the gender of the participant may be a subtle stereotype threat cue (Stone and McWhinnie, 2008).
RESULTS

Senior Students outperform Junior Students in both Geology and Spatial questions

Senior students in EOSC 332 and 328 scored significantly higher in the geology part of the test than those enrolled in EOSC 223 (two tailed p <0.001; Figure 5). The mean geology score of the senior group was 67% while the mean geology score of the junior group was 47%. Senior students also scored significantly higher in all three components of spatial visualization combined (two tailed p = 0.002; Figure 5). The mean spatial visualization score of the senior group was 54% while the mean spatial visualization score of the junior group was 43%.

For the combined junior and senior groups, geology and spatial visualization score are positively correlated ($R^2 = 0.40$, linear slope = 0.68±0.09). Regression analysis done for both groups separately yielded positive correlations in both the junior group ($R^2 = 0.38$) and the senior group ($R^2 = 0.28$). The slope of the regression line for the junior group was 0.61±0.10, while the slope of the regression line for the senior group was 0.50±0.16.

![Geology Score Vs. Spatial Visualization Score](image)

Figure 5. Distribution of the geology score against the distribution of the spatial visualization score. The red dots representing the senior students cluster near the upper right quadrant of the graph because they have overall score higher in the geology portion and the spatial visualization part of the GSVS.
Each Spatial Visualization Ability separately correlated with Geology Score

Although Figure 5 shows the general overview of all three spatial visualization abilities combined, regression plots of spatial relations (rotations), spatial manipulation (folding) and visual penetrative ability (slicing) were also created. These particular plots were created to discover which particular spatial visualization ability correlated closest to geology score.

Spatial Relations correlated with Geology Score

Regression analysis on spatial relations plotted against geology score was done for both groups combined ($R^2 = 0.17$ and slope $= 0.34 \pm 0.079$). Figure 6 shows the distribution of geology score and spatial relations of both senior and junior groups along with the respective group $R^2$ values and regression lines. Senior students also scored higher in the spatial relations part of the test. There was no statistically significant mean score differences in spatial relations between the junior and senior groups ($p = 0.8$). The mean spatial relations score of the senior group was 55% while the mean spatial visualization score of the junior group was 47%. The two-tailed p-value was close to being statistically significant, but as Figure 6 shows, the junior and senior scores were scattered throughout and were not clustered like in Figure 5.

Figure 6. shows the senior and junior distribution of geology score plotted against spatial relations.
Spatial Manipulation correlated with Geology Score

Regression analysis on spatial manipulation plotted against geology score was done for both groups combined ($R^2 = 0.31$ and slope $= 0.42\pm0.063$). Figure 7 shows the distribution of geology score and spatial manipulation of both senior and junior groups along with the respective group $R^2$ values and regression lines. There was a statistically significant difference in the mean scores of spatial manipulation between junior and senior students ($p < 0.001$). The mean spatial manipulation score of the senior group was 52% while the mean spatial visualization score of the junior group was 35%. Among the three spatial visualization tasks being tested, spatial manipulation was the best predictor and correlate to geology score.

![Spatial Manipulation Vs. Geology Score](image)

Figure 7. shows the senior and junior distribution of geology score plotted against spatial manipulation.

Visual Penetrative Ability correlated with Geology Score

Regression analysis on visual penetrative ability plotted against geology score was done for both groups combined ($R^2 = 0.22$ and slope $= 0.48\pm0.95$). Figure 8 shows the distribution of geology score and visual penetrative ability of both senior and junior groups along with the respective group $R^2$ values and regression lines. The mean visual penetrative ability score of the senior group was 57% while the mean visual penetrative ability score of the junior group was 50%. The two-tailed p-value was not statistically significant between
the groups ($p = 0.1$). The distribution of the junior and senior points were scattered like in spatial relations and were not clustered like in spatial manipulations, which had senior students clustering in the upper right quadrant of the graph (Figure 7).

![Geology Score Vs Visual Penetrative Ability](image)

Figure 8. shows the senior and junior distribution of geology score plotted against visual penetrative ability.

**Geology Question Outcomes matched to specific Spatial Visualization Ability**

One of the purposes of the GSVS was to measure how spatial visualization tasks are tied to specific geology tasks that utilize spatial visualization. For example, one geology task that utilizes visual penetrative ability is sketching a cross-section of a slice through a geologic block. Each geology question on the GSVS was tied to specific spatial visualization ability and the reasoning behind the relationship between a particular geology question and spatial visualization task was outlined in Appendix 2.

Regression analysis was performed for the specific spatial visualization task score and its corresponding specific geology question score. Regression analysis on spatial relations plotted against specific geology question scores (pertaining to spatial relations) was done for both groups combined. The combined $R^2$ value was 0.15 and the slope was $0.49 \pm 0.12$. Although it was a positive correlation, the $R^2$ value was lower than using spatial relations to predict all of the geology questions being asked on the GSVS.
Regression analysis on spatial manipulation plotted against specific geology question scores (pertaining to spatial manipulation) was done for both groups combined ($R^2 = 0.27$, slope = 0.42±0.072). Once again, it is noted that spatial manipulation was the best correlate to geology score compared to spatial relations or visual penetrative ability. Although it is the best correlate to geology score in this second set of regression analysis, it still has a lower $R^2$ value than when I plotted spatial manipulation against all geology questions ($R^2 = 0.31$).

Regression analysis on visual penetrative ability plotted against specific geology question scores (pertaining to visual penetrative ability) was done for both groups combined ($R^2 = 0.19$, slope = 0.47±0.10). The $R^2$ value for this analysis was similar to the $R^2$ value in the previous analysis ($R^2 = 0.22$) when visual penetrative ability was plotted against all geology questions.

Demographic Considerations

T-tests were done to determine whether differences in demographics might account for the patterns observed. The demographics of interest were gender, and major type in the senior and junior groups (Table 2).

<table>
<thead>
<tr>
<th></th>
<th>Male (%)</th>
<th>Female (%)</th>
<th>Geology (%)</th>
<th>Engineering (%)</th>
<th>Other (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Junior Group</strong></td>
<td>62</td>
<td>38</td>
<td>39</td>
<td>54</td>
<td>7</td>
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<tr>
<td><strong>Senior Group</strong></td>
<td>58</td>
<td>42</td>
<td>74</td>
<td>19</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2. shows total percentage of students in each demographic category divided by senior and junior group.

