International Journal for the Scholarship of Teaching and Learning

Volume 11 | Number 2 Article 15

July 2017

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Recommended Citation

Arslan, Ali Riza and Dazkir, Sibel Seda (2017) "Technical Drafting and Mental Visualization in Interior Architecture Education," *International Journal for the Scholarship of Teaching and Learning*: Vol. 11: No. 2, Article 15.
Available at: https://doi.org/10.20429/ijsotl.2017.110215

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Abstract

We explored how beginning-level interior architecture students develop skills to create mental visualizations of three-dimensional objects and environments, how they develop their technical drawing skills, and whether or not physical and computer generated models aid this design process. We used interviews and observations to collect data. The findings provide an insight on what kind of difficulties students experience during their learning process and how they overcome those difficulties. The results of the study indicate that the students' lack of skills in technical drawing and in creating 2D and 3D mental visualizations negatively influenced their design process. Using the existing body of literature, we discussed the findings and suggested teaching strategies to improve the learning process for the beginning-level interior architecture students. The findings of this study allowed us to have a better understanding of the student design and learning process.

Keywords

Interior architecture, interior design, technical drawing skills, mental visualization, computer aided design, architectural models

Technical Drafting and Mental Visualization in Interior Architecture Education

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(Received 14 June 2016; Accepted 15 March 2017)

We explored how beginning-level interior architecture students develop skills to create mental visualizations of three-dimensional objects and environments, how they develop their technical drawing skills, and whether or not physical and computer generated models aid this design process. We used interviews and observations to collect data. The findings provide an insight on what kind of difficulties students experience during their learning process and how they overcome those difficulties. The results of the study indicate that the students' lack of skills in technical drawing and in creating 2D and 3D mental visualizations negatively influenced their design process. Using the existing body of literature, we discussed the findings and suggested teaching strategies to improve the learning process for the beginning-level interior architecture students. The findings of this study allowed us to have a better understanding of the student design and learning process.

INTRODUCTION

Mental visualization of two-dimensional and three-dimensional objects is an essential skill in many disciplines including design, architecture, art, science, and engineering. Designers transfer the mental imagery of their design ideas onto two-dimensional (2D) and three-dimensional (3D) illustrations. Using those illustrations, they communicate their ideas and design solutions to their clients, colleagues, and contractors. Thus, it is important to explore how interior design students develop skills to create mental visualizations of 3D objects and environments, and how they develop their technical drawing skills. This study is focused on how Interior Architecture students develop their skills to mentally visualize 2D and 3D representations of interior settings and create technical drawings to communicate their design ideas. Using qualitative research methods, we aimed to answer the following questions: 1) How do students develop their skills to visualize 2D designs in 3D and how does this process affect their overall design process? 2) How do model making and computer-aided design influence this process? The findings allowed us to gain a better understanding of the student learning process and discuss ways to improve teaching strategies in the interior architecture education.

RESEARCH BACKGROUND

The design process starts with inspiration and identification of design problems. Ideas travel from the world of imagination to the world of objects (Aspelund, 2010). Many researchers (Bertoline, Wiebe, Miller & Nasman, 1995; Bevlin, 1993; Bilda, 2006; Dahl, Chattopadhyay & Gorn, 1999) emphasized the importance of mental imagery in design. Designers transfer their mental imagery and ideas into tangible illustrations, and imagery is instrumental as it provides a bridge between design ideas and their representations in sketching and drawing (Bertoline et.al., 1995). Through a variety of two-dimensional (2D) and three-dimensional (3D) technical drawings, artistic illustrations, tangible models, computer drawings, and digital models; designers communicate ideas and design solutions to others.

Perception as a concept plays an important role regarding how we analyze and understand our near environment. The mental visual images of objects and forms that we imagine can function like real objects (Farah, 1985; Finke, 1980). We can perceive objects using mental imagery not only when we look at them but also by recalling them. Thus, imagery and perception can function alike (Finke, 1980; Shepard, 1984). Through perception, we develop an understanding of our tangible surroundings. Accordingly, it is important to study how beginning level interior architecture students perceive walls, columns, and furniture that are drawn in 2D. For example, it is vital that students are able to perceive a line drawn on a 2D drawing as a 3D wall, and not merely as a line. How do students create 3D mental visualizations while working on their 2D technical drawings?

