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Using Physical Models in Improving Low Visualizers' Spatial Visualization Skills

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Abstract

Spatial visualization skills are essential for success in engineering education. These skills can be improved in engineering design graphics education. Due to multiple factors, engineering design graphics education has evolved from manual drafting techniques to more computer aided design oriented education. In general, improving engineering students' spatial visualization skill heavily depends on isometric pictorials in engineering graphics textbooks and 3-D modeling software. Meanwhile, recent research reports that low visualizers cannot significantly increase their examination scores with extra practice in engineering design graphics courses. Two engineering graphics design courses are offered to engineering students at a two-year college that is embedded in a four-year public institution. Engineering Graphics & Design I is the first course in a two-course sequence. Topics include but are not limited to fundamentals of engineering graphics: including orthographic projection and 2D drawing using AUTOCAD. Engineering Graphics & Design II introduces the principles of computer-assisted graphics and engineering design, with an emphasis on 3-D modeling techniques, using Inventor. This paper discusses how to improve students' spatial visualization skills by using physical models to produce orthographic views. The target group for this study is engineering students in a two-year college who are deficient in spatial visualization skills. Subsequently, they perform poorly in both Engineering Graphics & Design I & II courses. Low visualizers are identified based on their scores (less than 75%) on the first orthographic projection examination. Premade plastic physical models that include typical 3-D features such as normal surfaces, inclined surfaces, oblique surfaces and hidden surfaces/lines are offered to students who volunteer to participate for these extra hands-on activities. Students who take the assignments seriously show a dramatic increase in their final examination scores. This paper describes the methodology of the study and outcome of hands-on activities by using physical models to improve spatial visualization skills.

Introduction

Spatial Visualization is defined as the ability to "mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli."[1, 2] Researchers focused on how to improve Spatial Visualization skills for a very long time. With the development of Computer-aided design (CAD) software, many institutes and professors consider CAD as primary course content in engineering graphics. However, most engineering design graphics educators still agree that the most important topic in engineering design graphics curriculum is the improvement of students' visualization skills [3]. Many educators use 3-D models on a computer screen to help students to develop their visualization skills. From the author's teaching experience, students who have weak spatial ability cannot benefit much from 3-D computer models in a solid modeling environment. The survey results in the next section show students' responses regarding this conclusion. Research confirmed that 3-D computer models in a solid modeling environment do not develop spatial visualization skills as well as hand sketch [4].

Perimeter College (GSU-PC), which consolidated with Georgia State University (GSU) in fall 2016, is one of the largest feeder schools for the Georgia Institute of Technology, Kennesaw State University and Georgia Southern University. Many engineering students at Perimeter College are aiming to transfer to a four-year engineering institution through the Regents' Engineering Pathways Program (REPP). For the first two years in the REPP program, engineering students attend GSU Perimeter College and take all of the mathematics and science and seven engineering courses (two of them are engineering graphics courses) required in the first two years of the engineering curricula. Research has demonstrated that spatial visualization skills are fundamental for successes in STEM education [5, 6]. Other studies confirm that spatial visualization skills are associated with retention and graduation rates in engineering majors [2]. Improving spatial visualization skills are critical for our engineering students to be successful in their future engineering education at a four-year engineering institution. With lectures and enough exercises, most students can improve their visualization skills in engineering design graphics courses. However, recent research reports that low visualizers cannot significantly increase their examination scores with extra practice in engineering design graphics courses [7]. In this paper, the author discusses efficient spatial skills development method for low visualizers by using physical models.

