Spatial Cognition among Eleventh and Twelfth Grade Montana Agricultural Education Students

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Abstract

The purpose of this study was to determine Montana high school student’s spatial cognition abilities to identify features and attributes in agriculture production images, projected in two-dimension (2D) or three-dimension (3D). The effects of selected demographics on spatial cognition were examined. The population consisted of 101 high school students from selected Montana secondary agricultural education programs during the Fall Semester of 2003. Criteria for participation were that the class size be 10-15 students enrolled in 11th or 12th grade. The agricultural classes were randomly assigned as either participating in the 2D or 3D study. When viewing 2D and 3D images of production agriculture students were able to correctly identify features and attributes about 50 percent of the time. Based on the 17 multiple-choice questions of the 23 questions used, there was no significant difference in students’ spatial cognitive abilities when viewing 2D and 3D production agriculture images. When viewing production agriculture images in 3D, containing features and attributes relative to elevation, spatial cognition was enhanced. Age, grade level, semesters enrolled in agricultural education, gender, place of residence and prior GIS experience did not enhance spatial cognition.
Introduction

Humans talk about what they see. Frequently the phrase ‘a picture is worth a thousand words’ is used. Such statements raise an important question for theories of spatial cognition and for the geographic information system (GIS) users. Hayward & Tarr (1995) suggest that there is a connection between visual representation and our linguistic system. Gardner (1983) indicates that spatial intelligence is closely tied to and grows directly out of one’s observations. Thus, the visual world and the linguistic systems are necessary for accurate image processing.

The theory of multiple intelligence developed by Gardner (1985), indicates that people have a range of intelligences and learning styles, not just the linguistic and logical-mathematical intelligences. One of the intelligences is visual-spatial (directly related to drawing, architecture, and map-making) (The Master Teacher (b), 2003). Spatial intelligence requires the use of cognitive higher-order thinking skills. These cognitive higher-order thinking skills are analysis, synthesis, and evaluation (The Master Teacher (b), 2003). Hence, the cognitive ability to use reason, intuition, or perception is essential for the GIS users.

Mark, Freska, Hirtle, Lloyd & Tversky (1999) suggest that the way humans perceive and process information about geographic space differs from how they evaluate other types of space. For example, the space perceived between the desk and the chair is different than the space between Seattle and Miami. The desk and chair space exists within a person’s view, while Seattle and Miami are geographical space. This process relies on referenced information stored through experiences. What is the reference data of high school students who have spent most of their time within a city’s boundary when asked to interpret an agricultural image of a 320 acre field?

With the advancing use of GIS applications in agriculture, there comes a need to understand how non-experts interpret images. Would viewing field data or satellite images displayed in three dimensions enhance spatial intelligence? Before agricultural educators can enhance spatial intelligence and spatial cognition among students, there is a need to know what these abilities are.

Purpose / Objectives

The purpose of this study was to determine Montana agricultural education 11th and 12th grade students’ spatial cognition abilities when viewing agriculture production and satellite images projected in two-dimensions or three-dimensions. The data were collected during Fall Semester 2003. The specific objectives of the research were: to determine Montana agricultural education students’ abilities to use cognition (reason, intuition or perception) to correctly identify features in 2D images related to crop production, to determine agricultural education students’ abilities to use cognition to correctly identify features in 3D images related to crop production, to compare agricultural education students’ abilities to use cognition to correctly identify features in 2D and 3D images related to crop production, to examine the effect of selected demographics on agricultural education students’ ability to use cognition to correctly identify features in 2D and 3D images related to crop production. The selected demographics were age, gender, grade level, semesters enrolled in agricultural education, place of residence, and GIS experience.
Theoretical Framework – Spatial Cognition

One of the most important cognitive functions in daily life is spatial memory, which enables us to locate objects in our environment or to learn a route or a path (Kessels, Kappelle, de Haan, Edward & Postma, 2002). Chalfonte (1996) suggests there is a difference between memory for routes or paths, and memory for the location of objects. The difference between the two types of memory is that routes or paths cover a geographic space. Where an object, such as a sign, is viewed within an object space. For example, a route or path used by residence of a community would be considered geographic space. A stationary object space would be a sign along a path. Human spatial memory involves the encoding, storage, and retrieval of information about spatial layouts, enabling us to remember the position of objects in our environment (De Renzi, 1977).

