Student Visualization: Using 3-D Models in Undergraduate Construction Management Education

Scott Glick, Ph.D., LEED AP, Dale Porter MS, Charles Smith, Ph.D.
Colorado State University
Fort Collins, Colorado

Three-dimensional computer models used in the classroom may help increase student understanding of new and complex course material, and provide an opportunity to enhance visuo-spatial skills. Students lacking these abilities may have difficulty visualizing construction systems and components. This study explores the results of a survey conducted in the Fall of 2009 as part of a curriculum development project in the Construction Management Department at one University. Over twenty 3D models were created from figures in the course text and used, to varying degrees, in three sections of a materials and methods class. Focusing on four CSI divisions, the results indicate that students’ perceptions of learning masonry (F (2,123) = 12.01, p = .001) and metals (F (2,122) = 3.6, p = .031) increased when 3D models were part of the course material presentation. The results were also used to direct resources for additional 3D model development.

Key Words: Construction Education. Spatial Cognition, Curriculum Development, 3-D Computer Models, Building Information Modeling

Introduction

An ongoing challenge for Construction Management (CM) faculty and students is how to both teach and learn the myriad of construction specific information presented to incoming undergraduates. Students coming into CM typically do not have an extensive background in the field and sometimes struggle in core content courses like: construction materials & methods, plan reading, and estimating. The learning process may further be impacted by the availability of experiential courses within CM program curriculum. It is in these courses where students get hands on experiences that help them visualize the construction concepts, and associated definitions and terms with the actual materials, assemblies, and drawings. This issue is not unique to CM. Several studies have been conducted in the field of engineering where incoming students also lack real world experience. In both educational areas a common thread maybe the mental conversion process from a two-dimensional (2-D) plan/blueprint view into an understandable three-dimensional (3-D) visualization; a process that is frequently exasperating for students (Deno, 1995). The ability to visualize construction plans, integrate written specifications into the construction process, create an estimate and schedule are critical functions of the construction manager made easier by strong visualization skills. The development and use of visualization skills in the CM classroom may help convey the content of specific courses to the student. Without a point of reference to ground these new concepts, the ability of students to picture individual construction components, building sections, and assembly methods can be vexing.

The problem itself depends on, and is centered on each individual’s ability to visualize spatial relationships. Spatial visualization is often defined as the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimuli (McGee, 1979). The study of a person’s spatial visualization abilities has been of high interest within several disciplines of academia for nearly 90 years. Interest in this research stems from early performance aptitude tests that were used to predict the cognitive abilities of students, engineers, potential employees, and soldiers (Miller, 1996, McGee, 1979). Spatial ability tests for cognitive aptitude are still of high interest within academia as they allow researchers to test and monitor the progress of incoming college freshmen (Deno, 1995). While one might expect this research to be significant within the fields of architecture, engineering and construction; fields such as psychology, biology, mathematics and other hard sciences have offered contributions to current research on spatial ability (Huk, 2006; Olkun, 2003; Lord, 1985; McGee, 1979).

One possible reason for the peaked interest in visuo-spatial abilities is that engineering graphics course requirements in American programs appears to be in decline. These were the very courses that emphasized spatial relations
abilities and related lessons. This contrasts sharply with the fact that recent technological gains such as those made in computer aided drafting and estimating software demand even greater spatial visualization skills for users (Sorby & Baartmans, 1996). Similar to engineering students, those within the field of CM are no exception to the demands of technological advancement. Popular estimating software such as On Center’s On-Screen Takeoff (OST) offers such an example. Using OST, student estimators are required to locate, indicate, measure, and count particular building components within a 2-D plan view displayed on a computer screen. Because the view is limited in comparison to hard copies or paper plans, an even greater ability to imagine building construction and individual components is required.

Construction education curriculum has historically placed an emphasis on hands-on learning. Different types of building connections, material types, and assembly systems were introduced to students in lab environments. Unfortunately, in some programs, as the number of remedial classes has increased, the number of experiential construction labs has decreased. The challenge, to both students and educators, is the presentation of effective instructional materials that can help generate a utilitarian understanding of spatial relations and its associate understanding of construction system components. CM classes that were once taught from the perspective that students had already obtained basic spatial awareness are now being reorganized to educate at a remedial level (Deno, 1995). The current educational environment, especially within the discipline of CM, demands that students be able to obtain and exercise a reasonable degree of this awareness. Social changes have also affected the demographics of freshman college students, especially those from rural areas where farm related industries required a mechanical aptitude. The mechanization of agricultural jobs and equipment has reduced the need and ability for field repairs and ingenuity. The intent of most product manufacturers is to replace rather than repair, which can negatively impact the overall understanding of mechanical processes and spatial relationship skills.

The common thread that ties the majority of spatial ability studies together are questions regarding the inherent nature of spatial visualization (Vandenberg, 1969), whether it is acquired through childhood experience (Buchal, 2001; Deno, 1995), or can be taught (Strong & Smith, 2002; McGee, 1979;). It is this last question that should be of most interest to educators. One possible insight into the question of spatial relation training is the effect that Building Information Modeling (BIM) has within the construction industry. BIM is defined by the U.S. National Institute of Building Sciences (NIBS) as: “A building information model (BIM) is a digital representation of the physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward” (Kraus, Watt, & Larson, 2007, p.1). The difference between the creation and use of 2-D plans and the initiation of the 3-D design systems used in BIM models is that BIM allows draftsmen to use intelligent lines, meaning that the computer can recognize individual construction components. Individual components such as slabs, walls, windows, roofing and HVAC systems can now be identified and quantified by their particular properties (Kraus et al., 2007).