Methodology

At GSU Perimeter College, Engineering Graphics & Design I (ENGR 1211) is the first 3-credit-hour course in a two-course sequence. Main topics covered in this course are orthographic projection and 2-D drawing using AUTOCAD. Upon successful completion of Engineering Graphics & Design I students should be able to develop their spatial visualization skills successfully. Engineering Graphics & Design II (ENGR 1212) introduces the principles of computer-assisted graphics and engineering design, with an emphasis on 3-D modeling techniques, using Inventor software. In ENGR 1211, typical visualization exercises present the objects in isometric views, asking to create multiviews. More advanced exercises include adding missing lines in incomplete multiview projections, adding missing view by giving two views of a multiview drawing of an object, or sketching isometrics pictorial by providing a multiple view drawing of an object. The author believes no other tools can substitute physical models in Engineering Graphics education. Therefore, Premade plastic models with typical 3-D features such as normal surfaces, inclined surfaces, oblique surfaces and hidden surfaces/lines were used in the classroom as supplementary tools in teaching orthographic projection. Figure 1 shows four premade plastic models. Models were presented by using an overhead projector. First, the author rotated models and let students observe from different directions. All 3-D features of models were analyzed. Second, the author guided students to draw multiviews of models. There were six models used in three class periods, fifteen to twenty minutes per model. To seek a fuller understanding of the effectiveness of using physical models in learning orthographic projection, an anonymous survey was conducted among students in two sections at the end of the semester in fall 2015. Eighty percent of students (24 out of 30) in section 200 and 83% of students (25 out of 30) in section 201 responded in fall 2015 semester. Figure 2 demonstrates that about 88 % of the students strongly agree or agree that physical models helped them to understand orthographic projection.