In the interior architecture program where the study took place, students take courses to develop their technical drawing skills. They are expected to be able to draw objects correctly from different views, which requires an understanding of the relationship between shape and form. That understanding is related to visual thinking, spatial visualization, perception, and 3D mental visualization.

Visual thinking is important in design and problem solving whether it is in the field of product design (Dahl, Chattopadhyay & Gorn, 1999), architecture (Kavakli & Gero, 2001; Yagmur-Kilimci, 2010), engineering (Bertoline, et.al., 1995; Ferguson, 1992; Potter & Van der Merwe, 2001), or computer science (Casakin & Dai, 2002; Petre & Blackwell, 1999). Slack (1984) stated that research on visual mental imagery has been focused on how mental images are defined, produced, transformed, and understood. Mental imagery is defined by Kosslyn (1994) as a "basic form of cognition that plays a central role in many human activities -ranging from navigation, to memory, to creative problem solving" (p. 2). Visual mental images are pictorial depictions, and they are representations of the physical environment. Mental imagery may impact cognition (Kosslyn, 1980; Sorby et.al., 2005) and perception (Finke, 1980; Shepard, 1984). It can influence the generation and interpretation of information through spatial representation (Kosslyn, 1980). According to Sorby et.al (2005), higher-level thinking, reasoning, and creativity are related to spatial abilities. "The ability to visualize objects and situations in one's mind and to manipulate those images is a cognitive skill vital to many career fields, especially those requiring work with graphical images" (Sorby et.al. 2005, p.10.428.1). Mental rotation tests have been used to measure mental images and image transformation (Shepard & Metzler, 1971; Shepard &

Cooper, 1982) along with image restructuring (Pearson, De Beni & Cornoldi, 2001).

Spatial visualization is defined by Gorska and Sorby (2008) as the "ability to mentally manipulate, rotate, twist, and pictorially invert presented visual stimuli" (p.1). Students can develop their spatial visualization skills with training (Khairulanuar & Azniah, 2004; Olkun, 2003; Potter, et.al., 2009; Rafi, Khairulanuar & Che Soh, 2008; Sorby et.al., 2005). Inspired by Piagetian theory, Potter and Van der Merwe (2001) argued that spatial visualization skills affect academic performance, and they can be developed with training. The authors (2001) found that students with "low levels of spatial ability" (such as 3D spatial perception) were more likely to fail the first-year engineering graphics course without remedial intervention (p.7B5-5). Furthermore, Samsudin, Rafi, and Hanif (2011) found that secondary school students performed better at a given orthographic drawing task after they received spatial visualization training. The authors (2011) explained that many studies found spatial ability as the predictor of success in engineering drawing courses (Kajiyama, 1996; Olkun, 2003; Rafi & Khairulanuar, 2007; Sorby & Baartmans, 2000; Strong & Smith, 2001).

Despite the relationship between spatial abilities, spatial ability tests (such as mental rotation test), cognition, and academic performance as claimed by many researchers as outlined above; some researchers found no or inconsistent relationship between academic performance and visualization skills in architectural education (e.g., Akin, 2003; Ho, 2006; Yukhina, 2007). Some researchers (e.g., Hegarty & Waller, 2004; Yagmur-Kilimci, 2010) argued that mental rotation is not effective in understanding 3D mental visualization of large scale environments. Thompson, Slotnick, Burrage, and Rosslyn (2009) claimed that mental rotation can be dissociated from visualizing spatial locations. Some scholars found no or inconsistent evidence between spatial ability tests and architectural visualization skills. For example, Ho (2006) found a relationship between spatial visualization ability of architecture, industrial design, and mechanical engineering students and their studio (design lab course) grades only within the female participants. He (2006) also found no relationship between spatial visualization skills and years of design education. Akin (2003) found that upper level architecture students performed poorer compared to the lower level students regarding their skills in manipulating small-scale rectangular blocks. Yukhina (2007) compared first to fifth year architecture students regarding their spatial visualization ability and academic performance; and she did not find a consistent relationship between the two variables across the five groups. Those findings support that there are contrasting findings in the literature about the relationship between spatial visualization and academic success across all disciplines. Spatial visualization skills when measured with small-scaled objects may not be related to architectural visualization skills.

