AC 2011-2821: IMPLEMENTING STUDENT-BUILT PHYSICAL MODELS: ADVANCED FRAMING AND 3” CUBE TO IMPROVE SPATIAL REASONING ABILITY AMONG FRESHMEN ARCHITECTURAL ENGINEERING AND CONSTRUCTION MANAGEMENT STUDENTS

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Implementing Student-Built Physical Models: Advanced Framing and 3" Cube to Improve Spatial Reasoning Ability Among Freshmen Architectural Engineering and Construction Management Students

Abstract:

To design projects most efficiently, architecture and engineering students need to develop their spatial reasoning in order to augment their ability to visualize and manipulate two-dimensional and three-dimensional objects. At our institution, architectural engineering and construction management students collectively attend 2 non-design courses (Graphics I (manual drafting) and Materials and Methods of Construction I courses) in their freshmen year. Other than brief exercises, such as the incorporation of a field trip to a construction site, a soil sieve test lab, and provision of material samples and construction videos in the classroom, both of these courses are heavily dependent on two and three-dimensional graphics to depict how buildings are drafted and assembled. Physical model building is not part of the current curriculum for either of these two courses. This study provides quantitative results from a spatial reasoning ability test and qualitative results from student surveys given to four separate sections of freshmen – Graphics I test and control groups and Materials and Methods of Construction I test and control groups in 2010. The Materials and Methods of Construction I test group had built an advanced framing model (an energy-saving framing system) and the Graphics I test group had built a 3” cube model of solids and voids as part of their courses prior to the spatial test and survey. The control group in each course prepared an axonometric drawing instead of a physical model as part of their course. The statistically significant results of the quantitative test and student answers to the qualitative survey indicate that faculty of non-design courses should integrate student built physical models as a tool to improve students’ spatial reasoning ability.

Introduction:

The goal of this paper is to investigate if course-integrated, student-built physical models have a positive effect on students’ three-dimensional (3D) spatial reasoning, in comparison to that of their peers in different sections of the same non-design course who did not build a model. Students in the architectural, engineering and construction fields often express an interest in building actual structures. If their course program does not offer a building laboratory component, student-built scaled physical models offer students an active learning experience in which they can build a 3D project. Although virtual 3D models can be created digitally, the majority of students in the first semester of freshmen year do not yet have the skills needed to work with the modeling software. In order to add an active learning experience, one test group of students in a Materials and Methods of Construction I class built an Advanced Framing model to learn how this energy- and wood-saving framing technique is more advantageous to the traditional platform framing that they had just studied. In an separate test group, a Graphics I course built a 3”cube of solids and voids to aid their understanding of how to draw a plan, section, elevation and axonometric.

In this paper, quantitative spatial reasoning test results and qualitative data of students’ perception of a model project will be presented. This study is a follow-up to the author’s study of the use of visual aids in classrooms that are not supplemented with a laboratory component for hands-on learning.

Background:

Spatial reasoning is "the mental manipulation of objects and their parts in 2D and 3D space."[1] It has also been defined as concerning the locations of objects, their shapers, their relations to each other, and the paths they take as they move.[2] Research has shown that there are 3 aspects associated with spatial ability: mental rotations, spatial visualization, and spatial perception.[3] This paper will concentrate on 3D spatial visualization.

Spatial ability has long been known to be an important cognitive ability for architects, engineers and others working in design and technical fields.[4] In fact it is not unusual for architecture schools in Europe to administer a spatial ability test as part of the admissions process to their program.[5] Contero et al found that there are three important instructional elements for the future engineer: "spatial visualization, freehand sketching and normalized view generation."[6]