If BIM modeling has the ability to form a more inclusive overview of an entire construction project for industry professionals, including the more precise details necessary for shop drawings, then it is reasonable to ask if 3-D modeling alone can help CM students form a more accurate conceptualization of building components by enhancing their spatial visualization skills. Some of the potential problems with using BIM software for model or component viewing purposes include instructional time and initial cost. More simple versions of 3-D modeling software offer possible solutions. One such popular software group is Google’s SketchUp Pro. This product has the advantage of being quick to master and provides adequate detail to express construction components in a highly recognizable form. Additionally, Google allows customers to download a basic version of SketchUp for personal use at no cost. Instructors should be aware that additional time and effort will be required to create a working curriculum. This is perhaps one drawback to the use of 3-D models. However, like many community shared software packages, Google encourages public sharing of ideas and complete models can be accessed free of charge via their 3-D Warehouse.

**Background**

During the early part of the 20th century (1920-1940), Clair V. Mann was responsible for the creation of a great number of spatial visualization tests. Mann claimed that these tests were indisputable as indicators of specific engineering abilities because engineering is identified as one of the primary disciplines that demand a significant level of spatial ability (Miller, 1996; Deno, 1995). One of Mann’s objectives was to establish national norms for visualization tests in order to predict success in engineering students (Miller, 1996). Additional tests were developed
and standardized for use in predicting success in the fields of drafting, design, mathematics and several other hard sciences. Many of these same tests, such as the Minnesota Paper Form Board Test, the Link Spatial Relations Test, and the Packing Block Test, are still in use today (McGee, 1979).

The importance of spatial awareness abilities is dramatized by Deno (1995) in his conclusion that the failure rate of first year engineering students at Ohio State University is partially due to the lack of spatial visualization abilities. This lack of understanding and the accompanying frustration has led as many as 10% of the entering students to drop the program. As a possible stop-gap and spatial teaching method, Deno suggests that 3-D computer models might be effective in teaching spatial relationships. Deno is also a proponent of remedial spatial awareness education (1995). Engineering education has placed the greatest emphasis on studies concerning visuo-spatial education possibilities; many of these studies have a direct correlation to this exploratory study. Alias, Black, & Grey (2002) concluded that “...engineering educators need to place more emphasis on the development of these (spatial visualization) skills in their engineering students” (p.11). They continue with the idea that a spatial awareness curriculum should be developed and additional remedial classes should be provided for those with low spatial visualization abilities and for those students with low mathematical and analytical skills (Alias et al., 2002).

Several studies conclude that pedagogy plays an important role in the development of spatial abilities (Olkun, 2003; Strong & Smith, 2002; Lord, 1985). One such study concludes that computer model exercises were no more beneficial than traditional orthographic drawing exercises, yet both practices appeared equally promising when combined with mental rotation exercises (Braukmann & Pedras, 1993). Remedial classes that attempt to teach spatial awareness skills have been developed and their results published. Sheryl Sorby and Beverly Baartmans have collaborated on one curriculum designed for entering mechanical engineering students who scored lower than 60% on the Purdue Spatial Visualization Test: Rotations (PSVT:R) (1996). Student responses to the visualization class were generally positive, with one student commenting that: “It did teach me how to rotate things in my mind” (Sorby & Baartmans, 1996, p. 19). This comment is highly illuminating as mental rotation of 3-D objects is considered one the more difficult cognitive tasks (Kay, 1991).

Sorby and Baartmans have offered additional insight with a list of significant factors that predict success on the PSVT: R tests. These factors included: playing with construction toys (Lego™, Lincoln Logs™, and Erector Sets™), gender, math ACT scores, and previous experience in design related courses (1996). Combining both the ideas that construction toys and remedial spatial visualization classes are effective in improving spatial awareness skills, Buchal incorporated the two and had his students virtually construct Lego™ toy models using 3-D modeling software. His students reported that they believed the actual model building exercises, rather than simply viewing the models, were the most effective at improving their visuo-spatial skills (Buchal, 2001).

3-D modeling software ranges from the simple to complex. The question is: what level of detail is necessary to convey the intended message? Some universities are developing Distributed Virtual Reality (DVR) environments that utilize visor hoods to immerse their students in full scale 3-D virtual atmospheres (Green & Sulbaran, 2006). These methods of display qualify as highly complex. These types of virtual trainers have been used by both the aviation industry and military with a high degree of success (Ramaswami, 2009). DVR has also found success in the world of manufacturing, proving its potential in shortening the time from design-to manufacturing and assembly cycles for new products (Steffan, Schull & Kulhen, n.d.). DVR appears to provide greater interaction with proposed plans and assembly systems, allowing designers to avoid mistakes and costly inefficiencies. The counter-argument to the construction of these DVR labs is cost. Construction scheduling classes in particular have recorded a higher level of understanding using these impressive arrays, but the expense of these systems places them outside the reach of many (Green & Sulbaran, 2006).