The use of a frame of reference for recalling information provides structure for spatial information and provides for the involvement of spatial knowledge. In addition, spatial information prompts the recollection of mental pictures. Humans have to search their memories for experiences, understanding, and events relating to the mental picture. Recalling mental pictures can evoke emotions that stimulate excitement, focus attention, and builds interest and confidence (The Master Teacher (a), 2003).

In terms of geographical information, humans store reference data in a categorical, hierarchical fashion (Mark et al.1999; Mennis, Peuquet & Quan, 2000; Leung, Leung & He, 1999). As humans move from categories of objects such as tables, chairs, and desks, to geographical categories such as rivers, lakes and mountains, the hierarchical structure of these categories changes.

When testing for spatial ability, people often solve spatially presented cognitive problems more easily than non-spatial problems. Gardner (1983) explains that spatial intelligence is closely tied to and grows directly out of one’s observations of the visual world. Entities perceived in spatial relation to one another produce a more accurate representation (Freska, Barkowsky & Klippel, 1999). According to Barsalou (1999), images (perceptual symbols) are easily understood if they share the properties for arrangement and order of occurrence with the “real” perceptions of the viewer. Thus, the more experiences an individual has with the environment of an image, the easier it is to mentally conceptualize the image.

The larger the environment represented by an image, the more difficult it is to conceptualize spatially the area of interest. For example, in an agricultural setting what difficulties would a producer have when viewing an image of 320 acres? Lockman and Pick’s (1984) study suggests that spatial behavior in different scale (size) environments is driven by the cognitive information processing skills of encoding, internal manipulations and decoding. Thus, the scale used by the GIS user to create images is critical in helping the viewer correctly interpret an image. The scale of maps and diagrams all rely upon scale transformation too accurately represent space. Cartographer’s large scale represents a small area in great detail, while a small scale shows a larger area in less detail (Bell, 2002).
The use of animation and navigation has visual benefits as human vision is “hardwired” to detect motion. In addition to animation through time, visualizations and navigation allows the viewer, using their intuition, to move through a 3D landscape. The combination of visualization and animation can provide a more effective representation of data describing changing land cover (Dunbar et al., 2003). Thus, placing images in 3D has the potential to enhance spatial cognition.

For hundreds of years, agricultural producers have been using their knowledge and spatial ability for agriculture production. Producers have been dependent on memory, knowledge and the ability to use these skills when managing production. However, the size of operations has increased substantially, creating a need for precision agriculture. Precision agriculture is in an early and rapidly changing phase. With the use of technology and precision agriculture, there is a potential to change the decision making process (National Research Council, 1997).

Precision agriculture uses GIS, global positioning system (GPS), and remote sensing technologies to establish a base line of information. This process will provide better record keeping, yield monitoring, and farm research for producers. According to the National Research Council (1997) “a disadvantage of the current generation of GIS is the complexity of the software and the steep learning curve involved in using and interpreting spatial data in a valid and robust way” (p. 30). A limitation is that spatial relationships from data layers are hard to interpret. They reveal only visual relationships for the producer to interpret with GIS software. Practical applications of the technology and the need for an understanding of precision agriculture should find its way into the agriculture classroom. As evidence of this movement, The National Council for Agricultural Education produced and distributed to agriculture teachers a curriculum on precision agriculture. In addition, a number of universities are currently offering courses in precision agriculture technology.

Studies have shown that infants have a strong awareness of the permanence of objects around them and that the perceptual constancies of size and shape develop early and quickly (Blaut, 1997). Yet, Piagetian theory suggests that when children reach the concrete operations stage, they acquire the ability to conceptualize geographical space, and to “project” from the earthbound perspective of ordinary experience to the overhead perspective of a map or aerial photograph (Blaut, 1997).