Yagmur-Kilimci (2010) compared architects and mechanical engineers involved in design regarding their 3D mental visualization skills. She (2010) found that mechanical engineering students significantly outperformed architecture students regarding their spatial visualization skills. Although the engineers were able to visualize the buildings from the given 2D drawings, their skills were significantly lower compared to the architects. Thus, she claimed that 3D mental visualization of buildings is an architectural skill mostly gained during their education rather than professional life. The author further (2010) argued that:

> 1) communication of building information through 2D drawings in architectural design bears on the 3D mental visualization practices, (2) architects, during such practices, appear somehow to be capturing the 3D appearance of the building designs in their minds, (3) many architects claim to carry out such 3D mental visualization practices during design and think that they benefit from these practices in thinking about the 3D aspects of their designs, and (4) many believe that these practices highly rely on spatial visualization abilities. (pp. 5-6)

Architectural education influences designers' drawing skills, spatial visualization skills, and design process. Kavakli and Gero (2001) found differences between second year architecture students and experienced architects with more than 25 years of experience regarding their number and richness of sketches in the conceptual design process. The authors (Kavakli & Gero, 2001) explored the reasons behind the difference in content and levels of productivity between the two groups: They (2001) argued that novice designers were slower at image generation and cognitive activity, novice designers' poorer sketching ability in matching their imagery to sketches (Finke, 1990) as well as their lack of mental rotation ability might have impeded information processing and production of alternate ideas, and experienced designers used imagery more efficiently compared to novice designers. Similarly, Helmi and Khaidzir (2016) found that novice students' sketches failed to support their mental imagery.

Yagmur-Kilimci (2010) found that all architects who participated in her study had 3D visualization skills independent of their years of experience in practice. She argued that architectural education helps students gain 3D visualization skills; however, those who have low levels of 3D visualization skills could be relying more on physical models and computer programs. Thus, they could be spending most of their time on creating those physical or digital models instead of creating ideas. The author (Yagmur-Kilimci, 2010) explained that it's difficult to explore how we can support the improvement of 3D mental visualization skills in architectural design education because we do not know what the underlying abilities are.

There is a lack of empirical findings in the field of interior architecture regarding the relationship between spatial abilities and performance; and also between visualization skills and the use of physical or digital models. Some studies from the field of engineering and science such as Huk (2006) found that students with high spatial abilities benefited from 3D models in biology education, whereas students with low spatial abilities became cognitively overloaded. Keehner, Montello, Hegarty, and Cohen (2004) found that participants with high-spatial abilities performed better at a test when they were asked to determine the cut line on a 3D model without rotating it. However, when participants had the ability to rotate the 3D computer model, there was no difference between high and low-spatial participants. Katsioloudis, Javanovic, and Jones (2014) asked students to create a technical drawing of a given object when it is rotated to a certain position. The authors (2014) found that the group of students who were presented with a 3D image or model significantly performed better compared to the group that was only presented with a 2D image (a side view with no depth) of the object. Finally, Katsioloudis, Javanovic, and Jones (2014) claimed that 3D models can improve spatial visualization skills.

METHODS

The participants were 15 undergraduate (12 female, 3 male), beginning-level 'Interior Architecture and Environmental Design' (IAED) students enrolled in a public university in Turkey. All of the participants were at the beginning of their second year (third semester) in the program when interviews took place. The same group of 15 students took six IAED beginning-level courses together ("Introduction to Interior Architecture", "Basic Space Analysis", "Interior Design I', "Computer-aided Design", "Model Making", and "Technical Drawing") during their first academic year in the program. Many of those courses required 3D mental visualization of 2D drawings and vice versa. During those classes, students are expected to develop technical drawing skills and acquire the ability to visualize and document their designs in both 2D and 3D. The "Interior Design I" course is the main design lab course where students develop design ideas and use 2D and 3D drawings to express those designs. The participants worked on a two-story residential building design in this class, creating space planning for both structural and furnishing elements. The students created floor plans, a roof plan, a lighting plan, and elevation (side view) drawings in "Interior Design I".

In the "Computer-aided Design" course, the students learned to use AutoCAD, and they created 2D and 3D drawings of their "Interior Design I" project on computer. In the "Technical Drawing" course, the students learned about line quality, lettering, and how to draw different views of objects in scale. In this course, the students learned how to create 3D drawings by looking at 2D views of objects. In the "Model Making" course, the students created small-scale models of their "Interior Design I" residential projects and models of buildings given to them by their "Model Making" instructor.