One possible answer to the expense vs. detail debate can be found in the research conducted by Herrington, Reeves and, Oliver (2007). Their research suggests that “cognitive realism” can supplant reality itself, and that realistic problems are just as important as one’s exploratory environment (Herrington, Reeves & Oliver, 2007). If what Herrington et al. suggest is true, then one has to consider the benefits of introducing 3-D models as a spatial awareness resource and, what level of detail and expense must be provided to truly improve visuo-spatial skills. The current literature is inconclusive as to whether or not spatial abilities can even be taught. However, those who are proponents of visuo-spatial education open a second debate on the effectiveness of using 3-D models, compared with the more traditional methods of hands-on drafting.
Proponents of improving students’ spatial abilities by teaching traditional drafting methods argue that by explaining technical rules, students can be taught to “think” correctly (Olku, 2003). They stress that hands-on sketching and drawing will improve spatial skills compared with courses based on computer models (Leopold, Gorska & Sorby, 2001). Conversely, several authors have concluded that visualization can be taught, and that 3-D computer models, when combined with detailed discussion and the correct teaching methodology, are effective (Clayton, Warden, & Parker 2002; Deno, 1995). Additionally, several authors prefer a mix of the two methods or base their conclusions entirely on student preference (McLaren, 2007; Paas, Renkl, & Sweller, 2004).

**Sex Difference**

While not the focus of this paper, several studies have concluded that cognitive spatial abilities differ greatly between men and women (Lewin, Wolgers, & Herlitz, 2001). Studies consistently show men ranking higher in their ability to rotate visualized objects mentally. New research has found that these differences appear in children as young as 5 months old (University of California, 2008). The difference in gender may play an important role in future CM learning studies as the number of women increase in these programs.

**Cognition**

One of the more unique theories presented in the available literature suggests that spatial visualization is connected to personal beliefs; subjects often mentally envision objects based on previous knowledge and experience (Olson & Bialystok, 1983). While this concept may sit outside the normal range of ideas, it is most easily understood when presented in a colloquial format. Cartoonist Bill Watterson effectively illustrated this same idea in his *Calvin and Hobbs* comic strips. The young and imaginative cartoon character Calvin would often visualize shadows in his darkened bedroom as drooling, slithering monsters. Following some mildly destructive antics, the lights would come on to reveal a dresser or chair as the envisioned terror. These delusive images came all too easily when Calvin’s mind was primed with scenes from scary movies or comic books (Watterson, 1988). Olsen et al. are suggesting a very similar idea. When subjects are presented with representations of unfamiliar objects, the mind will automatically focus in on seemingly familiar shapes, and form conclusions that may or may not be accurate (1983). This is one additional item that instructors must be aware of when presenting new material and this information should be considered in conjunction with the pedagogy being employed.

To avoid incorrect perceptions, one must ask what level of detail is necessary to avoid incorrect interpretations of displayed models. While praising the sophistication and realism of one virtual reality simulation system, one study goes on to suggest that the physical reality of the environment is still of less importance than the task design (Herrington et al., 2007). Clayton et al. avoid this conflict by stating that in the modern classroom there is little choice. Hands-on training is either too expensive, time consuming, or in the case of field trips, presents too high of a risk factor (2002).

Cognition overload is one more consideration when dealing with high definition, immersive reality, or complicated graphics. The postulation is that performance degrades at the cognitive load extremes of excessively low load (underload) or excessively high load (overload). When subject to conditions of both under-load and overload, all learning may cease. Using this premise, one study recommends that curriculum and tasks should vary based upon an individual’s abilities (Paas, Renkl, & Sweller, 2004). Allen Kay, formerly of Apple Computers, also warns about the dangers of cognitive overload. He complains that computer generated information may generate too much information to be readily assimilated. Kay states that some of the graphics based curriculum offered in modern classrooms “…is like being taken to the world’s greatest restaurant and being fed the menu” (1991, n.p.). Another study dealing with cognition overload proposes that high spatial ability learners should benefit from computer generated models. These students would have the cognitive capacity for mental model construction. In contrast, low spatial ability learners would suffer as they commonly have difficulty mentally constructing their own visualizations (Huk, 2006).

At the other end of the spectrum is a study that suggests too little definition in representative graphics might also be problematic and delve towards cognition under-load. In Miller’s review of spatial awareness literature he quotes Devon, Engle and Foster who state that: “…exposure to a solid modeling curriculum did advance students spatial abilities more so than the exposure to wireframe modeling (as cited in Miller, 1996, p. 30). This research suggests
that there might be a necessary balance between hyper-rich graphics and simple wire frame models. On a cautionary note, Green and Sulbaran both warn that instructors in spatial awareness remedial classes must not fall victim to what they refer to as “edutainment”, or hyper-rich graphics for the sake of engagement. They cite several studies that indicate students who spend much of their free time playing graphic rich video games will easily become bored with common pedagogical tools; by this the authors are referring to 2-D presentation formats (Green & Sulbaran, 2006). However, the use of 3-D modeling software is not designed to compete with the “flash and bang” of modern video games, and accordingly, their work also suggests that task driven assignments are essential for success. Spatial cognition has also been shown to affect one’s writing abilities. Grow proposes that talented writers are highly proficient at spatial skills, and have the ability to articulate places, objects, or directions effectively to the reader. According to Grow’s research, the sense of vision may be overrated in spatial visualization abilities, as mental visualization skills have been developed by people who lack the sense of sight (Grow, n.d.).