**Gender Studies**

There was no significant statistical difference in geology score between genders (Figure 9). In the junior group, the means were 47% and 48% for females and males respectively ($p = 0.79$). In the senior group, the means were 66% and 68% for females and males respectively ($p = 0.43$; Figure 9).
A t-test was also done on spatial visualization score divided by gender for junior and senior groups combined. The mean spatial visualization score was 43% for females while it was 49% for males. The two-tailed p-value was almost statistically significant at 0.08 so there is not clear cut statistically significant score difference for the combined groups based on gender. Further analysis was carried out to determine the cause or specific spatial visualization ability that caused the difference in mean percentage separated by gender. The two-tailed p-values for spatial relations, spatial manipulation and visual penetrative ability were <0.001, 0.95 and 0.15 respectively. The difference in gender performance in the combined spatial visualization scores is attributed to the difference between the mean percentage in spatial relations of female (37%) and male (57%) students.

**Comparisons by Major**

There were significantly more engineers in the junior group (54%) than in the senior group (19%). There was no statistically significant difference in geology score between engineers and geologists when both groups were combined (p = 0.38). The mean geology score was 51% for engineers while the geology score was 55% for geologists. Similarly, there was no statistically significant difference in visualization score between geologists and engineers when both groups were combined (p=0.99). To further investigate if major skewed
particular cohort results, t-tests were done on geology and visualization score in junior and senior groups between engineers and geologists (Figure 10). There was no statistically significant difference in the geology score between engineers and geologists in the junior (p = 0.41) or senior (p = 0.92) cohorts. Similarly, there was no statistically significant difference in spatial visualization score between engineers and geologists in the junior (p = 0.16) or senior (p = 0.79) cohorts.

![Geology Score By Major](image)

Figure 10. The distribution of average geology score percent by major and cohort.

**DISCUSSION**

**Evaluating the Predictive Power of Spatial Visualization**

*Senior Group Spatial Visualization does not predict Geology Score as effectively*

Senior students scored significantly higher in the geology and in the spatial visualization parts of the GSVS. There was a positive correlation between spatial visualization abilities and geology tasks that utilized spatial visualization abilities. The $R^2$ value was 0.40 for junior and senior groups combined, but when both groups were separated, the overall $R^2$ value decreased to 0.28 and 0.38 for the senior and junior groups respectively.
In the senior group, the predictive ability of all three spatial visualization tasks combined is lower than that of the junior group. This can be interpreted to mean that as students go through the UBC geology program their overall geology performance improves more than their overall spatial visualization. Further support for this interpretation is found in observing the range of geology scores in Figure 5. Several junior individuals had lower geology scores than the lowest senior individual and several senior individuals had higher geology scores than the highest junior score. This implies that at least the upper and lower ranges of the scores are what one would expect from student improvement during their geology education.

*Spatial Visualization ability threshold for high Geology Score*

Another interesting observation about the data in Figure 5 is that some senior students with mediocre spatial visualization scores still have high geology score. There are at least four senior students who have high geology scores ($\geq 80\%$) with a corresponding mediocre spatial visualization score ($40\%$ to $60\%$). With the exception of a few outliers, students with poor spatial visualization ($\leq 40\%$) never have good geology scores ($\geq 70\%$). This suggests that as long as some threshold for spatial visualization ability is met, students can perform very well in geology questions that utilize spatial visualization. This threshold would be a score of $40\%$ to $60\%$ on the spatial visualization part of the GSVS.

*The range of Spatial Visualization is similar for both cohorts*

Although the means of the combined spatial visualization were statistically significant between junior and senior students ($p \leq 0.003$), the ranges of the two groups are nearly identical (Figure 5). One interpretation is that the majority of the junior students improve their visualization skills in the next year or two of the program. Some at the low end do not improve and those in the junior group at the high end retain their good spatial abilities. Another interpretation is that the average improvement is not significant and the observed difference is due to students with poor geology and spatial visualization abilities leaving the program. In previous studies, students with poor visualization abilities have
difficulty with program requirements that utilize spatial visualization skills and have even left programs because of this difficulty (Sorby, 2005).

When spatial visualization abilities are analyzed separately, the respective ranges are different (Figure 6, 7, and 8). The range of spatial relations points was nearly identical for both groups. Furthermore, spatial relations scores between groups is the least well correlated to geology scores and there was no statistical difference between the cohorts. In contrast, there were eight students in the junior cohort that scored lower in spatial manipulation than the lowest senior score. Similarly there were four students in the junior cohort that scored lower in visual penetrative ability than the lowest senior score. The best predictor of geology score (spatial manipulation) also had the greatest improvement in range among the senior cohort. This suggests that spatial manipulation is the visualization ability that improves the most with education.

Spatial Manipulation: Greatest improvement between cohorts

Spatial manipulation score outcome is the closest correlate to geology score outcome compared to the two other spatial visualization abilities tested. Furthermore, the discussion in the last section suggests that this is the visualization ability that improves the most with education. My results are similar to the results of other studies as Baldwin and Hall-Wallace (2005) and Titus and Horsman (2009) also found that spatial manipulation could be improved throughout the school year provided the curriculum involved spatially intensive geology questions. Orion et al. (1997) suggest there is a two-way relationship between studying geology and spatial visualization skills: the study of geology itself may improve general spatial visualization skills. My results support this idea of a two-way relationship between the study of geology and spatial visualization abilities.

Specific Geology questions that utilize specific Visualization abilities

Contrary to one of my hypotheses, the spatial visualization tasks selected to predict performance on related geology tasks were not better predictors than using the spatial visualization task to predict the scores of the entire geology section of the GSVS. For example, using visual penetrative ability to predict the geology score of the entire geology
section for both groups combined yielded a higher correlation ($R^2 = 0.22$) than using that ability to predict specific geology question scores utilizing visual penetrative ability ($R^2 = 0.19$). This was an unexpected result because my hypothesis was that visual penetrative ability (slicing) would correlate more closely to questions involving cross-sections. This was also observed with spatial relations correlated to (entire geology part of the GSVS: $R^2 = 0.17$, specific geology questions: $R^2 = 0.15$) and spatial manipulation correlated to (entire geology part of the GSVS: $R^2 = 0.31$, specific geology questions: $R^2 = 0.27$).