Gardner (1983) describes that Piaget introduced a distinction between “figurative” knowledge, in which an individual retains the configuration of an object (as in a mental image) and “operative” knowledge, where the emphasis falls upon transforming the configuration (as in the manipulation of the image) (p. 179). The Master Teacher informed educational instructors that having a student draw pictures and make pictographs is a strong symbolic teaching strategy ((a), 2003). The process of transforming a mental image into a physical representation helps students gain a stronger grasp of relationships, applications, and conceptual subtleties (Master Teacher (a), 2003).

Kirasic (2000) reported that older adults do not perform as well as younger adults on spatial tasks. Blaut (2003) reported that Piagetian theorists believe that children up to the late
elementary grades are unable to cope with abstract ideas such as spatial concepts. Thus, the grade level of individuals involved in this study is critical. Eleventh and twelfth grade students are considered young adults. Therefore, these students should be able to demonstrate spatial cognitive abilities. Whereas ninth graders and tenth grade students may have not fully developed their spatial cognitive abilities.

There have been discussions for numerous years about the effects of gender in spatial cognition. Moffat, Hampson and Hatzipantelis (1998), state that there is evidence favoring males in spatial performance, which is one of the most reliable of all cognitive gender differences in humans. In the study conducted by Sharps, Price and Williams, (1994) men performed at higher levels than women in the spatial instruction conditions, but no gender differences were observed under non-spatial instructions. These differences are diminished or obviated by addressing the nature of spatial representation through linguistic description of spatial layout and the study of cognitive maps (Hayward & Tarr, 1995).

One of the demographic factors included in this research was place of residence. This decision was based on Blaut, Stea, Spencer and Blades (2003) research. They report that geographical space has some fundamental and very important differences from object space. Not only does the geographic space and object space influence spatial cognition, but is also influenced by the culture in which one is raised or lives. Blaut et al. (2003) report that studies should be conducted to determine the influence of culture on children’s ability to use map-like models. This idea is supported by Mark et al. (1999) which report that a persons view of geographical space is based on referenced information obtained through life experiences.

Wright, Goodchild and Proctor (1997) indicate that GIS as a tool involves the use of software, hardware, and digital graphic data in order to achieve some specific purpose. Shelhamer (personnel communication, February 10, 2003) reported that GIS is a tool to enhance the ability to explore and discover relationships between variables. Thus, it appears that the use of GIS has the ability to influence how one conceptualizes data and the development of referenced information. Since, ArcView has been given to every public school within the state there was the potential for every student to have utilized GIS software. These experiences may influence students’ spatial cognitive abilities.

**Methods / Procedures**

The population for this study consisted of students from selected secondary agricultural education programs during the Fall Semester of 2003. Criteria to participate were that the class size be 10-15 students enrolled in 11th or 12th grade. Using the fish-bowl technique, these classes were randomly selected to participate in 2D or 3D group. The results of this process placed 55 students in the 2D group and 51 students in 3D group.

To accomplish the objectives of the study the researcher utilized ArcView 8.3 to developed 36 2D and 136 3D images. Once the images were incorporated into Microsoft PowerPoint®, questions were developed for each set of images. A total of nine sections consisting of: field elevation, soil organic matter, soil nitrogen, soil pH, soil texture based on electro conductivity using Veris technology, barley yield, satellite imagery, relationships
between yield, slope and elevation, and student interest. Twenty-three questions, 17 multiple-choice and 6 open-ended questions, were developed based on information present in the PowerPoint images. A panel of experts consisting of graduate committee members and university researchers viewed the 2D and 3D PowerPoint presentations and questionnaire for content validity and face validity. The images and instrument was pilot tested at a school in Arlington, Washington.

To ensure consistency between presentations, images were placed on a time base. With the total allotted time for each question being the same for 2D and 3D questionnaire. The first PowerPoint slide of each section contained a title, image, legend, scale, and question number identifier. A question number identifier was added to the images to ensure that the students were answering the question that corresponded with image shown.

The researcher traveled to each school to collect the data. The agriculture instructors allowed the researcher a 50-minute class period to collect the data. At the start of each class period, the researcher introduced herself and gave a brief explanation about the research. Students were encouraged to give honest responses to help ensure validity of the research. Based on prior selection of either 2D or 3D presentation, the instrument was color coded to ensure accurate recording of data. A set of instructions were read to the class. Following Witkins Group Embedded Figures Test model, each class was shown two practice 2D images relating to moisture and soil electro conductivity, followed by a question about the image.