In 1963 Dr. John B. Carroll of Harvard University produced a paper entitled: A Model of School Learning. Within his paper Carroll creates a model that proposes “… a learner will succeed in learning a task to the extent that he spends the amount of time that he needs to learn the task” (Carroll, 1963, p. 60). A student’s need to learn is often self-defined. Time needed to learn differs greatly from the total time spent working on a particular problem. Organization, daydreaming and personal ergonomic adjustments take up study time, but those items do not add to the understanding of the intended content. The author’s model takes into account the quality of instruction, time allowed for learning, and student’s aptitude, ability to understand instruction, and individual perseverance. Possibly one of the most crucial elements in Carroll’s model is the quality of instruction (Carroll, 1963). This factor has a degree of control over any additional time students need to understand the material presented. Real learning time is proving to be a valuable commodity. Therefore the use of 3-D models must add to the learning environment, or they relegate themselves to merely entertainment; or worse, distraction.

Several recent studies/papers in CM focus on the integration of BIM into CM curriculum to enhance estimating skills, the undergraduate and capstone experiences, and to integrate technology into the curriculum. The use of technology in the classroom from a student perspective highlighted differences in students and faculty views on technology, student expectations for technology use in the classroom, and how to bridge the technology gap in the classroom (Hatipkarasulu, Liggett, and Padilla, 2008). This article did not mention the impact technology may have on helping new CM students learn core concepts. Gier (2008) looked at the impact of BIM in teaching CM students estimating. Drawing from existing literature that supported using BIM for estimating, in conjunction with drawing on the student’s experience, the article found that students needed to take the initiative to learn BIM and OST type programs on their own. The study looked at fourth year student time needed to complete an estimate and did not consider the students experience level. The author noted that BIM, as a visualization tool, appears to be an effective tool for teaching estimating although no mention was made of the impact on visualization skill development (Gier, 2008).

Three students in an undergraduate capstone course studied the impact of using BIM to help complete a “traditional thesis” using a survey and descriptive statistics (Azhar, Sattineni, and Hein, 2010). While the study was of interest, it focused on seniors and did not mention the impact of BIM on the development of visualization skills among the students surveyed. In conjunction with the student, faculty at the same institution looked at integrating BIM into an ACCE accredited CM curriculum (Taylor, Liu, and Hein, 2008). The discussion covered several programs, student learning of BIM type software, and course integration at several non-identified levels. Of particular note from a student was the comment that “I think BIM would be an excellent teaching aid in working drawings and specs. A professor could get a model in three dimensions and show the section, elevations, and plans from it. This would help students visualize exactly how 2 dimensional plans translate into a three dimensional structure” (Taylor, Liu, and Hein, 2008, p 8).

While the existing literature is revealing and pertinent to understanding spatial visualization skills there have been no studies that focus on the use of 3-D models at the introductory level in CM programs as a replacement for experiential education class components. It is important for the CM educator to understand the impacts on student learning from the lack of experience in construction prior to college, and the change over time decline of incoming student spatial skill sets. This research will look specifically at the continued relevance of existing studies, the impact of 3-D models at the introductory course level in a CM program, and the impact they have on students’ perceptions of learning core concepts. The later will be done in an effort to determine if further development of 3D models will be effective in raising student understanding of course content.
Research Objective

The intent of this exploratory research is to understand and compare CM student perceptions, preferences, and interpretations of several course material presentation methods. Additional information was collected to compare findings of previous research and determine continued relevance in CM. The students in an introductory materials and methods course were the subject of this study. Several survey questions were included to gather background information. The study focused on the use of 3-D computer models in the classroom as a way to increase student understanding of complex relationships important to understanding foundational concepts. The goal of this exploratory study is to establish a baseline to determine whether future research on spatial analysis and visualization is warranted in a university's construction management education curriculum. A secondary objective was to determine where to allocate faculty time and department resources to better reach students in the classroom.

Methodology

This study used a survey instrument and parametric statistical analysis to collect and analyze data from students. The purpose was to understand the development of teaching methods in an introductory CM course; specifically the use of 3D models. The study used a convenience sample of students in an introductory materials and methods course. Given the small number of participants (N=127) the results will not be generalizable to the entire population of CM students. However, given the nature of the study and the intended use of the results, making a decision to continue with 3D model development in a specific course, the method used was appropriate. This research method is acceptable in an exploratory setting providing results and direction expeditiously. The use of inferential statistics (one way analysis of variance (ANOVA)) is appropriate for analyzing the survey results based on the number of groups and dependent variables in this study. There were three class sections with random assignment of students and faculty through the standard enrollment process. Two faculty members were assigned to teach the three sections; one faculty member taught one section, the other faculty taught two sections. To control for teacher effect both teachers used the same traditional course presentation materials and tests. The traditional teaching presentation methods included textbook readings and accompanying drawings and pictures, Power Point presentations, actual material samples, some small scale system components, handouts, homework, and photos of topic related construction projects. This study was designed to record and compare student opinions of any perceived benefits of the use of 3-D computer models in addition to the traditional curriculum presentation formats. The following construction specifications institute (CSI) divisions were chosen for study: 3, concrete; 4, masonry; 5, metals, and 6, woods and plastics.