When all three spatial visualization components are taken together, it is a good correlate to geology score ($R^2 = 0.40$), but when specific geology questions are compared to specific spatial visualization abilities, the relationship is positive but result in less correlation. The fact that it correlates less and not more is a question that is broader than the scope of my thesis. Further investigation is needed to figure out why this is the case. The correlations are positive, so spatial visualization tasks are related to geology questions, but the specific problems in which the students utilize these abilities were not determined in this thesis.

**Comparing my Results with the Results of other Geoscience Researchers**

*Greater Spatial Visualization improvement between cohorts in Titus and Horsman (2009)*

In Titus and Horsman’s (2009) study, there was statistically significant improvement in spatial visualization scores of the pre tests compared to the post tests of one given student cohort within the following courses: Introductory Geology, Tectonics and Structural Geology. Similarly, in Orion et al. (1997), a pre and post visualization test was administered to an introductory geology course. In my thesis, I do not track the progress of individuals; rather, I compare two cohorts at different points in their geology education program. Furthermore, my thesis differs from these studies as I did not only test spatial visualization; I tested geology concepts along with spatial visualization.

Although Titus and Horsman (2009) did not focus on comparing junior and senior groups, they do have comparable group data. The post test for Introductory Geology in Titus and Horsman’s (2009) study is comparable to the results of my junior group which was a pre test for Field Techniques since there was only one pre-requisite which is a first year or
introductory geology course. The means of the post test for Introductory Geology were 41%, 50% and 46% for spatial relations, spatial manipulation and visual penetrative ability respectively. My junior mean scores were 47%, 35% and 50% and my senior mean scores were 55%, 52% and 57% for spatial relations, spatial manipulation and visual penetrative ability respectively. My senior group was comparable to Titus and Horsman’s (2009) post Structural Geology group results because I based my senior cohort on students that had taken both Field Techniques and Structural Geology. Typically those who have completed Structural Geology have taken at least one field course (S. Titus, personal communication, 2010). Titus and Horsman’s (2009) post test means for Structural Geology were 61%, 73% and 63% for spatial relations, spatial manipulations and visual penetrative ability respectively. The increase in percentages between Titus and Horsman’s (2009) junior and senior cohorts are much greater than in my junior and senior cohorts.

Accounting for institutional differences in Spatial Visualization score gains

This significant difference in study results could be explained by the fact that Titus and Horsman (2009) have administered this test in more than one class. As a result, students have had a chance to familiarize themselves with spatial visualization tasks. Students (n=28) in their study group have taken the visualization survey four times as a result of taking two out of the three possible courses that they administer the visualization test to (Titus and Horsman, 2009). Studies have shown that repetitively administering the same test to students result in better performance (Roediger and Karpicke, 2006). This improvement in performance with repeated testing occurs even when no studying time is allowed in between taking these tests. So the very act of taking the test again improves the performance (Roediger and Karpicke, 2006). Another possible reason for the greater increases in performance in the Titus and Horsman (2009) cohorts is that their educational institution is different. The University of British Columbia is a large research university, while Carleton College is a smaller, private liberal arts college.
**Spatial Relations versus Spatial Manipulation as best predictor of Geology score**

In the Black (2005) study, spatial visualization tasks were tested along with a developed geology test: Earth Science Concepts (ESC). The ESC was developed after considering the Earth Science misconception and conceptual difficulties literature (Black, 2005). In their study, spatial relations was the best predictor of Earth Science Concepts (ESC) score results ($p < 0.01$ and $R^2 = 0.52$). Similarly, I developed the GSVS considering multiple spatial visualization tasks (spatial relations, spatial manipulation and visual penetrative ability). Unlike Black (2005), however, I found spatial relations to be the least correlated to geology score performance ($R^2 = 0.17$) compared to the other two visualization tasks in my study.

This difference could be accounted for by differing research goals: I designed the GSVS to specifically test Field Techniques and Structural Geology concepts, while the ESC was much broader and tested four different areas of Earth science. Some examples of the topics given on the ESC: causes of seasons, moon phases, tides, map projections, aerial photo interpretation and geologic block diagrams. Furthermore Black (2005) compare spatial relations to spatial perceptions and spatial visualization. I did not test spatial perception and the spatial visualization questions she used differed from the ones I used. It may be the case that if Black (2005) were to use the exact same spatial visualization kit I used, she would find that spatial relations was the least correlated.

**Gender Studies**

*No difference in Geology Score between Genders*

There were a similar number of female and male students in each cohort. There was no statistically significant difference in mean geology scores separated by gender in the junior or senior cohorts. This outcome suggests that there is nothing happening in the UBC geology program that is advantaging or disadvantaging either gender with regard to development of these spatially intensive geology skills.
Only Spatial Relations differ between Genders

There was no statistically significant difference in combined spatial visualization score or spatial manipulation or visual penetrative ability examined separately. Only spatial relations scores were different between genders. This gender disparity is noted in all spatial relations or rotations studies (Bodner and Guay, 1997; Black, 2005; Titus and Horsman, 2009). Although men out performed women in spatial relations (p <0.001), this result has little bearing on geology score in either cohort. Moreover, spatial relations was the least effective predictor of geology score. In the previous work section, the spatial relations (rotations) test was used to measure Gestalt ability which does not allow for a step by step analysis of a given rotation. Furthermore, the most effective predictor of geology score was spatial manipulation which does allow for a step by step analysis of folding. My results suggest that spatially intensive geology problems utilize step by step analysis abilities more than Gestalt abilities.