Recent research on spatial ability has found that students who are exposed to appropriate learning environments show improvement in their spatial abilities. This is contrary to former beliefs that spatial visualization skills are developed through experiences and could not be taught effectively by formal education.[7] In a separate study, Alias et al reported that the spatial visualization ability of civil engineering students can be improved though spatial activities consisting primarily of object manipulations and free hand sketching.[8] A subsequent study by McArthur and Wellner found that where there was a decreased course focus on spatial ability training, students' spatial thinking and ability suffered.[9] Surveys of learning styles have shown that 65% of the student population are predominately visual learners, 30% are predominately auditory learners and 5% are predominately kinesthetic learners. Current students are said to the most visually stimulated generation that our educational system has ever had to teach.[10] Bonwell and Eison in their book titled *Active Learning: Creating Excitement in the Classroom* define active learning strategies as instructional activities involving students in doing things and encouraging thinking about what they are doing.[11] Willingham recommends that instructors present their course content in the mode (visual, auditory or kinesthetic) that best suits the subject matter rather than the students preferred modality.[12] Many topics, such as describing a molecular structure, a machine part or the components of a building connection would benefit from student interaction with a hand-held model. A scaled physical model can help to increase a student's understanding of how an object is put together or to determine how spaces interact with each other.

Building physical models is a common practice in traditional design studio classes. In the case of a building design course, students use working models throughout the project process to examine solids and voids, how spaces and volumes relate to each other, and to the planned building site and its surroundings, before they build a final presentation model. These models are tactile, visual, and spatial, can often be taken apart and reassembled, and can often be rotated or revolved. Students also produce virtual models of their work in computer programs such as AutoCAD Architecture™, Revit™, Google SketchUp™ and 3-D Studio Max™. Although they are not building a physical model that can be picked up and examined, computer models have many other benefits including being easily altered, electronically shared, virtually/digitally walked-through and used in the creation of construction drawings and schedules. Sorby has found that freshman engineering students in a spatial skills course who sketched images while working with physical models and a computer imaging program significantly improved their score on a three-dimensional aptitude test and achieved higher GPA's in subsequent engineering, calculus, and physics courses at Michigan Technical University than their peers who had not taken the spatial skills course. The study suggests that physical models can be helpful to many students.[13]

In another study, Harris et al found that biology students who had used hand-held models and molecular imaging programs together over several weeks "produced higher quality answers to certain higher-order questions than students who only used computer imaging programs during the same time period." [14] The authors conclude that their finding and those of previous studies — by Wu and Shah[15] (chemistry), Roberts et al[16] (biochemistry) and Sorby[17] (engineering) — indicate a relationship between tactile model use and student learning gains.

Kuo et al found in their 2004 study that computer models had an advantage over flat or perspective drawings in 2-dimensions (2D), but add that they were perceived by students as more difficult to work with than hands-on models. [18] There appears to be research on the spatial ability benefits of using physical models and computer generated model images in non-design lecture courses. However there is minimal data on the effects of student-created models on the development of their spatial intelligence.

Course Background:

First semester freshmen in our department programs – Architectural Engineering Technology and Construction Management Engineering Technology – take 2 non-design courses, namely Graphics I and Material and Methods of Construction I. The Graphics I course is a 2 credit course, conducted as one 3-hour session per week of the semester. It is a manual drafting class that introduces the student to plans, sections, elevations and axonometric drawing. Materials and Methods of Construction I is a 3 credit, one 3-hour session per week, introductory course to building materials and techniques including: soils, foundations, heavy and light wood frame, masonry construction, and steel-framed buildings. Sustainable building practices such as Advanced Framing are integrated throughout the program. This course is in lecture format and, other than a soil sieve test and site visits, it currently does not have a lab component. Traditionally both courses have been heavily dependent on faculty showing the students spatially symbolic representation items such as building material samples; drawing axonometric, isometric, 2-D drawings and diagrams on the blackboard; referencing textbook photos and PowerPoint slides; and teaching using a visual dictionary project (in the Materials and Methods course). Physical model building is not part of the current curricula for these courses. In addition, students do not take courses that incorporate 3D drawings and/or physical model building, such as Graphics II (AutoCAD) and Design 1 until their second semester or later.