The survey instrument was developed using information gathered from a comprehensive review of the literature involving visuo-spatial abilities and questions specific to the researcher’s interest. Based on this review a survey instrument was created to measure the students’ perceived impact of using 3-D computer models on their understanding of complex construction systems in the four CSI divisions. In addition to 3-D model impacts, information on student preferences in presentation methods, student’s prior construction experience, gender, upbringing, and age were also collected. These data will be used to help identify topical areas where the inclusion of 3-D models may increase student understanding. The survey instrument was piloted internally to faculty members in the CM department.

Analysis and interpretation of data were processed with IBM Statistical Package for the Social Sciences (SPSS) software. Descriptive statistics were included to provide simple summaries of the sample groups and their measures. A one-way ANOVA compares different means, and was chosen to assess any differences found between the three groups being surveyed. Additionally, one-way ANOVA considers answers provided by individual participants. The data was cleaned and screened for missing or nonsensical values. A Levene’s test was performed to check for homogeneity and the data was found to be normal. The Levene’s test assumption that the variances in the three class groups are equal for each of the dependent variables was supported. To prevent type one errors and to obtain a more conservative result in the following hypotheses, a Tukey Post Hoc was also performed on any F (F is used to see if the expected values of what is being measured quantitatively differ from one another within several pre-defined groups) that was found to be statistically significant.
Concrete Hypothesis
Use of 3D computer models will have no impact on students’ perceptions of their understanding of the concrete teaching unit.

Masonry Hypothesis
Use of 3D computer models will have no impact on students’ perceptions of their understanding of the masonry teaching unit.

Metals Hypothesis
Use of 3D computer models will have no impact on students’ perceptions of their understanding of the metals teaching unit.

Woods and Plastics Hypothesis
Use of 3D computer models will have no impact on students’ perceptions of their understanding of the woods and plastics teaching unit.

3-D Models
Several 3-D models of specific construction components were created using Google Sketch Up Pro software. This software was chosen due to its limited expense, ease of use, popularity, and high visual quality. 3-D models created in SketchUp Pro representing specific building systems and components were designed to virtually replicate construction materials/systems presented in the materials and methods course textbook; Olin’s Construction: Principles, Materials, and Methods (Simmons, 2007). The choices of what to model in 3-D was based on a review of the isometric drawings (Figure 1) used in; the course text. However, the difference in between the two presentation methods is quite stark, isometric drawings are static in nature and 3D models can be manipulated to show multiple vantage points. The systems were then converted/modified into 3-D computer models using Google SketchUp Pro as shown in figure 2. The 3D models were used in lecture to provide viewpoints from all perspectives by using the rotation, flip, invert, and zoom features in SketchUp to provide students with viewpoints they could not achieve from looking at the traditional textbook isometric drawings.
The modifications to the book figure (Figure 2) included framing one bearing wall using a 16” O.C. stud layout and the opposite bearing wall using 24” O.C. layout to show the students the differences in top plate systems and load paths. In addition the floor system was designed to show the use of manufactured rim joist and TJI’s, subfloor layout, and methods used to secure the platform to the foundation. The in-class demonstration included rotating the building to a position where the students saw the floor system from a perspective that it looked like a vertical wall system to help them understand the similarities of the two framing systems.

Approximately 20 models were created and used during this course. The inclusion of these models with the traditional teaching methods allowed students to view several construction concepts in multiple formats. This process allowed students to compare the presentation methods and form opinions and preferences on the perceived impact of each method on their individual learning.
Sample Design

The students in this convenience sample were enrolled in an entry level CM Materials and Methods class at a University encompassing all grade levels. The enrollment process provided some randomization to group members. The Materials and Methods course is taught to both CM and Interior Design majors. Unlike higher level CM courses, this course is a core requisite that introduces construction materials and methods to students from various backgrounds. This study was limited to the 127 students enrolled in the fall 2009 course. The sample was limited to one semester to expedite the process of deciding whether or not to move forward with additional 3D model development.

Instrument

The survey instrument (Appendix A, Appendix B) was designed to include several of the core concepts that were the basis of previous studies identified in the literature. The survey in Appendix A was given to the students in G1 and G2 and while the survey in Appendix B was given to G3. The differences between the two surveys are questions 1, 9, and 10 relating to 3D modeling. The survey was designed to determine if the questions and results of prior spatial awareness studies are relevant. In addition to relevancy, the researchers wanted to measure the CM students’ perceived value of 3D models in classroom instruction and the impact on understanding of course materials. Questions were divided into three sections: Section 1 asked about student preferences in subject presentation methods. Specifically perceptions of how 3-D computer models aided in understanding 4 particular CSI divisions. Section 2 questions focused on students’ demographics including prior experience, age, declared college major, and family background. Section 3 asked students to rank their perceptions of difficulty in understanding the 4 CSI divisions: concrete, masonry, steel, and woods and plastics. Students used a rating scale to rank their perceptions with 1 indicating the highest level of difficulty and 4 being the lowest level of difficulty.