To determine if there was any difference between the schools, students’ responses for each school were compared to responses from similar groups. 2D responses were compared to responses from other schools who participated in the 2D groups. The same comparison occurred for the 3D group. Analysis of variance procedures where used to determine if schools could be treated as one group or had to be treated as separate programs. Results found that there was no significant difference between the selected programs in 2D and 3D. Therefore, the data were combined by 2D or 3D groups and compared using an independent sample \( t \)-test. A one way analysis of variance (ANOVA) procedure was also conducted to determine if identified demographic groups differed significantly when comparing means on the 17 multiple-choice questions.

Findings

The questionnaire contained 17 questions that had a right or wrong answers. These 17 questions were scored with a 1 for the correct response and 0 for an incorrect response. Data in Table 1 exhibits the mean and standard deviation of the 17 questions that had a correct or incorrect answer. In the 2D group, the mean was 8.58 with a standard deviation of 2.04. The 3D group had a mean of 8.31 and standard deviation of 2.43. An independent sample \( t \)-test was conducted to determine if there was a significant difference between the average questionnaire score for the 2D and 3D groups. Results found that there was no statistical significant difference on the average questionnaire score for 2D and 3D students, \( t(99) = .595, p = .553. \)
Table 1.
Mean and Standard Deviation for the 17 Questions.

<table>
<thead>
<tr>
<th>Group</th>
<th>M*</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>8.58</td>
<td>2.04</td>
</tr>
<tr>
<td>3D</td>
<td>8.31</td>
<td>2.43</td>
</tr>
</tbody>
</table>

* Total possible score was 17.

The percentage of students that correctly responded to each question ranged from 8% to 90% for the 2D group. The 3D group varied from 19% to 92% correct responses. The questions that were answered correctly by less than 40% of the students in both 2D and 3D groups were: identify the number of points classified as having the highest elevation (2D, 36%; 3D, 39%), identification of visual relationship between elevation and organic matter (2D, 24%; 3D, 19%), identifying a nitrogen distribution patterns (2D, 20%; 3D, 22%), identifying relationship between elevation and pH (2D, 32%; 3D, 27%), and identifying elevation by color (2D, 8%, 3D; 31%). Students who viewed images in 3D scored higher in the following questions: identification of color of elevation (3D, 53%; 2D, 44%) identification of highest concentration of nitrogen (3D, 67%; 2D, 54%), identifying elevation by color (3D, 31%; 2D, 8%), identifying aspect within an image, (3D, 41%; 2D, 32%) and recognition of different shades of red within the image (3D, 90%; 2D, 84%).

Viewing an object in 3D may provide more information for the students to process. However, more information may have caused the students to misinterpret the data, adding to the number of incorrect answers. Questions in which the 2D group scored higher are: number or different levels of organic matter (2D, 88%; 3D, 80%), identify elevation of field organic matter, (2D, 60%; 3D, 51%), and use of prior knowledge to identify which part of a field had been planted to alfalfa previously (2D, 52%; 3D, 29%).

Using a standard of 5%, the researcher counted the number of questions that had an advantage for 2D or 3D. If there was less than a 5% difference, it was classified as having no difference. For 8 questions, viewing in 2D or 3D made no difference in the score. Viewing an image in 3D was advantageous for 6 images, while viewing in 2D was a benefit for 3 questions.

Age
For the 2D group, 23 students who were 15 and 16 year olds had a test mean of 8.52, while the 18, 17 year olds had a test mean of 8.72. The 7 students who were 18 and 19 year olds had test mean of 8.42. In the 3D group, 14 students who were 15 and 16 year olds had a test mean of 8.71, while the 26 whose age was 17 had a test mean of 7.92. The 11 students who were 18 and 19 year olds had a test mean of 8.72. A one way analysis of variance (ANOVA) was conducted to determine if age groups differed regardless of survey condition on mean scores. Results suggest that there were no differences between age groups, $F(2,98) = 1.495, p = .747$.