Recommendations for future investigation

Cohort or individual tracking of Geology or Spatial Visualization Scores

Differing student cohorts are ideally comparable if the background courses, gender and major are similar. Neither gender nor major differences within either cohort affected my mean results despite the fact that there were many more engineers in the junior group than in the senior group. Although comparing pre and post test scores for the same individual avoids potential errors arising from demographic differences, it has been shown that the GSVS was not significantly skewed by these differences. In the future if the GSVS was administered as a pre and post test for the same group, one could track individual progress. The gains in spatial visualization could then be monitored for an individual continuously through their program like in Titus and Horsman (2009).
Future changes to the GSVS based on observations of previous studies

In the future, I would either administer the entire spatial visualization kit by itself, or administer each component of spatial visualization with its corresponding geology question as three separate tests. In Titus and Horsman (2009), the spatial visualization kit was administered by itself and research was done focusing on spatial visualization itself and not how it relates to specific kinds of geology questions (like cross sections or rotational deformation). In Kali and Orion (1996) research was done specifically on how visual penetrative ability could predict the geology scores of questions that specifically utilized this ability (cross sections, completing blank faces of block diagrams). They had 13 open ended questions pertaining to visual penetrative ability as opposed to my four open ended and single multiple choice question. The GSVS could be improved by cutting out one or two spatial visualization tasks and adding more geology questions that pertain to the task(s) that are left.

Future changes to the GSVS based on my Results

The most problematic part of the GSVS was the part pertaining to spatial relations. Spatial relations was the least statistically significant visualization task. This may have been the case because there were only three corresponding geology questions (Appendix 2). Spatial manipulation and visual penetrative ability, on the other hand, showed more promising results. These two spatial visualization abilities had many more corresponding questions (Appendix 2) and had more statically significant results. In the future, I would either add more geology questions to the GSVS to be more representative of a particular visualization task or focus on one particular spatial visualization tasks and its corresponding geology task. Since spatial manipulations was the best predictor of geology score in a field or structural geology context, it is worth testing again with more questions to further define the geology questions that utilize this ability.
**Curricular Implications**

In previous studies, it was found that spatial visualization tasks were a good measure of spatial reasoning aptitude. This observation was thought to be important because students who struggled with spatial visualization tasks also struggled with course material that utilized spatial visualization abilities (Bodner and Guay, 1997; Black, 2005; Sorby 2005; Titus and Horsman, 2009). Similarly, I have found that spatial visualization was a good correlate to geology questions that utilizes spatial visualization abilities. This spatial visualization kit could be used to gauge student’s spatial visualization abilities.

Moreover, spatial manipulation by itself can be used to measure spatial visualization ability since it correlates the best with geology questions. If instructors were to administer the spatial visualization kit, it would only take 15 minutes of class time and expose potential weaknesses in students’ spatial abilities. If the instructor had little lecture time to spare, they could administer the spatial manipulation part of the survey which would take five minutes. The information gathered from these surveys can alert instructors as to which students could struggle with geology questions that utilize spatial visualization abilities. There are two compelling reasons to administer these spatial visualizations tests: (1) It has been shown in my study and in others that spatial visualization abilities can be improved with practice. (2) It has also been shown in my study and in others that students who performed poorly in spatial visualization tasks also struggled with problems that utilize spatial visualization abilities.

**CONCLUSION**

The GSVS was developed for a number of reasons. First of all, it was developed to explore potential differences in the visualization abilities of junior and senior geology students. Second of all, it was developed to determine which spatial visualization ability was the best correlate to geology score outcomes of spatially intensive questions, thirdly, to find a link between specific types of geology questions that utilize specific spatial visualization abilities. And finally, it was developed to explore gender differences within both cohorts.
Senior students scored significantly higher in the geology and spatial visualization parts of the GSVS. In the senior group, spatial visualization did not predict geology score as effectively. This may be due to a minimum threshold of spatial visualization ability being met to perform well in the geology portion of the test. In the future, educators could administer a spatial visualization kit such as the one found in the GSVS to improve students’ abilities to meet this minimum threshold.

Spatial manipulation was the best predictor of geology score which also had the most discrete range improvement among the senior cohort. There were a number of junior students who had a lower spatial manipulation score than the lowest senior student score. The best predictor of geology score is also the spatial visualization ability that improves the most with education in my study and in others (Baldwin and Hall-Wallace, 2005; Titus and Horsman, 2009).

Although there was a positive correlation between the scores of geology questions that utilized specific visualization tasks and the scores of the specific visualization task, the correlation was greater when a spatial visualization task was compared to the entire geology part of the GSVS. For example, visual penetrative ability scores were no better of a correlate to cross section geology question scores than comparing visual penetrative ability scores to the scores of the entire geology section. Spatial visualization correlates to spatially intensive geology questions but the specific types of geology questions that correlate closest with specific types of visualization abilities were not constrained.

There was no difference in geology score between genders. The only spatial visualization ability that differed between genders was spatial relations where males outperformed females. Spatial relations was the least effective predictor of geology score and had little bearing on the geology score outcomes.

The Geological Spatial Visualization Survey is a dual function assessment tool that can be used by instructors of spatially intensive geology courses: (1) to gauge students’ spatial visualization abilities (2) or as a skill development exercise tool. The information gathered from the GSVS exposes weaknesses in student’s abilities individually or as a whole. Spatial manipulation is the best predictor of geology score and it is also the spatial visualization ability that improves the most between junior and senior students in my study.
and in others. There is some impetus towards improving these abilities since those who performed poorly in spatial manipulation also performed poorly in geology tasks relevant to geology program requirements. The outlook on my results is positive as spatial manipulation abilities can be improved by administering spatial visualization questions such as the ones found in the GSVS.
REFERENCES CITED


Appendix 1. Material referenced, used or modified in the creation of the GSVS.

<table>
<thead>
<tr>
<th>Section of GSVS where Question Appears</th>
<th>Source of Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts I, II, III</td>
<td></td>
</tr>
<tr>
<td>Spatial Visualization Kit</td>
<td>From Titus and Horsman (2009)</td>
</tr>
<tr>
<td><strong>Part IV</strong></td>
<td></td>
</tr>
<tr>
<td>Question 1, 2, &amp; 3</td>
<td>Modified from Dutch (2009)</td>
</tr>
<tr>
<td>Question 4</td>
<td>Modified from Titus and Horsman (2009) skill puzzle packet</td>
</tr>
<tr>
<td>Question 5</td>
<td>I created this question based on course material from Structural Geology I</td>
</tr>
<tr>
<td>Question 6</td>
<td>I created this question based on a final exam question used in Structural Geology I (2008)</td>
</tr>
<tr>
<td>Question 7</td>
<td>I created this question based on a midterm question used in Structural Geology I (2009)</td>
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<tr>
<td><strong>Part V</strong></td>
<td></td>
</tr>
<tr>
<td>Question 1, 2, 3, &amp; 4</td>
<td>Modified from Titus and Horsman (2009) skill puzzle packet</td>
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</tbody>
</table>

Appendix 2. The rationale behind specific geology question development pertaining to respective spatial visualization ability.