We used qualitative research methods to gain a deeper understanding of the research phenomenon. We interviewed the students using a semi-structured interview guide, and asked them about their process of 3D mental visualization. The semi-structured and inductive approach of the study allowed us the flexibility to explore new topics, search for new meanings, and learn from participant perspectives (Creswell, 2007).

The interview data was triangulated using observations of student work and in-class performance. The students were observed in the "Interior Design I" class, and their works such as their hand-drafted drawings, physical small-scale models, and computer drawings were observed. The students were interviewed individually at the beginning of their third semester (second year) in the program. During those interviews, their ability to perceive their 2D drawings in 3D was investigated. During the interviews, the students were asked about: whether or not they could understand the 2D drawings during the first weeks of "Interior Design I" course; how they created 2D and 3D drawings; how they figured out what the shapes and forms should look like on plan (top view), elevation (side view), and 3D views; whether or not they understood the relationship between what they drew on plans and their actual representations; if they had any difficulties perceiving or visualizing objects while drawing them; if there were any instances when they could not mentally visualize 3D representation of the floor plan elements; and whether or not they consider the actual dimensions of furniture when they place/draw them on their floor plans.

The interviews were recorded with a digital voice recorder, and they were typed verbatim. We also took notes during the interviews not only about the participants' responses but also about their nonverbal reactions such as their body language and facial expressions to better understand their responses during the analysis stage. At the beginning of the interviews, we collected data about the demographics of the participants (*M*Age = 19). The interviews lasted about 20-30 minutes. We coded the responses and grouped similar responses together to create themes.

FINDINGS AND DISCUSSION

Our first research question was focused on how students develop their design skills to visualize 2D designs in 3D and how this process affects their overall design process. During the interviews, the participants discussed their experiences creating and understanding 2D and 3D drawings, their struggles gaining those skills, and how those experiences affected their overall learning and design process. For example, the analysis of the interview data revealed that students struggled with developing design ideas while working on their 2D drawings in the "Interior Design I" course. Their lack of skills in technical drawing and in creating 2D and 3D mental visualizations influenced their design process negatively. A student, Suna (ID2) explained: "While working on my floor plan and section view, I thought I would develop design ideas, but I was wrong. It happened in time." Ayla (ID1) discussed how her lack of experience and beginning level skills affected her performance in class:

> I could only draw the floor plan by recalling and copying what we already did in class. Even though I was taking the technical drawing class at the same time [as the Interior Design I course], I still did not know how to create a floor plan or top views of structural and furnishing items.

Those testimonials support that students developed their drawing skills and skills to visualize those drawings in time. The participants explained that they struggled to create drawings outside what their instructor showed them. This impeded their design process and their creativity. Those findings support the literature that lack of drawing skills can impede cognitive and creative process in design (Brooks, 1968; Finke, 1990**;** Helmi & Khaidzir, 2016). Because of this struggle, the students searched for photographs of furniture and interiors that were similar to what they wanted to create. Then, they made alterations on those pictures to come up with their own design ideas.

The students were asked if they could draw elevation (side) views from a given floor plan and visualize it in 3D without seeing a physical or digital model. Koray (ID11) explained that by mid-spring semester, they (he and his classmates) knew what they were supposed to do to create elevation views. Figen (ID9) further explained, supporting Yagmur-Kilimci's (2010) findings that visual mental imagery skills are gained through architectural education:

> During the first semester, it took me hours to create an elevation view. I just could not perceive the relationship between a floor plan and what it represents. Now, when I look at floor plans, I know where to look. I understand the plan and visualize it in my head.

During their technical drawing class, the students created 2D drawings such as top and side views of given 3D geometric shapes, and vice versa. This engineering graphics style technical drawing class was focused on visualizing and drafting small scaled objects. Despite this training, it was observed that the students struggled with doing the same type of drawings of interior elements in the "Interior Design I" course. They copied and used the dimensions and shapes that were given to them by their instructor in class. This supports the literature that spatial visualization skills with small objects may be different than visualization skills needed for interior environments (e.g., Akin, 2003; Ho, 2006; Yukhina, 2007). On the other hand, it appears that students developed their understanding of how forms should look like in 2D and 3D views in time. The findings support the literature that training and experience help with mental imagery and visualization skills (Piaget & Inhelder, 1971; Potter et.al., 2009).