Grade Level
For the 50 participants in the 2D group the test mean for 11th grade was 8.45 and 12th grade was 8.86. For the 51 students in the 3D group the test mean for 11th grade was 8.42 and 12th grade was 8.20. An independent sample t-test was conducted to determine if there was a significant difference between the average questionnaire score for grade levels. Results found
that there was no significant difference for 11th and 12th grade students when comparing average questionnaire scores, \( t(99) = -.016, p = .987 \).

**Semesters Enrolled**

Data in Table 2 exhibit the mean and standard deviation for the number of semester participants that were enrolled in agriculture classes. The semesters were placed in pairs, as most programs are year long courses consisting of two semesters. In the 2D group, the mean was 7.83 for 6 students in 1 or 2 semesters, 10 students enrolled in 3 or 4 semesters had a test mean of 9.2, while 23 students enrolled in 5 or 6 semesters produced a test mean of 8.39. Ten students enrolled in 7 or 8 semesters had a test mean of 8.50. In the 3D group, the mean was 7.87 for 8 students in 1 or 2 semesters, and 15 students enrolled in 3 or 4 semesters produced a test mean of 8.66. Ten students enrolled in 5 or 6 semesters produced a test mean of 6.90, 11 students enrolled in 7 or 8 semesters produced a test mean of 8.72, and 5 students enrolled in 9 or 10 semesters produced a test mean of 10.20. A one way analysis of variance (ANOVA) was conducted to determine if semesters differed on mean questionnaire scores. Results suggest that there was no statistical difference between semester groups, \( F(5,94) = 1.399, p = .232 \).

Table 2.
Participants Test Mean and Standard Deviation by Number of Semesters Enrolled in an Agriculture Program.

<table>
<thead>
<tr>
<th>Semesters</th>
<th>2D</th>
<th>3D</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M*</td>
<td>SD</td>
</tr>
<tr>
<td>1 or 2</td>
<td>6</td>
<td>7.83</td>
<td>1.47</td>
</tr>
<tr>
<td>3 or 4</td>
<td>10</td>
<td>9.20</td>
<td>1.75</td>
</tr>
<tr>
<td>5 or 6</td>
<td>23</td>
<td>8.39</td>
<td>2.29</td>
</tr>
<tr>
<td>7 or 8</td>
<td>10</td>
<td>8.50</td>
<td>1.84</td>
</tr>
<tr>
<td>9 or 10</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>11 or 12</td>
<td>1</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

*A total possible score of 17.

**Gender**

As reported by Moffat, Hampson and Hatzipantelis (1998) gender has been shown to make a difference in spatial cognition. In the 2D group, the mean for the females was 8.52 compared to a test mean of 8.62 for the males. The 3D group females had a test mean of 8.63 and the males had a test mean of 8.22. An independent sample \( t \)-test was conducted to determine if there was a significant difference between the average questionnaire score for gender. Results found that there was no significant gender difference on the average questionnaire score, \( t(99) = .355, p = .723 \).

**Residence**

The images used in this study were from production agriculture. The information in Table 3 displays the mean and standard deviation for place of residency of participants at the time of this study. In the 2D group, the students who lived in town had the highest test mean (9.50) followed by those who lived in town and worked on farm or ranch (8.56). This pattern was not true for those in the 3D group as the highest score was for those who lived in town and worked on a ranch or farm (8.47). Those who lived on a farm or ranch had a mean test score of
A one way analysis of variance (ANOVA) was conducted to determine if residence differed on mean questionnaire scores. Results suggest that there were no differences between place of residence, $F(2,98) = .038, p = .963$.

Table 3.
Mean and Standard Deviation of the 17 Questions by Place of Residency.

<table>
<thead>
<tr>
<th>Residency</th>
<th>2D</th>
<th>3D</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M*</td>
<td>SD</td>
</tr>
<tr>
<td>Town</td>
<td>6</td>
<td>9.50</td>
<td>2.25</td>
</tr>
<tr>
<td>Farm/Ranch</td>
<td>28</td>
<td>8.39</td>
<td>2.04</td>
</tr>
<tr>
<td>Live in town/work on ranch</td>
<td>16</td>
<td>8.56</td>
<td>1.99</td>
</tr>
</tbody>
</table>

*A total possible score of 17.