<table>
<thead>
<tr>
<th>Question in GSVS</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part IV</strong></td>
<td></td>
</tr>
<tr>
<td>Question 1</td>
<td>Tests spatial manipulation which is the ability to mentally manipulate an image into another arrangement. Here students are expected to know that geological units are deposited in beds with the youngest on top and the oldest on the bottom, they are then expected to bend these layers in their mind into a syncline which employs spatial manipulation abilities while maintaining those spatial-temporal relationships. (Beginner level 223)</td>
</tr>
<tr>
<td>Question 2</td>
<td>Tests spatial manipulation and visual penetrative ability (which is the ability to imagine what is inside an object). Here, students are expected to know that geological units are deposited in beds with the youngest on the top and the oldest on the bottom; they are then expected to mentally bend these layers into a concentric form while maintaining the spatial-temporal relationships between layers. After that, they are expected to use spatial manipulation to visualize how geological structures change with surface weathering. Finally, they have to use their visual penetrative ability to “see” the subsurface of a structure in plan view (bird’s eye view). (Advanced level 223)</td>
</tr>
<tr>
<td>Question 3</td>
<td>This question involves the same techniques described in question 2 with emphasis on visual penetrative ability. To get this question right, students have to visualize the subsurface. (Advanced level 223)</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Question 4</td>
<td>This question involves visual penetrative ability which is the ability to create a slice through a solid object. Students are expected to use the strat column (and the relative ages of the rocks) to determine the sense of fault movement. They are then expected to visualize this slice taking into account the strike slip movement. (Advanced level 223 and 323).</td>
</tr>
<tr>
<td>Question 5</td>
<td>Tests spatial relations because students are expected to visualize the half rotational bend that causes the deformation. This question also tests spatial manipulation which is the ability to mentally manipulate an image into another arrangement. (Beginner level 323)</td>
</tr>
<tr>
<td>Question 6</td>
<td>Tests spatial manipulations which is the ability to fold, bend or manipulate an image into another arrangement. Here students envision how strike slip movement along a fault deforms the surrounding rock due to the bend. (Beginner level 323). This question also tests spatial manipulation which is the ability to mentally manipulate an image into another arrangement (Beginner level 323). The student must visualize the fault moving and figure out if rotation occurs.</td>
</tr>
<tr>
<td>Question 7</td>
<td>Tests spatial relations because it shows dextral simple shear leading to non-coaxial strain, which allows for the rotation of the principle axis of the rock body. Visualizing this process requires that the participant rotate the object’s axis. (Advanced level 323)</td>
</tr>
</tbody>
</table>

**Part V**

<table>
<thead>
<tr>
<th>Question 1</th>
<th>Tests spatial manipulation and visual penetrative ability. Students employ visual penetrative ability when they imagine what is inside a solid object, but in this case, they have to go visualize ‘backwards’ and imagine how the inside structure projects onto the outside surface. Students also employ spatial manipulation when they mentally ‘flip’ the beds into another arrangement like the folding paper activity in Part II. (Beginner level 223)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Question 2</td>
<td>Tests visual penetrative ability which is the ability to mentally imagine what is inside a solid object. Students are expected to sketch a cross section by projecting the sinclinal structure through the block while taking into account that the entire structure is “plunging” downwards to the east. (Advanced level 223 and 323)</td>
</tr>
<tr>
<td>Question 3</td>
<td>Tests visual penetrative ability which is the ability to mentally imagine what is inside a solid object. Students are expected to use the relative ages of the strat column to determine the sense of strike slip movement. Students are also expected to sketch a cross section by visualizing the strike slip movement along the fault and projecting the anticlinal structure through the block. (Advanced level 223 and 323)</td>
</tr>
<tr>
<td>Question 4</td>
<td>Tests visual penetrative ability which is the ability to mentally imagine what is inside a solid object. Students are expected to not only imagine</td>
</tr>
</tbody>
</table>
what is inside a solid object given a few faces, but they are expected to be able to project all three cross sections into the block and understand the relationship between the cross sections. The relationship being that the beds are moving ‘up’ relative to the cross section A-A’ which employs spatial manipulation which is the ability to mentally manipulate an image into another arrangement. (Advanced level 223 and 323).

Appendix 3. Modifications and changes made to the GSVS during the student validation process and with instructor feedback.

<table>
<thead>
<tr>
<th>Original Question</th>
<th>Rationale for Changes</th>
<th>Final Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part IV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. In the above cross-section through a fold, where are the oldest rocks likely to be?</td>
<td>The answer depends on whether or not the fold is overturned, I made this change in the validation process when a senior geology student mentioned it aloud that they answered assuming it was not overturned.</td>
<td>1. In the above cross-section through a fold, where are the oldest rocks likely to be? The fold has not been overturned.</td>
</tr>
<tr>
<td>a) At location Z</td>
<td>e) At location Z</td>
<td></td>
</tr>
<tr>
<td>b) At location W</td>
<td>f) At location W</td>
<td></td>
</tr>
<tr>
<td>c) At location X</td>
<td>g) At location X</td>
<td></td>
</tr>
<tr>
<td>d) At location Y</td>
<td>h) At location Y</td>
<td></td>
</tr>
<tr>
<td>2. The above diagram is a bird’s eye view of a geologic structure. The topography is flat (no hills). The oldest rocks are Unit 4 and the youngest are Unit 1. What geologic structure does this diagram represent?</td>
<td>The rationale is the same for question one except that Sara Harris pointed out that the geologic feature could look different if it were not eroded uniformly.</td>
<td>2. The above diagram is a bird’s eye view of a geologic structure. The topography is flat (no hills). This structure has not been overturned and was eroded uniformly. The oldest rocks are Unit 4 and the youngest are Unit 1. What geologic structure does this diagram represent?</td>
</tr>
<tr>
<td>a) Dome</td>
<td>a) Dome</td>
<td></td>
</tr>
<tr>
<td>b) Homocl ine</td>
<td>b) Homocl ine</td>
<td></td>
</tr>
<tr>
<td>c) Basin</td>
<td>c) Basin</td>
<td></td>
</tr>
<tr>
<td>d) Anticl ine</td>
<td>d) Anticl ine</td>
<td></td>
</tr>
<tr>
<td>3. In the structure above, if you drilled a well at X, what would you hit below unit 3?</td>
<td>I added ‘directly below’ to clarify my question. This change was made during the validation process.</td>
<td>3. In the structure above, if you drilled a well at X, what would you hit directly below unit 3?</td>
</tr>
<tr>
<td>a) Unit 1</td>
<td>a) Unit 1</td>
<td></td>
</tr>
<tr>
<td>b) Unit 2</td>
<td>b) Unit 2</td>
<td></td>
</tr>
<tr>
<td>c) Unit 4</td>
<td>c) Unit 4</td>
<td></td>
</tr>
<tr>
<td>d) Rocks older than 4</td>
<td>d) Rocks older than 4</td>
<td></td>
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</tbody>
</table>
Question 4 option d) was not a very convincing distracter, so I created a new option.