3D Model Presentation

The Materials and Methods class was taught three times per week; each lecture section is 50 minutes long. Weekly assignments include selected readings from the text book, homework assignments and pop-quizzes. To minimize discussions about the 3-D models between groups, the models were not provided to the students outside of class. To control for teacher effect both instructors used the same syllabus, power point presentations, handouts, and tests. The first instructor taught two sections (G2 and G3) and the second instructor taught the remaining section (G1). The first instructor was responsible for the mixed group (G2) which was allowed to view some of the 3-D models with traditional instruction, and (G3) which was the control group and received only traditional instruction. The second instructor taught the experimental group (G1) whose students viewed all of the 3-D models in addition to the traditional presentation methods.

Prior to administering the survey at the end of the semester, the students from G2 and G3 were given a presentation and explanation of all 3-D models used in the experimental class. Group G2 was shown some of the models throughout the semester but G3 did not see any of the models. The presentation of the models to these two groups was done in an effort to solicit feedback on the use of 3D models from students in the three sections. The measurement of student perception from all points of view is important to future research, survey design, and course development.

Results

Descriptive Statistics

Demographic descriptive statistics included major, upbringing, gender, experience, and family member in construction (Table 1).
Table 1

**Descriptive Statistics**

<table>
<thead>
<tr>
<th>Major</th>
<th>CM</th>
<th>ID</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>76%</td>
<td>22%</td>
<td>2%</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td></td>
<td>69%</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>Construction Experience</td>
<td>None</td>
<td>&lt; 6 Months</td>
<td>3-5 Years</td>
</tr>
<tr>
<td></td>
<td>41%</td>
<td>12%</td>
<td>36%</td>
</tr>
<tr>
<td>Geographical Background</td>
<td>Urban</td>
<td>Rural</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Family Member In Construction</td>
<td></td>
<td></td>
<td>66%</td>
</tr>
</tbody>
</table>

The majority of the students included in the survey were construction management majors (76%), 22% were interior design majors and the remaining 2% listed “other”. Of the entire parameter population, 31% were female and 69% were male. No statistically significant differences were found between males and females in their preferences of presentation methods, or their perceived difficulty in learning material in the four CSI divisions. This contradicts current literature on cognitive spatial abilities indicating there is typically a gender difference in visualization skills. Over one-half the students in this study indicated some level of construction background: 41% had no experience, 12% had less than 6 months, 36% had 3 to 5 years’ experience, and 11% had over 5 years’ experience. The students were also asked in which type of geographical environment they were raised: 60% said they had been raised in an urban setting and 40% recorded a rural upbringing. No statistically significant difference was found between these groups’ preferences for presentation methods or their abilities to understand the material in the four CSI divisions studied. Of the students surveyed, 66% had at least one family member involved in a construction related industry.

**ANOVA**

**Concrete and Wood Teaching Units**

One Way Analysis of Variance (ANOVA) was run for all four CSI divisions to determine whether there was a difference in students’ perceptions of the impacts that the use of 3D models had on their understanding of course material. The four CSI divisions studied were concrete, masonry, metals, and woods and plastics. No statistically significant differences were found in the concrete and wood divisions (Table 2). There is no evidence to suggest that either hypothesis should be rejected.

Table 2

**One Way Analysis of Variance Summary for 3-D Model Impact for Learning Concrete and Woods**

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
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<td>Concrete Between Groups</td>
<td>2</td>
<td>2.73</td>
<td>1.36</td>
<td>.989</td>
<td>.375</td>
</tr>
<tr>
<td>Wood Between Groups</td>
<td>2</td>
<td>.722</td>
<td>.386</td>
<td>.292</td>
<td>.747</td>
</tr>
</tbody>
</table>

**Masonry Teaching Unit**

A statistically significant difference was found among the three levels of 3D model presentation, F (2, 123) = 12.01, p = .001 (Table 4). Table 3 shows that the mean perceived impact for 3D models is 3.09 for students in the experimental 3D model group, 2.07 for students in the mixed traditional and some model, and 2.30 for students in the control traditional instruction group. The results of the post hoc Tukey HSD are presented in Table 4. There is evidence to suggest that the hypothesis be rejected. The frequent use of 3-D models did make a statistically significant difference in how students surveyed perceived the use of 3D models in the masonry teaching unit. Post hoc Tukey HSD tests indicated that the experimental 3D models/mixed traditional and some model groups differed significantly in their perceptions with large effect size (p < .05, d =1.49). Likewise, there were also significant mean differences on perceptions experimental 3D models/ control traditional instruction (p < .05, d = 1.22).
Table 3
Means and Standard Deviations Comparing Presentation Methods

<table>
<thead>
<tr>
<th>Presentation Method</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental 3D Models</td>
<td>35</td>
<td>3.09</td>
<td>.161</td>
</tr>
<tr>
<td>Mixed Traditional and Some Model</td>
<td>41</td>
<td>2.07</td>
<td>.148</td>
</tr>
<tr>
<td>Control Traditional Instruction</td>
<td>47</td>
<td>2.30</td>
<td>.139</td>
</tr>
<tr>
<td>Total</td>
<td>123</td>
<td>2.45</td>
<td>.148</td>
</tr>
</tbody>
</table>