GIS Experience

The researchers felt that having experience with GIS might also influence test scores. The mean test scores for those with GIS experience ranged from 8.55 to 8.80, while those with no previous GIS experience ranged from 8.26 to 8.37. An independent sample $t$-test was conducted to determine if there was a significant difference between the average questionnaire score for GIS experience. Results found that there was no significant GIS difference on average questionnaire scores, $t(98) = .835, p = .406$.

Students were asked about their level of interest when viewing the images. Among 2D participants, 15 (30%) students expressed that they were bored, 12 (24%) indicated somewhat interested, 20 (40%) responded curious, and 2 (4%) explained that they were excited and stimulated. Among 3D participants, 22 (43%) students expressed that they were bored, 15 (29%) indicated somewhat interested, 10 (19%) responded curious, and 3 (6%) were very interested, and 1 (2%) explained that they were excited and stimulated. When examining the levels of interest the data show that a higher percentage of the 3D students, were bored, (3D, 43, 14%; 2D, 15, 30%). Forty percent of the 2D students were curious compared to only 20% of the 3D students.

Conclusions/Implications

The procedures used to select the schools and assign a class to either 2D or 3D means that result can only be generalized to Montana agricultural education students in 11th and 12th grade in those schools. Based on the analysis and summarization of the data, the following conclusions have been drawn:

1. When viewing 2D images of production agriculture, students were able to correctly identify features or attributes present about 50 percent of the time. The mean score on the 17 questions for the 2D group was 8.58, which translates into an average of 50.47 percentage correct.

2. When viewing 3D images of production agriculture students were able to correctly identify features or attributes present about 50 percent of the time. The mean score on the 17
questions for the 3D group was 8.31, which translates into an average of 48.88 percent correct.

3. Based on the 17 question test scores there is no significant difference in students’ spatial cognitive abilities when viewing 2D and 3D production agriculture images.

4. When viewing production agriculture images in 3D, containing features and attributes relative to elevation, spatial cognition is enhanced. The 3D group scored higher than did the 2D group on 6 questions. These questions revolved around features and attributes that are influenced by elevation. By viewing the features in the images from different angles spatial cognition improved.

5. Age, grade level, semesters enrolled in agricultural education, gender, place of residence and prior GIS experience do not significantly enhance spatial cognition. Gender in this study had little effect on spatial cognition when viewing agriculture production images. This is contrary to what the Moffat et al. (1998) reported.

6. Students are interested in learning with 2D or 3D production agriculture images. Sixty-three percent of all students indicated that they were curious to excited, when viewing these images. In a 2D school where there was only one class involved in the study so, the researcher showed the students the 3D images. As a result, students demonstrated a desire to learn more about the agriculture production images.

7. The data suggests that in some images there maybe too much information for the spatial cognition abilities of these participants. With the inclusion of more 3D viewing opportunities, students may gain more spatial cognition. The overwhelming amount of data may have influenced the answers for some of the 3D participants. With further development of those skills, the students may be better able to interpret the information.

Recommendations

Spatial cognition is a skill that will be in high demand in the future. This demand will be based on the increased utilization and expansion of geospatial applications. Spatial intelligence is enhanced with the use of real world applications common in agricultural education. The following recommendations are based on the research findings of this study, the comments made by the students and the need for improved spatial cognition of agricultural education students.

1. Agricultural Education teachers need to incorporate GIS instruction into their instructional programs to enhance spatial cognition. The use of satellite imagery and remote sensing technologies need to be incorporated into the curriculum to enhance spatial cognition.

2. Agricultural Education teachers should incorporate a variety of instructional strategies that will enhance spatial cognition.

3. Agricultural Teacher Education programs should incorporate GIS and basic remote sensing in preservice instruction. Workshops in these subjects should be provided to current teachers.
4. There needs to be more research conducted on spatial cognition abilities of high school students. Hopefully, this study will serve as a starting point for further research in this area.

References