5. In the diagram above, a geological layer is folded. Where does stretching and compression occur in the fold? The locations are indicated by x and y.
   a) Features at point x experience compression while features at point y experience stretching.
   b) Features at point x and y both experience compression
   c) Features at point x and y both experience stretching
   d) Features at point x experience stretching while features at point y experience compression.

After personal correspondence with B. van Straaten (2010), I modified question 5 because there were technical difficulties with the question. Namely that not all geologic layers behaved in the way I had imagined initially and the term rigid geologic layer was introduced. I also added ‘likely’ because the jargon introduced would be too confusing for the junior cohort who had not been introduced to the technical terminology of Structural Geology I.

7. In the diagram above, a body of rock deforms plastically. Stress (to the right) is applied to the upper part of the body and stress (to the left) is applied to the bottom part of the body. How does this body of rock deform?
   a) The body of rock is stretched and elongated

With instructor feedback (B.van Straaten, personal communication, 2010) I added a material line to the question to make it valid.

7. In the diagram above, a body of rock deforms plastically. Stress (to the right) is applied to the upper part of the body and stress (to the left) is applied to the bottom part of the body. How does the vein in this body of rock deform?
   a) The vein is stretched and elongated
   b) The vein is shortened and compressed

No changes made during the validation or expert feedback processes.

5. In the diagram above, a rigid geological layer is folded. Where are stretching and compression most likely to occur in the fold? The locations are indicated by x and y.
   a) Features at point x experience compression while features at point y experience stretching.
   b) Features at point x and y both experience compression
   c) Features at point x and y both experience stretching
   d) Features at point x experience stretching while features at point y experience compression.
<p>| | |</p>
<table>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>b) The body of rock is shortened and compressed</td>
<td>c) The vein is first shortened and compressed then stretched and elongated</td>
</tr>
<tr>
<td>c) The body of rock is first shortened and compressed then stretched and elongated</td>
<td>d) The vein is first stretched and elongated then shortened and compressed</td>
</tr>
</tbody>
</table>

### Part V

<table>
<thead>
<tr>
<th>Question</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Please sketch the top of this block diagram below. Use the two cross sections on the sides of the diagram to guide your sketching. Assume uniform weathering of the surface and flat topography.</td>
</tr>
<tr>
<td>2.</td>
<td>The following block diagram shows folded stratigraphy that is plunging downwards. Please sketch in the box to the right a slice through the block indicated by the dotted line.</td>
</tr>
<tr>
<td>3.</td>
<td>The following block diagram show folded stratigraphy that has been faulted. The fold hinge is horizontal (the fold is not plunging). The area’s stratigraphy is shown in the stratigraphic column to the left. There has been some movement along the fault shown on the block. Please sketch in the box to the right a slice through the block indicated by the dotted line.</td>
</tr>
</tbody>
</table>

In the student validation process, I noticed students were not automatically filling in the textures of the geologic layers, so I added that instruction to my final version.

1. Please sketch the top of this block diagram below and roughly fill out the textures. Use the two cross sections on the sides of the diagram to guide your sketching. Assume uniform weathering of the surface and flat topography.

I noticed students were not automatically filling in the textures of the geologic layers, so I added that instruction to my final version.

2. The following block diagram shows folded stratigraphy that is plunging downwards. Please sketch in the box to the right a slice through the block indicated by the dotted line. Don’t forget to sketch the textures in the different layers.

Same rationale for Part V Questions 1 & 2

3. The following block diagram show folded stratigraphy that has been faulted. The fold hinge is horizontal (the fold is not plunging). The area’s stratigraphy is shown in the stratigraphic column to the left. There has been some movement along the fault shown on the block. Please sketch in the box to the right a slice through the block indicated by the dotted line. Don’t forget to sketch the textures in the different layers.
<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Given three cross sections (A-A’), (B-B’) and (C-C’). Please sketch all three sides of the following block diagram.</td>
<td>During the validation process, students mistakenly believed there were faults indicated by the dotted line in the diagram, so that misconception was cleared up.</td>
</tr>
<tr>
<td>4. Given three cross sections (A-A’), (B-B’) and (C-C’). There are no faults in this block diagram. Please sketch all three sides of the following block diagram.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 4. Validation Interview Consent Form

T H E  U N I V E R S I T Y  O F  B R I T I S H  C O L U M B I A

Carl Wieman Science Education Initiative (CWSEI)
University of British Columbia
Wesbrook Bldg.
300-6174 University Blvd.
Vancouver, BC Canada V6T 1Z3
Tel: (604) 827-3119
Fax: (604) 827-3118

Consent Form

Development and Validation of Surveys Probing Students’ Understanding of Concepts in Science

Principal Investigator: Dr. Sarah Gilbert
Carl Wieman Science Education Initiative (CWSEI)
604-822-3193

Co-Investigator: Dr. Carl Wieman
Carl Wieman Science Education Initiative (CWSEI)
604-822-1732

Study Team Members/Researchers:
Jackie Stewart, Chemistry, 604-822-5912
Jennifer Duis, Chemistry, 604-827-5969
Steven Wolfman, Computer Science, 604-822-0407
Sara Harris, Earth and Ocean Sciences, 604-822-9651
Brett Gilley, Earth and Ocean Sciences, 604-822-2138
Francis Jones, Earth and Ocean Sciences, 604-822-2138
Erin Lane, Earth and Ocean Sciences, 604-822-2138

UBC undergraduate students are invited to participate in a study aimed at improving the learning and appreciation of science. This study is conducted by science departments at UBC and the Carl Wieman Science Education Initiative (CWSEI). Conclusions and the survey instruments based on composite interviews of many students may be published in some form and/or presented publicly, but without any information that could be used to identify the participants.
Purpose:
The purpose of this study is to develop and validate surveys that examine university students’ understanding of concepts in particular science disciplines. This study will test students’ understanding of particular topics and survey questions on those topics through interviews with a range of students that span the populations for which the surveys will be used. Interviews are an important development and “validation” step in the development of a survey; they explore how students think and learn a topic and test whether survey questions are worded so that the students interpret them as intended.