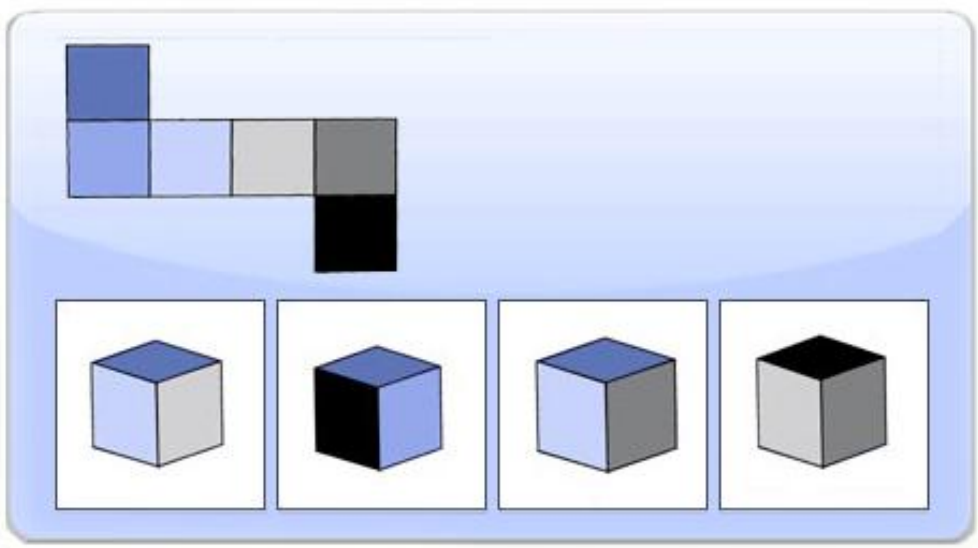
Methodology: Student Model Building

In this study, student model making was integrated into a project in one section of Graphics I and one section of Materials and Methods of Construction I in the fall semester of 2010. The goal was to determine if first semester freshmen students who build a physical 3-D model improve their spatial reasoning skills more than students who manually draw an axonometric drawing of the same material but do not build a model. In addition, students who prepared models were requested to rate their response to a statement regarding this model project on a 5-point Likert scale.

As a short baseline pre-test, students in 2 Graphics I classes (17 respondents in each class) and 2 Material and Methods of Construction classes, (18 respondents in each class), were given one simple 3-D spatial visualization problem to answer.[19] This question and all of the post-test questions have a flat plate with lines indicating folds and different colors on sections of the plate. Below the image, four objects are shown, only one of which might be made by folding the flat plate along the lines. The goal is to circle the one correct object that would be made by folding the flat plate with no overlaps and no concealed sections of the plate folded inside.

All students correctly answered this question as shown below. This result and results from previous class tests indicated that the 2 sections of students in each course were of equal ability regarding spatial visualization at the start of the study.

Pre-Test Question:

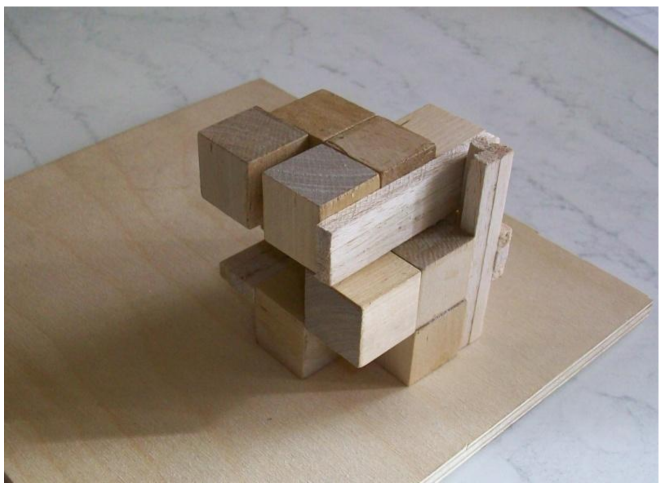


Answer = 1st image on left

Graphics I:

As an introduction to fundamental drawing techniques – scaled plans, sections, elevations and axonometric drawings – students in one section of this course (n=17) were asked to create a 3" solid/void cube model of their own design using 12 ¾" x ¾" x 3" wood rods and 1" wood cubes. The model was glued together with rubber cement and positioned on a 'site' - a 9" x 9" x ½" wood base. The author had experience using a variation of this project[20] in the past as an adjunct instructor at another institution, and thought it would be of benefit to this group of students as an interactive project. The students design, build, disassemble and rebuild if necessary, site the model on the base and draw their project to scale as plans, sections, elevations and axonometric. The physical models were built in class and brought back each session. As a group we discussed each of their ideas and its placement on the square base (which was their model's only site context). In previous years, students worked in isolation on their own individual project, transforming a small residential floor plan that they had selected, into the required drawings. But in this new exercise, they not only interacted with their own model and drawings, but also offered suggestions to their peers and learned basic design concepts in class by way of instructor led discussion. Through the introduction of this model project, a once non-design, static, first project turned into a rudimentary design project that was dynamic. Students could hold their model up and rotate it to inspect where the best location to "cut" a plan and section would be, and measure it to draw elevations and project the axonometric drawings. They also photographed their models and added these photos to their Graphics I portfolios, along with their drawings.

In contrast, the control Graphics I class (n=17), performed the standard coursework – manually reproducing scaled plans, sections, elevations and an axonometric of 2-D residential drawings from their textbook. Only the test group produced a model.



Graphics I Student Model (John Cheng)

Materials and Methods of Construction I:

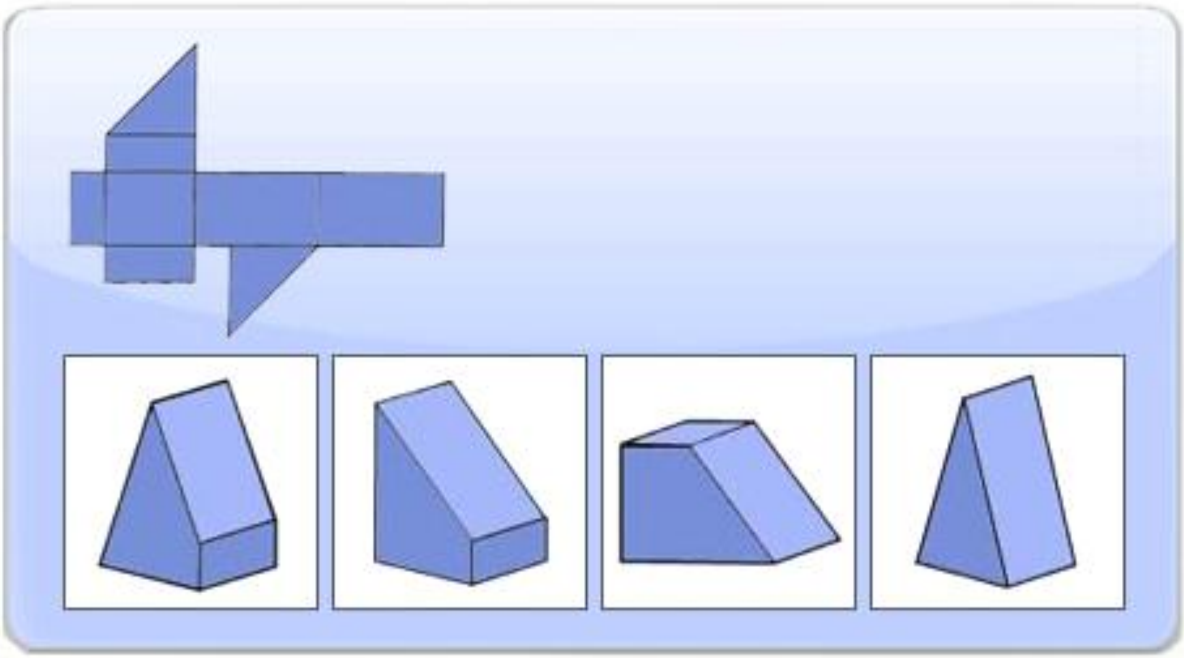
Two Material and Methods of Construction I classes, each with 18 respondents took part in this research. Each student in each group was given a list of Advanced Framing (2' o.c. light wood platform framing that saves energy and wood) building components, a simple isometric drawing of a framed wall showing the same components, and a grading checklist. The control group was required to draw a 1" = 1'-0" scaled axonometric of the corner of an Advanced Framed building showing and labeling the components. The test group was required to build a model of the same scale, using the same framing information and labeling requirements. Only the control group produced an axonometric drawing and only the test group produced a model. Both groups were given the same time period for their projects and were graded using the same checklist