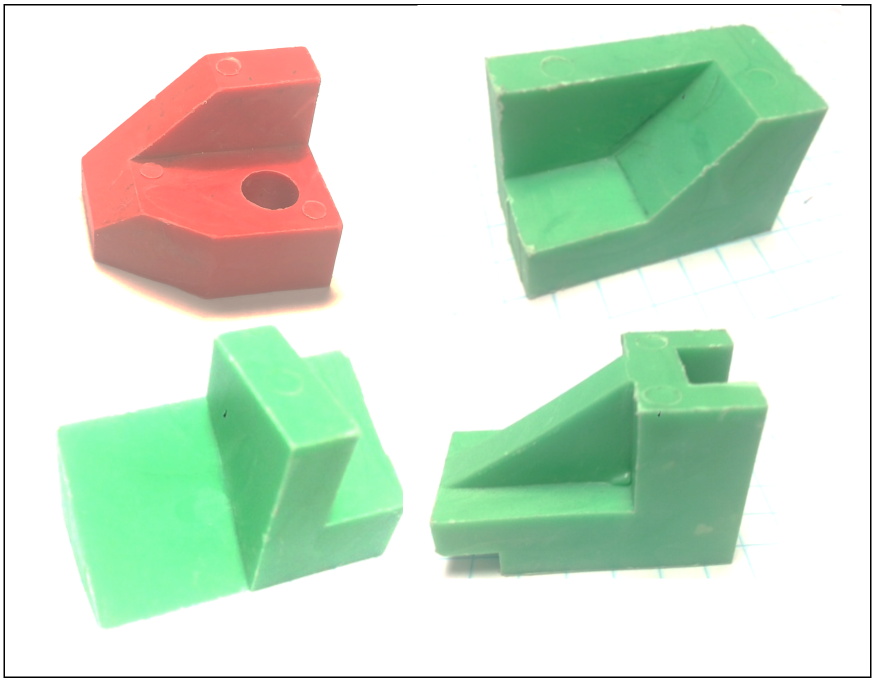

Figure 1. Premade physical model used in hands-on activities

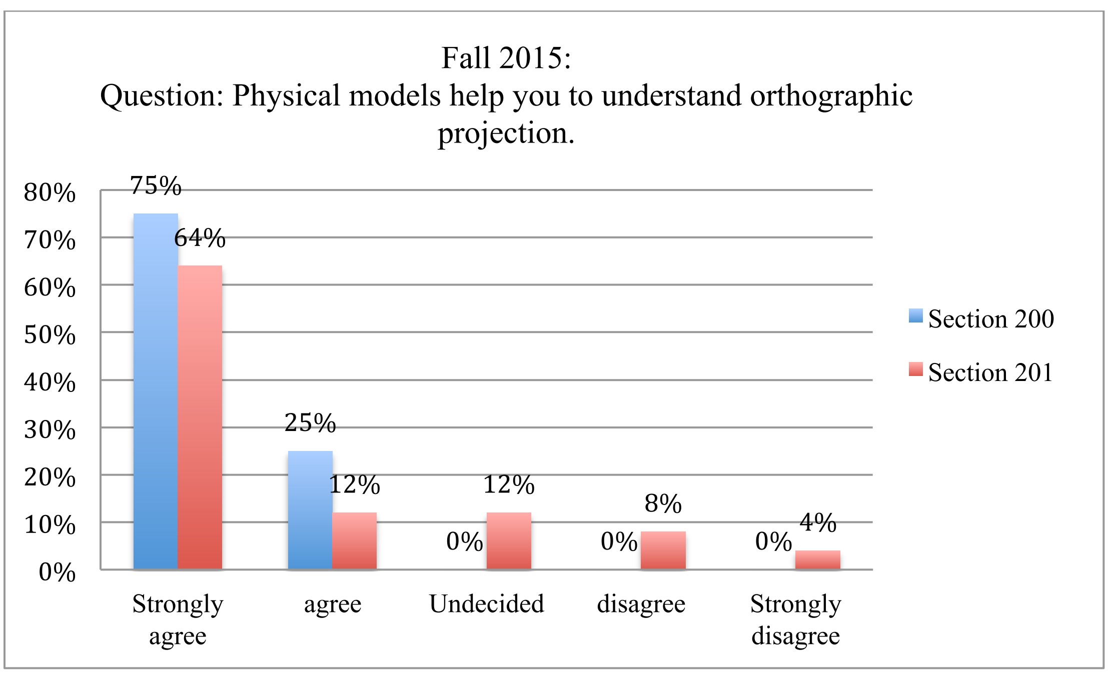

Figure 2. Survey responses in fall 2015 semester

Because of limited resources, the author also uses Inventor software to build 3-D models in class to help students understand their exercises such as sketching isometric pictorials by giving a multiple view drawing of an object. To understand learning outcomes by using textbook problems, 3-D models from Inventor and physical models, another survey was administered to the students in fall 2016. Eighty-one percent of students (26 out of 32) in section 015 and 72% of students (23 out of 32) in section 012 responded. Figure 3 demonstrates that about 72 % of students strongly agree or agree that they can visualize much better by using physical models compared with isometric pictorials in the textbook or PowerPoint presentation. Figure 4 demonstrates that about 64 % of students strongly agree or agree that physical models help them more to understand orthographic projection.