Study Procedures:
Your participation will involve watching online learning materials, listening to questions, or filling out a survey on some key concepts in a science discipline. Then the interviewer will ask questions in order to understand how you think about the topic, interpret each question, and the reasons for your particular responses to the survey question or to questions or online materials. They will proceed in this fashion through the survey, or, set of online materials, or conceptual topics to be covered in this interview. Typical interviews will last no more than one hour. All interviews will be audio recorded and may be video recorded with your permission.

Participants will be selected based on their grades to ensure an equal representation of students from each grade band. In the event that there are more participants than needed, subjects may be selected based on gender, ethnic background, and age for the sole purpose of ensuring the best match to the demographic representation of the overall UBC student population. At the time of recruitment, researchers will ask students for their ID numbers and permission to review their grades and background information for this purpose of participant selection.

Potential Risks:
There are no known risks to participation in this study.

Potential Benefits:
The benefits to you are indirect; the surveys developed as a result of these interviews are part of a major UBC initiative to improve science education. Input from the surveys is an essential component in understanding what changes in educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.

The benefits to society in general will be improved science education that most students will find more interesting and relevant to their lives.

Confidentiality:
Your confidentiality will be respected. Interviews will be transcribed and no one except the researchers will have access to your identity. The interviewer will be a faculty or staff researcher from each participating department with expertise in the respective discipline and
will not be an instructor of any course in which you are currently enrolled. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet and will not be available to any of your current instructors. Any information in electronic format will be stored on password protected computers. No individual student identifiers will be used in any published or publicly presented work.

**Remuneration/Compensation:**
For your participation, you will receive the monetary compensation of $15.

**Contact for information about the study:**
If you have any questions or would like further information about this study, you may contact the appropriate researcher for the particular survey instrument as follows:

- Earth and Ocean Sciences – Sara Harris (604-822-9651)
- Brett Gilley (604-822-2138)
- Francis Jones (604-822-2138)
- Erin Lane (604-822-2138)
- Joshua Caulkins (604-822-2138)
- Alison Jolley (alisonjolley@gmail.com)
- Carrie Wong (carriewong778@gmail.com)

**Contact for concerns about the rights of research subjects:**
If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598 or if long distance e-mail to RSIL@ors.ubc.ca.

**Consent:**
Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time without jeopardy to your class standing.

*If you require additional time to review this consent form, please feel free to do so and return the signed form to the appropriate researcher by tomorrow.*

Your signature below indicates that you have received a copy of this consent form for your own records.

Your signature indicates that you consent to participate in this study.

________________________________________________________________________

Participant’s Signature                                    Date

________________________________________________________________________

Printed Name of the Participant signing above
Appendix 5. The final version of the Geologic Spatial Visualization Survey that was administered to the junior and senior cohorts.

**Spatial Visualizations Student Survey (Pre-Test)**

Please answer the questions below to the best of your abilities. The test is timed, and you will have three minutes Part I, II and III, 5 minutes for Part IV and 10 minutes for Part V. We do not expect students to finish the first three sections in the time allotted so please flip to the next section as soon as you are told the time is up. This test is not “graded”. There is no penalty for not knowing the correct answer, just do your best with what you currently know. Thank you!

**Part I: Spatial Relations**

In this part of the survey, you are to:
1. Study how the first object in the top line of the question is rotated;
2. Imagine what the second object looks like when rotated in exactly the same manner;
3. Select from among the five drawings A, B, C, D, and E given in the bottom line of the question the one that looks like the object rotated in the correct position.
4. Circle your answer. There is only one correct answer for each question.

**EXAMPLE:**

![Spatial Relations Example](image)

**NOTE:** The first object that is rotated will be the same for all questions although the rotations may be more complex than the example above. There are 10 questions in this section. You will have 3 minutes to complete this section of the survey on the next page.
Part II: Spatial Manipulation

In this section you are to try to imagine or visualize how a piece of paper can be folded to form some kind of object. Look at the two drawings below. The drawing on the left is a piece of paper that can be folded on the dotted lines to form the object drawn at the right. You are to imagine the folding and are to figure out which of the lettered edges on the object are the same as the numbered edges on the piece of paper at the left. Write the letters of the answers in the numbered spaces at the far right.

Now try the practice problem below. Numbers 1 and 4 are already correctly marked for you.

NOTE: The side of the flat piece marked with the X will always be the same as the side of the object marked with the X. Therefore, the paper must always be folded so that the X will be on the outside of the object.

In the above problem, if the side with edge 1 is folded around to form the back of the object, then edge 1 will be the same as edge H. If the side with edge 5 is folded back, then the side with edge 4 may be folded down so that edge 4 is the same as edge C. The other answers are as follows: 2 is B; 3 is G; and 5 is H. Notice that two of the answers can be the same.

There are **20 questions** (4 objects to fold with 5 questions each) in this section. You will have **3 minutes** to work.

**Flip to the next page (page 5) to start Part II**
Part III: Visual Penetrative Ability

The final part of this survey tests your ability to mentally slice through a three-dimensional object. Each problem consists of a picture of an irregularly shaped 3-d block set inside a rectangular outline. The outline indicates the position of a plane passing through the block. You are to determine the shape of the surface which would be made by cutting off the block along the plane (i.e., the intersection of the plane with the block). Circle the correct answer from those given.