Materials and Methods of Construction Student Model (Dana Nally)

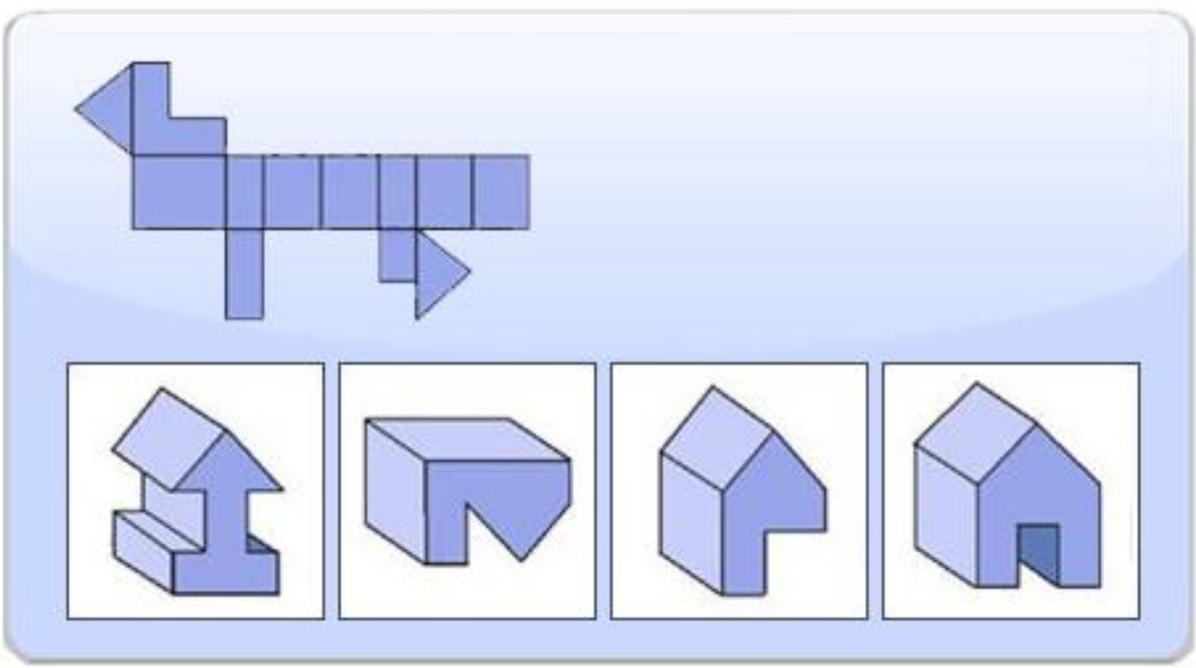
Quantitative and Qualitative Post-Tests:

On the last day of class, the 2 Graphics I groups and the 2 Material and Methods of Construction I groups were asked a short qualitative question (see below for more details) and given a standard spatial reasoning aptitude test from a reputable aptitude assessment test training website[21] as a post-test. The aptitude test was a combination of 2 tests and contained a total of 20 three-dimensional spatial visualization questions that ranged in complexity. The test had the same instructions as the pre-test question: a flat plate with lines indicating folds and different colors on sections of the plate above images of four objects, only one of which might be made by folding the flat plate along the lines. The goal was to circle the one correct object that would be made by folding the flat plate with no overlaps and no concealed sections of the plate folded inside. The pre-test question was not duplicated in the post-test. This type of test was closest to one of the sections of probably the most widely used spatial visualization tests - Project Talent. Project Talent was a test containing 4 spatial visualization sections that was given to 400,000 people in high school in the 1950's. This group was then tracked from that point to recent years. The results showed that people with higher spatial visualization scores in high school were more likely to enter Science, Technology, Engineering, and Mathematic (STEM) careers than those with lower scores.[22]

Sample Questions from the Post-Experiment Test:



Answer = 2nd image from the left



Answer = 3rd image from the left

Quantitative Results:

The following are the results for the 20 question spatial reasoning aptitude test.