When asked about whether they consider the actual size of furniture on floor plans or if they understand the relationship between what they draw and their actual representations (such as lines representing walls, columns, and windows), one student, Sebnem (ID3) responded: "I had no idea about dimensions and scale of objects; and until now, I never paid attention. Now, I seek information about them when I draw." Another student, Deniz (ID4) explained that she drafted her plan by copying from examples (such as drawings created by the instructor or a fellow student) when she did not know about the dimensions she needed to use. Suna (ID2) revealed that if she were to use a sofa that she saw at a furniture fair, she would draw it out of scale and not in line with ergonomics. Those testimonials reveal that beginning level students struggled with how to correctly draw objects in scale and mentally visualize those objects. Some students looked for information on the size of furniture whereas, other students learned how to draw furniture in correct scale by looking at instructor's examples. Although many students learn how to draft by copying from examples in the beginning level, they are expected to locate size information and draft objects without help as they progress in the program. If the students struggle with mentally visualizing 2D views and creating technical drawings, they should be encouraged to seek help from their instructors.

In-class observations from first semester revealed that students could not fully grasp what they were actually drawing. They repeatedly asked their instructor questions about what the size of objects should be in the plan and section views. Suna (ID2) claimed that they developed only their technical skills such as draftsmanship and drawing conventions in the "Technical Drawing" course, and she claimed that they did not develop skills to visualize furniture from their drawings. She further explained, "We can only explain/communicate as much as we are able to comprehend." Ayla (ID1) explained:

> I could not see my mistakes on my drawings even when I realized something was not right. For example, I could not see where the armrest [of a seating unit] should be. I was following the technical drawing rules, extending the lines to create an armchair that was placed diagonally, but I could not visualize it. I also had a lot of difficulty creating the scaled model.

The following findings further support that the participants developed technical drafting and mental visualization skills with practice and in time answering research question 1. The students were required to place an armchair at a 45-degree angle next to a straight horizontal wall. Although they could draw this armchair in a plan (top) view, they struggled to transfer it to an elevation (side) view. The participants were asked if they could visualize how the furnishings should look like in plan and elevation views or if they were simply copying what their instructor showed them, if they had difficulty transferring plan views to elevation views, and if they can now draw an armchair that is placed diagonally by a horizontal wall. Ayla (ID1) revealed that she and some other classmates could not draw the diagonally placed armchair, and they took a picture of a classmate's work and copied from there. Ayla (ID1) further explained, "I knew what was missing on my drawing when I asked for my instructor's help; I just did not know how to fix it". Ceren (ID6) had similar experiences as she could not figure out how to properly draw the armchair. "… I did not know how to do it. For this reason, my drawing looked weird."

The students were observed to be having difficulty visualizing interior furnishings from their 2D drawings. They also had difficulty figuring out the proper height of the diagonally placed chair. They could have determined the height of the chair by looking at the chairs that were already available to them in the classroom. Those findings suggest that students would benefit from having more integration between technical drawing and design courses. The technical drafting course should be revised to emphasize mental visualization skills. The course should also focus on drafting furniture rather than just small geometric objects. Students can be asked to draft existing pieces of furniture that are available to them in class, which in turn would help them develop skills to draw furniture in scale and feel more confident creating similar drawings in their design courses.

We asked the participants how they developed their ability to understand their 2D drawings and visualize those interior settings in 3D. We asked the respondents what helped them develop those skills. Suna (ID2) explained that she developed those skills with practice. She emphasized the importance of technical drawing skills. On the other hand, Gamze (ID10) revealed that she started to understand the relationship between the floor plans and the actual 3D settings when they stopped working on its technical aspects and focused on the creativity aspect. Another student, Ayla (ID1) explained:

> Towards the end of the semester, I noticed that I think about my project even during my spare time. When I have the freedom to explore, I noticed that I imagine things that are a little too unrealistic. When I am relaxed, I realize that I am better able to think in 3D: I start to create the space in my head. For example; when I draw a cabinet, I visualize how it will look like in the room - as if I am walking around the room. That's what started to happen. When I draft the 2D floor plan, I no longer just see the lines and rectangles; I perceive the space with its third dimension.