Table 4
One Way Analysis of Variance Summary for 3-D Model Impact for Learning Masonry

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2</td>
<td>21.70</td>
<td>10.85</td>
<td>12.01</td>
<td>.001*</td>
</tr>
</tbody>
</table>

* p < .05

Metals Teaching Unit

A statistically significant difference was found among the three levels of 3D model presentation, F (2, 122) = 3.6, p = .031 (Table 6). Table 5 shows that the mean perceived impact for 3D models is 2.54 for students in the experimental 3D model group, 3.02 for students in the mixed traditional and some model, and 2.96 for students in the control traditional instruction group. As expected a statistically significant difference was found between $M_{G1}$ and both $M_{G2}$ and $M_{G3}$. The results of the post hoc Tukey HSD are presented in Table 6. There is evidence to suggest that the hypothesis be rejected. The frequent use of 3-D models did make a statistically significant difference in how the surveyed students perceived the use of 3D models in the metals teaching unit. The effect size $d$ for experimental 3D models/mixed traditional and some model is $d = .71$ which is larger than typical in the social sciences. The effect size $d$ for experimental 3D models/control traditional instruction is $d = .60$ which is close to medium.

Table 5
Means and Standard Deviations Comparing Presentation Methods

<table>
<thead>
<tr>
<th>Presentation Method</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental 3D Models</td>
<td>35</td>
<td>2.54</td>
<td>.142</td>
</tr>
<tr>
<td>Mixed Traditional and Some Model</td>
<td>41</td>
<td>3.02</td>
<td>.131</td>
</tr>
<tr>
<td>Control Traditional Instruction</td>
<td>46</td>
<td>2.96</td>
<td>.124</td>
</tr>
<tr>
<td>Total</td>
<td>122</td>
<td>2.74</td>
<td>.132</td>
</tr>
</tbody>
</table>

Table 6
One Way Analysis of Variance Summary for 3-D Model Impact for Learning Metals

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>2</td>
<td>5.06</td>
<td>2.53</td>
<td>3.6</td>
<td>.031*</td>
</tr>
</tbody>
</table>

* p < .05

Conclusion

The results of this study are twofold, examining the existing literature and providing guidance in further development of 3D models for use in a materials and methods course. The authors feel that we learned a great deal about how our students learn and this study helped focus our resources on the creation of 3D models in masonry. In regards to previous studies, identified in the background section, the results of this study suggest Deno’s (1995) assertion of the effectiveness of 3-D computer models in teaching spatial relationships may still be relevant and applicable to CM students. Two CSI divisions, masonry and metals, showed statistically significant differences in
the use of 3D models supporting increased student understanding of course materials. In addition, the students’ favorable response to 3-D models is consistent with Sorby & Baartmans (1996) finding where one student commented: “It did teach me how to rotate things in my mind” (page 19). His comment is highly illuminating as mental rotation of 3-D objects is considered one of the more difficult cognitive tasks (Kay, 1991). While not the focus of the study, in contrast to earlier studies that identified a gender difference (Lewin, Wolgers, & Herlitz, 2001), this study found no student perception that would suggest a link between gender and spatial abilities. In addition the differences in instructors, family construction connections, and geographical upbringing also showed no statistically significant difference in the perceived abilities of these students to understand the presented materials.

The research did fulfill the goal of identifying potential high impact curriculum areas that could benefit from the use of 3D models. This helped the CM department target limited resources aimed at increasing student understanding of core course topics. While these results are not generalizable to the entire population of CM students they identify topical areas in CM education that may benefit from the use of 3-D models in class curriculum. The students were asked to provide information on four CSI divisions (concrete, masonry, metals, and woods and plastics), identified by faculty as difficult for students to learn, and about the perceived impact of 3-D models on their understanding of the subject. The results show that students believe the use of 3-D models helped increase their understanding of metals and masonry. The effect size supports this perception. While the effect size in metals was medium as expected the effect sizes in masonry were much larger than typical and indicate that from a statistical significance and practical point of view the use of 3-D models may help students learn masonry and metals better in class room settings.

The research was successful in reviewing the applicability of 3D models in teaching and identifying specific content areas that may impact CM student learning. However, the use of new and existing presentations formats still need to be better understood in CM education. Future research is needed to ensure that over time educators understand any change in CM student culture which may impact student’s visuo-spatial abilities and their ability to learn core concepts. The survey results, based on student perceptions, indicate that further research in spatial awareness pedagogy aimed specifically at construction education is warranted. To accurately prepare the most advantageous curriculum for CM students, certain topics require further research. One topic of particular importance is the measurement of student perceived impact of new content presentation methods. To build on and validate this study’s findings, longitudinal studies of larger samples should be undertaken. Pre-test and post-test visuo-spatial abilities of CM students should be measured using testing tools referenced in the literature or available on the internet. Once the assessment tools are identified or created they could also be used to compare the effectiveness of visuo-spatial skills using not only 3-D model presentations, but student controlled computer modeling, and simple hands-on drafting instruction. Semester grades should be collected and compared to measure improvements in student understanding of the course curriculum. This research will require measurement over time and a commitment from faculty, students and departments. Information collected from such experiments could help orchestrate more efficient class instruction and improve in-class time management. Additional research areas may also include creativity and problem solving skills and the impact 3D model use could have in those areas.