Here’s an example problem:

And here’s an example of the process you might go through in your head to find the correct answer. First you slice the object with the plane, then you rotate the object in your head and look at the leftover shape.

Notice that the shaded region (the intersection of the object and the slicing plane) is the same shape as answer D given above. Answer C is incorrect because it shows more than just the interaction of the object and the slicing plane. So you’d circle D and move on to the next question.

There are 15 questions in this part of the survey and you will have 3 minutes to work.

Flip to the next page (page 7) to start Part III
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<table>
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<tr>
<td>1</td>
<td>A</td>
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<td>C</td>
<td>D</td>
<td>E</td>
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<tr>
<td>2</td>
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<td>10</td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="imageA10.png" alt="Image" /></td>
<td><img src="imageB10.png" alt="Image" /></td>
<td><img src="imageC10.png" alt="Image" /></td>
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<tr>
<td>11</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="imageA11.png" alt="Image" /></td>
<td><img src="imageB11.png" alt="Image" /></td>
<td><img src="imageC11.png" alt="Image" /></td>
<td><img src="imageD11.png" alt="Image" /></td>
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<tr>
<td>12</td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="imageA12.png" alt="Image" /></td>
<td><img src="imageB12.png" alt="Image" /></td>
<td><img src="imageC12.png" alt="Image" /></td>
<td><img src="imageD12.png" alt="Image" /></td>
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<tr>
<td>13</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="imageA13.png" alt="Image" /></td>
<td><img src="imageB13.png" alt="Image" /></td>
<td><img src="imageC13.png" alt="Image" /></td>
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<tr>
<td>14</td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="imageA14.png" alt="Image" /></td>
<td><img src="imageB14.png" alt="Image" /></td>
<td><img src="imageC14.png" alt="Image" /></td>
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<td>15</td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="imageA15.png" alt="Image" /></td>
<td><img src="imageB15.png" alt="Image" /></td>
<td><img src="imageC15.png" alt="Image" /></td>
<td><img src="imageD15.png" alt="Image" /></td>
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</tbody>
</table>
Part IV: Multiple Choice. Please circle your answer. You have 5 minutes to complete this section.

1. In the above cross-section through a fold, where are the oldest rocks likely to be? The fold has not been overturned.
   i) At location Z
   j) At location W
   k) At location X
   l) At location Y

2. The above diagram is a bird’s eye view of a geologic structure. The topography is flat (no hills). This structure has not been overturned and was eroded uniformly. The oldest rocks are Unit 4 and the youngest are Unit 1. What geologic structure does this diagram represent?
   e) Dome
   f) Homocline
   g) Basin
   h) Anticline

3. In the structure above, if you drilled a well at X, what would you hit directly below unit 3?
   e) Unit 1
   f) Unit 2
   g) Unit 4
   h) Rocks older than 4
4. The above block diagram shows folded stratigraphy that has been faulted. The fold hinge is horizontal (the fold is not plunging). The area’s stratigraphy is shown in the stratigraphic column to the left. There has been some movement along the fault shown on the block. If you were to slice this block through the plane indicated by the dotted line, and removed the top half, what would the surface look like?

a) 

b) 

c) 

d)
5. In the diagram above, a rigid geological layer is folded. Where are stretching and compression most likely to occur in the fold? The locations are indicated by x and y.

   d) Features at point x experience compression while features at point y experience stretching.
   e) Features at point x and y both experience compression
   f) Features at point x and y both experience stretching
   g) Features at point x experience stretching while features at point y experience compression.

6. The diagram above is a bird’s eye view of an irregular fault with a bend in it. There is movement along this fault as shown by the black arrows. What kind of deformation happens inside the grey circle as a result of this bend?

   a) Extension
   b) Compression
   c) Clockwise rotation
   d) Counter-clockwise rotation
7. In the diagram above, a body of rock deforms plastically. Stress (to the right) is applied to the upper part of the body and stress (to the left) is applied to the bottom part of the body. How does the vein in this body of rock deform?
   e) The vein is stretched and elongated
   f) The vein is shortened and compressed
   g) The vein is first shortened and compressed then stretched and elongated
   h) The vein is first stretched and elongated then shortened and compressed

Part V: In this section you will be drawing and sketching.

1. Please sketch the top of this block diagram below and roughly fill out the textures. Use the two cross sections on the sides of the diagram to guide your sketching. Assume uniform weathering of the surface and flat topography.
2. The following block diagram shows folded stratigraphy that is plunging downwards. Please sketch in the box to the right a slice through the block indicated by the dotted line. Don’t forget to sketch the textures in the different layers.

3. The following block diagram show folded stratigraphy that has been faulted. The fold hinge is horizontal (the fold is not plunging). The area’s stratigraphy is shown in the stratigraphic column to the left. There has been some movement along the fault shown on the block. Please sketch in the box to the right a slice through the block indicated by the dotted line. Don’t forget to sketch the textures in the different layers.
4. Given three cross sections (A-A’), (B-B’) and (C-C’). There are no faults in this block diagram. Please sketch all three sides of the following block diagram.
Courses you are currently taking (please check all that apply):  
☐ EOSC 110  ☐ EOSC 111  ☐ EOSC 112  
☐ EOSC 114  ☐ EOSC 116  ☐ EOSC 223  
☐ EOSC 323  ☐ EOSC 328  ☐ EOSC 332  

Courses you have taken already (please check all that apply):  
☐ EOSC 110  ☐ EOSC 111  ☐ EOSC 112  
☐ EOSC 114  ☐ EOSC 116  ☐ EOSC 223  
☐ EOSC 323  ☐ EOSC 328  ☐ EOSC 332  

A few demographic questions (please check off all that apply):  
Major: ☐ EOSC major  ☐ Engineer  ☐ Science major  ☐ Other major: ____________  
Gender: ☐ Male  ☐ Female  
Have you ever taken an earth and ocean science course outside of UBC?  ☐ Yes  ☐ No  
EOSC courses taken outside of UBC: ____________________________________________  
Are you a transfer student (from a different Canadian University/College)?  ☐ Yes  ☐ No  
Are you an exchange student (from a different country)?  ☐ Yes  ☐ No  

*For an answer key please contact the author (carriewong778@gmail.com) or the Department of Earth and Ocean Sciences at the University of British Columbia (Vancouver).