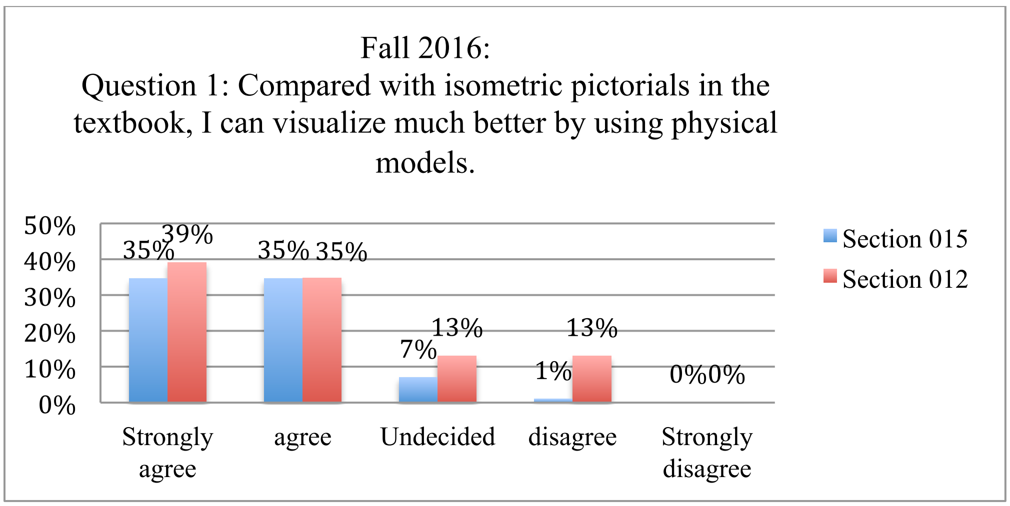

Figure 3. Survey question 1 responses in fall 2016 semester

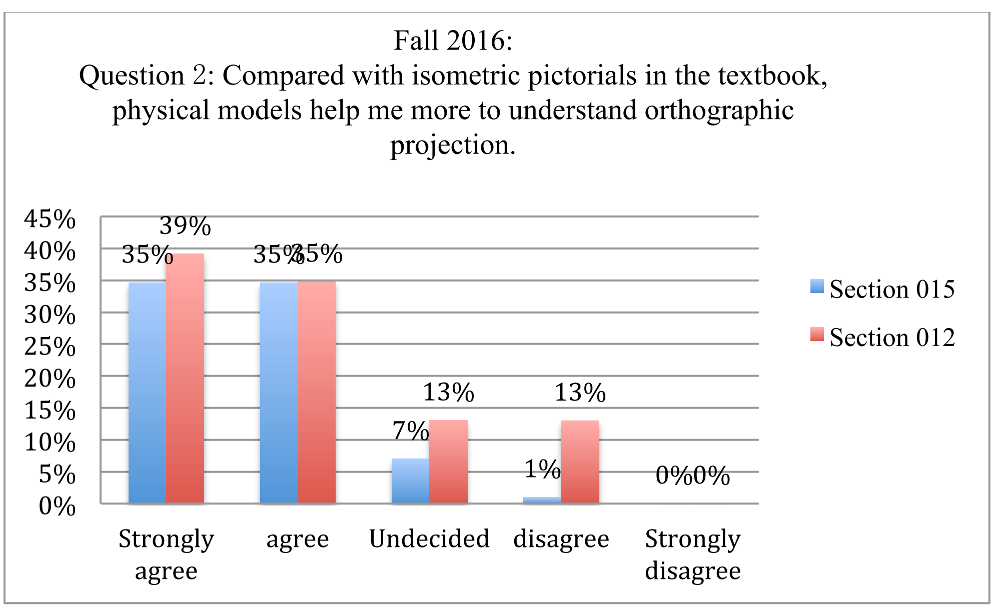

Figure 4. Survey question 2 responses in fall 2016 semester

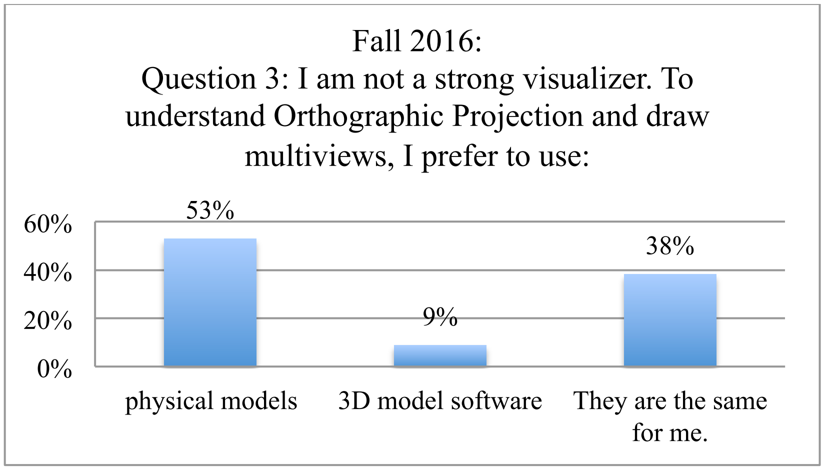

Figure 5. Survey question 3 responses in fall 2016 semester

Based on the author's teaching experience, strong visualizers always perform well in engineering graphics courses regardless of teaching methods. Implementing innovative learning materials are more important for average and weak students. Question 3 in the survey is designed to identify average and low visualizers and their preference in learning orthographic projection. Sixty-nine percent of students (34 of 49 students) identify themselves as non-strong visualizers. Figure 5 demonstrates that 53% of these students prefer to use physical models and 38% consider physical models and 3-D computer models are the same for them. In the classroom, students can only observe from an overhead camera, even though, the survey still confirmed that physical models are the most useful teaching tools for non-strong visualizers. Theoretically, if students can observe carefully with these physical models, they should be able to have a better perception of 3-D models. Before 2015, the author assigned additional exercises to help weak students who were seeking extra help. All homework and additional exercises are from the textbook/on paper. The result was not very significant for low visualizers. From fall 2015 to fall 2016, low visualizers were identified based on their score (less than 75%) on the first orthographic projection examination (Midterm exam score). Some exam sample problems are in Figure 6. Most of the examination problems are from the textbook Technical Graphics Communication by Bertoline etc [8] and the teaching material. Premade plastic physical models were offered to students volunteered to participate in extra hands-on activities. There are ten models used in hands-on activities. The author separated physical models into two groups based on their complexity. The simple models are the ones without oblique surfaces. First, students worked with five simple models independently until they fully understand the 3-D features and draw multiviews and isometric pictorial correctly. In general, students need to redo once to correct all mistakes. Second, students worked with five relatively complex 3-D models that contain oblique surfaces. The hands-on activities are explained in the flowchart in Figure 7. It took students about two weeks after class to complete hands-on activities.