The significance of this exploratory study on overall CM education is limited to the initial goal of identifying what areas to use 3D models would benefit CM students based on their perspective. However, once the student outcomes are measured over time to determine if the actual student performance outcomes support the students’ perceptions of what helps them learn, additional studies could be done. One study would be to measure the success of student perception of teaching methods that help them learn across different topical areas. If the students perceptions are accurate about how they learn this may help instructors improve classroom presentations. This may be a significant improvement to help bridge any generational difference between teachers and students as to how students learn. An increased understanding of why metals and masonry were significant but not woods and concrete may also help CM instructors understand how to become better teachers. Students with prior experience in these areas would be different than students without prior experience in these areas from an educational perspective. Students with greater understanding of woods and concrete that have no prior experience may tell the instructor that they are doing a better job of teaching these topics than they are in metals and masonry.

References


Appendix A

1. Which method of course material presentation best suited your learning style? Please rank with 1 most helpful to 5 being least helpful.

_____ Required readings
_____ Handout material
_____ References to drawings in the textbook
_____ Viewing samples of materials brought to class
Viewing 3D computer models of the CON 151 course material

2. Identify the level of impact you think the use of three dimensional (3D) models had on your understanding of complex course materials in CON 151.
   a. No impact
   b. Limited impact
   c. Some impact
   d. High impact
   e. Very high impact

3. What is your level of field construction experience?
   a. None
   b. Less than 6 months
   c. One - three years
   d. Three – five years
   e. More than 5 years

4. Please indicate your college major.
   a. Construction Management
   b. Interior Design
   c. Other, please specify _______________________________

5. Please identify your childhood interest from the following list. Circle all that apply.
   a. Coloring books
   b. Lego
   c. Video games
   d. Outdoor sports (list 3): _______________________________
   e. Indoor sports (list 3): _______________________________

6. Please identify members of your family that are in construction related industries.
   a. Father
   b. Mother
   c. Sibling
   d. Other, please list: _______________________________

7. Please list the three divisions that were the hardest for you to comprehend and learn.
   ________________________, ________________________, _______________________

8. Rank the following divisions in order of difficulty for you to learn/understand (1-4 with 1 being the most difficult).
   _____Concrete
   _____Masonry
   _____Metals
   _____Wood & Plastic

9. Rank the impact of the available class resources listed below on your learning/understanding of the subject matter listed in question 7 ( 1 highest impact, 7 lowest impact).
   _____Textbook readings
   _____Power Point Presentations
   _____Instructor comments
   _____Samples of materials brought to class
   _____3D simulations
   _____Class Handouts
10. Rank the impact on your learning/understanding of 3D simulation models by division (1 highest, 4 lowest).

- Concrete
- Masonry
- Metals
- Woods & Plastics

11. What is your age _____________________?

12. What type of setting were you raised in?

- Urban
- Rural

13. What is your Gender?

- Female
- Male

Appendix B

No use of models in class presentations

1. Which method of course material presentation best suited your learning style? Please rank with 1 most helpful to 5 being least helpful.

- Required readings
- Handout material
- References to drawings in the textbook
- Viewing samples of materials brought to class
- Viewing 3D computer models of the CON 151 course material

2. Identify the level of impact you think the use of three dimensional (3D) models would have on your understanding of complex course materials in CON 151.

   a. No impact
   b. Limited impact
   c. Some impact
   d. High impact
   e. Very high impact

3. What is your level of field construction experience?

   a. None
   b. Less than 6 months
   c. One - three years
   d. Three – five years
   e. More than 5 years

4. Please indicate your college major.

   a. Construction Management
   b. Interior Design
   c. Other, please specify ________________________________

5. Please identify your childhood interest from the following list. Circle all that apply.

   a. Coloring books
   b. Lego
   c. Video games
d. Outdoor sports (list 3): ___________________________________________________

e. Indoor sports (list 3): ___________________________________________________

6. Please identify members of your family that are in construction related industries.

   a. Father
   b. Mother
   c. Sibling
   d. Other, please list: _______________________________

7. Please list the three divisions that were the hardest for you to comprehend and learn.

   ______________________, ________________________, ______________________

8. Rank the following divisions in order of difficulty for you to learn/understand (1-4 with 1 being the most difficult).

   _____Concrete
   _____Masonry
   _____Metals
   _____Wood & Plastic

9. Rank the impact of the available class resources listed below on your learning/understanding of the subject matter listed in question 7 ( 1 highest impact, 6 lowest impact).

   _____Textbook readings
   _____Power Point Presentations
   _____Instructor comments
   _____Samples of materials brought to class
   _____Class Handouts
   _____Class discussion

10. Rank the impact on your learning/understanding of 3D simulation models by division (1 highest, 4 lowest).

    _____Concrete
    _____Masonry
    _____Metals
    _____Woods & Plastics

11. What is your age ____________________?

12. What type of setting were you raised in?

    _____Urban
    _____Rural

13. What is your Gender?

    _____Female
    _____Male