Graphics I Course

Graphics 1 Course
One-Tailed t-Test for Unequal Variances (Welch)
α = 0.05

	No Model	***Model***
Observations	17	17
Mean	5.471	7.471
Median	5	7
Mode	5	8
Variance	1.015	3.890
df	24	
t Stat	-3.724	
t Critical, one-tail	1.711	
P(T<=t), one-tail	0.001	

Materials and Methods of Construction I Course

Materials & Methods Course
One-Tailed t-Test for Unequal Variances (Welch)
α = 0.05

	No Model	***Model***
Observations	18	18
Mean	5.333	7.556
Median	5	7.5
Mode	5	7
Variance	5.294	2.614
df	30	
t Stat	-3.353	
t Critical, one-tail	1.697	
P(T<=t), one-tail	0.001	

Assessment of Quantitative Data:

The above statistical results are significant and indicate that incorporating a student model building project into both the Graphics I and Materials and Methods of Construction I courses accrued a higher spatial reasoning score than equal courses that incorporated axonometric drawings alone. These results support the integration of model-building into curricula of non-design courses.

The timing of the test administration – the last day of class after models, drawings and portfolios were submitted may be the cause for the low overall average grade on this test. Students were not as focused a they were previously possibly due to fatigue.

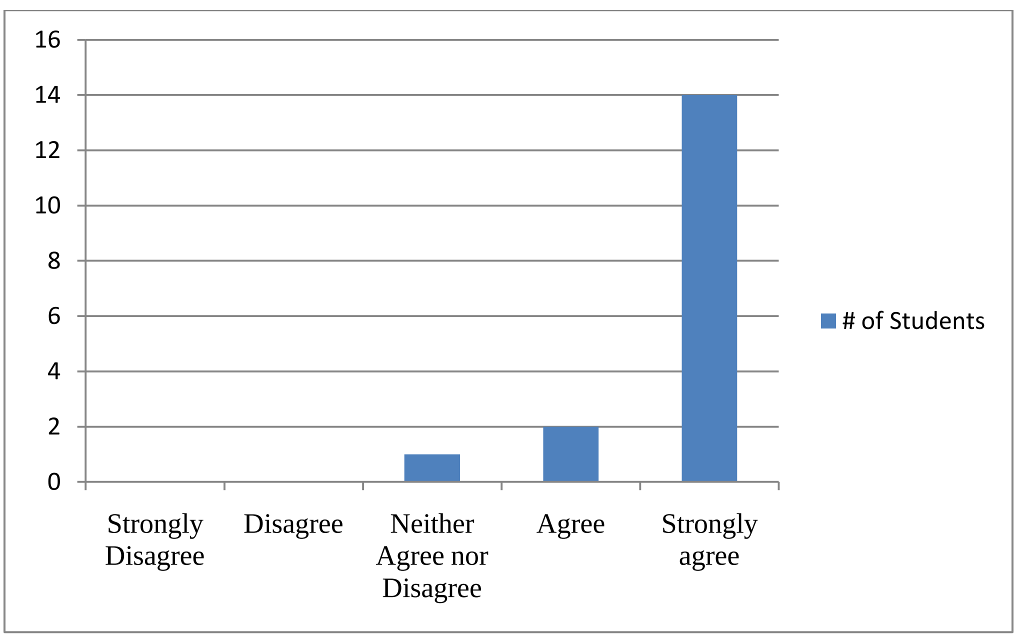
The female to male ratios in each group were as follows: Graphics I control group there were 0 females, 17 males; Graphics I test group there were 2 females and 15 males and in the Material and Methods of Construction I groups: control group = 5 females, and 13 males; test group = 1 female and 17 males. Contrary to previous studies that found that female scores on spatial reasoning tests were generally lower than male scores[23], this study found that the female students' test scores were in line with that of their male peers.