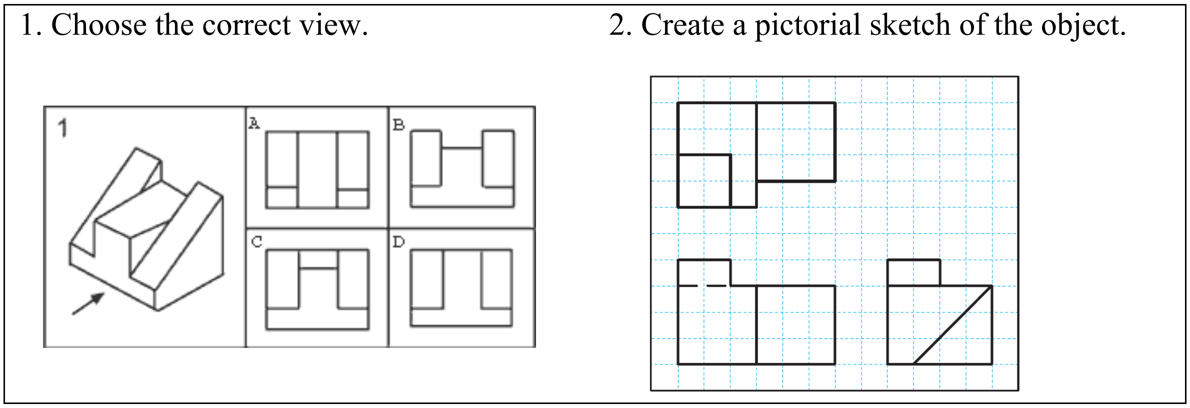

Figure 6. Sample exam problems

There were four students who completed these hands-on activities actively in three semesters. Although the sample size is small, the result is very promising as shown in Table 1. By participating in hands-on activities with only ten physical models, students increased their averages on exam score from 69.9 on the midterm exam to 88.8 on the final exam. Meanwhile, the majority of students who did not complete hands-on activities have no difference between midterm score and final exam score in average.

Table 1. Result of hands-on activities

	Midterm exam score	Final exam score	Score change
Low visualizers with hands-on activities (n=4)	69.9	88.8	18.9
Students without hands-on activities (n= 91)	84.7	83.3	-1.4

Conclusion

The study indicates that the majority of students agreed that physical models help them to visualize 3-D models and they prefer to use physical models in learning orthographic projection in Engineering Design Graphics. Future more, hands-on activities by using physical models can improve low visualizers' spatial visualization skills efficiently. With as little as ten physical models in two weeks period, low visualizers increased their exam score significantly. There are many challenges in teaching at two-year colleges. Some students enroll in courses without a clear track in mind. Because of students' diverse background, it is tough to reach all low visualizers outside the classroom who lack motivation. Therefore, future research includes design in-class hands-on activities that can fit a two-year college learning environment and reaches more students. The author plans to design and build physical models by using 3-D printing techniques based on the current teaching module. Redesign the curriculum and assure the hands-on activities embedded with current teaching plan to enhance learning outcome without extra works after class.

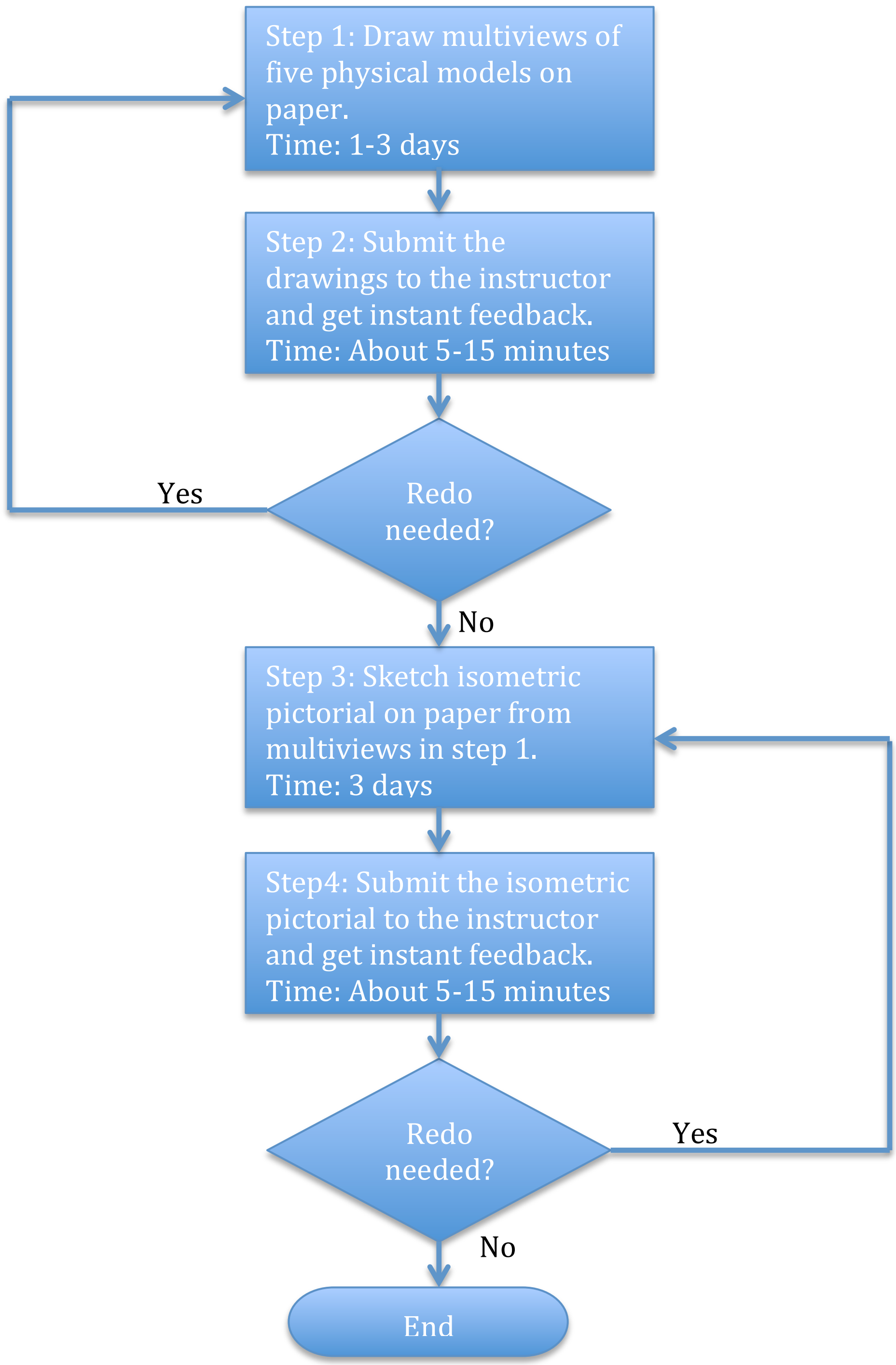

Figure 7. Hands-on activities flowchart

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