Qualitative Results:

Both test groups were asked to anonymously rate their answer to the following statements on a Likert scale (1 to 5 representing strongly disagree to strongly agree)

Graphics I Test Group (with model) Statement: "Project 1: 3" Cube Model was an appropriate first project in this course"

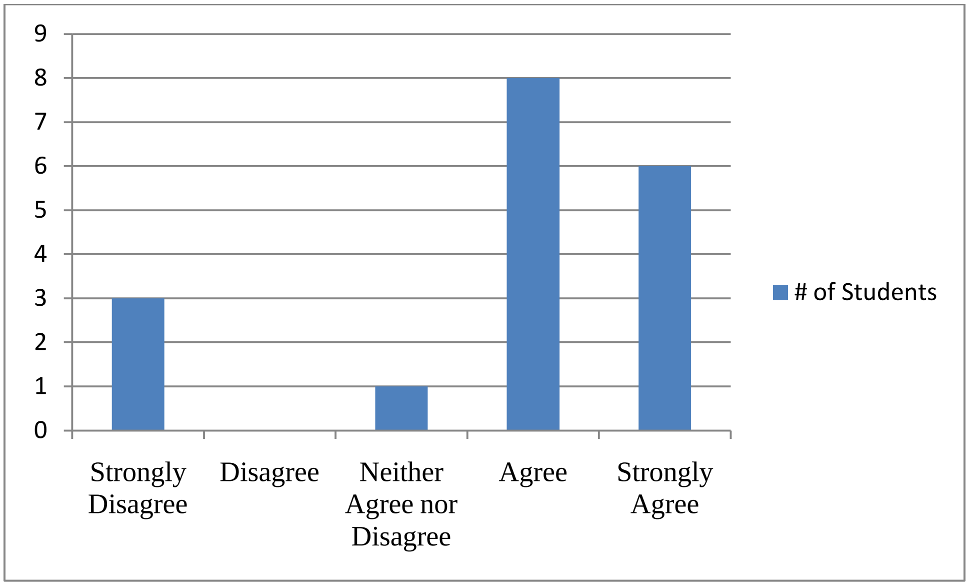
The following bar chart depicts the students' response to this statement:



Graphics I Group with Model - "3" Cube Model was an appropriate first project in this course" (n=17)

Materials and Methods of Construction I Test Group (with model):

Statement: "The ***Advanced Framing Model Project*** increased my knowledge of how this framing system is constructed."



Materials and Methods of Construction I Group with Model - "The ***Advanced Framing Model Project*** increased my knowledge of how this framing system is constructed." (n=18)

Assessment of Qualitative Data:

16 of the 17 Graphics I test students (94.18%) agreed or strongly agreed that their model project was an appropriate first project for that course.

14 of the 18 (77.78%) Materials and Methods test students agreed or strongly agreed that the model building project increased their knowledge of how an advanced framing project is constructed. It should be noted that this survey was conducted immediately after the students had submitted their models at the end of the semester. Undoubtedly the toll of having perhaps just finished their project may have rested heavier on some more than others. The 'strongly disagree' responses (16.66%) could due to any number of reasons for example: students who did not like producing something with their own hands; students frustrated by a project that may not have turned out as they had hoped, student dislike for the course or faculty in general, students who were or felt they were more advanced than the project topic or students who were achieving less than desirable grades.

Conclusion

The results of this study are statistically significant and indicate that the integration of student-produced physical models improve three-dimensional spatial ability and are welcomed by the majority of students. Based on these results, the author recommends adding student-built physical models as appropriate throughout the non-design course curricula starting in the first semester of freshmen year. This will aid the development of students' visual skills, provide an active learning exercise and increase the variety of teaching tools in the learning environment.

On an assessment level, the author also recommends that further study be conducted with a more extensive pre-test and a carefully planned administration time for the post-test.

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