All the testimonials discussed so far shed light on how students developed their skills to visualize their designs in 2D and 3D and how this process affected their overall design process, answering research question 1. The rest of this section is focused on the second research question, which is focused on how model making and computer-aided design influenced students' skills in creating and visualizing 2D and 3D drawings.

The students took "Interior Design I", "Computer-aided Design", and "Model Making" courses together in the spring semester. During the second half of the spring semester, the "Computer-aided Design" students were asked to reproduce their hand-drafted drawings from "Interior Design I" using AutoCAD. They were also asked to create a physical small-scaled model of their "Interior Design I" project in the "Model Making" class. When asked about how using AutoCAD and model making influenced their understanding of 2D and 3D drawings, students responded:

> Sevgi (ID5): I had a sloped ceiling design in the bedroom of my project. I was not able to determine the height of that ceiling. I just could not visualize it in my head. When I took the Computer-aided design class, I created a 3D model of my project. By this way, I was able to measure the ceiling height. I had difficulty hand-drafting objects in 3D view because I struggled to visualize them in my head. Model making helped me better understand it, and it made drawing easier.
>
> Ayla (ID1): I could not visualize how a spiral staircase should look like in plan and elevation views. I looked at a spiral staircase, I climbed it, and analyzed it, but I still could not figure it out. After I drew it in AutoCAD with the help of my professor, I was finally able to understand it.
>
> Alp (ID7): It was during the model making class that I was able to perceive the 3D look of my project a lot better, and I was better at understanding the size of furnishings and interior structural elements. I understood what I was actually drafting. When you do not think about the scale, it is a lot simpler. I can draw my floor plan in scale, but I cannot create the scaled model of my project. It is just too complicated. Regarding perspective views, AutoCAD definitely helps me perceive the 3D view as I can orbit the view [rotating the 3D computer model to see it from different angles].

We investigated students' basic visualization skills by asking them about how a simple geometric object would look like in different views. We asked them if they were able to understand how a cylinder would look like in plan and elevation views. One of the students, Elif (ID8) explained that she had difficulty making the connection between the circle (the top/plan view of a cylinder) and the cylinder and that AutoCAD helped her see the connection. All those responses and in-class observations indicate that model making and use of computer-aided design allowed students to improve the accuracy of their project drawings. Those skills also helped them visualize their floor plans in 3D and in elevation views.

The testimonials from the students as given above support the literature (Yagmur-Kilimci, 2010) that design students with low levels of 3D visualization skills could be depending more on 3D physical or digital models causing them to spend more time on those models and less time on creating ideas. Working with physical and 3D computer models, and the ability to see those models from different viewpoints can help designers improve their visualization and problem solving skills as well as their design communication skills. The findings also support the literature (Katsioloudis, Javanovic, & Jones, 2014; Keehner, et.al. 2004) that the use of computer generated or physical models can help close the gap between low and high spatial students.

In summary, the participant responses revealed that students developed their skills in creating and mentally visualizing 2D and 3D drawings using computer-aided design, small-scaled models, and their technical drawing skills, by practicing and looking at examples in their surroundings, imagining how the space would look like, visualizing a walk-through of the space, by thinking about the projects, and by brainstorming ideas.

CONCLUSION

Mental visualization of objects and spatial visualization skills are essential in many fields of study such as design, engineering, art, and architecture. Those skills are found to be related with higher-level thinking and creativity which are essential skills in many fields (Sorby, et. al., 2005). It is especially important for students studying disciplines such as interior architecture, architecture and industrial design that they develop the necessary skills to create 2D and 3D technical drawings and be able to visualize 2D drawings in 3D. One of our research questions was about exploring how students develop those skills. The findings of this study suggest that students gain those skills in time. Students' lack of experience and skills cause uncertainty and prompt them to copy drawings from others and sometimes without understanding what they are copying. Learning by copying existing examples can help students develop technical drawing skills however, students should seek help in their design and other studio courses if they struggle with understanding and mentally visualizing those examples when they are copying them.

Despite the help of technical drawing training, students start to perceive and visualize the space better when they have more experience, use physical and computer generated models, or when they have the creative freedom. The creative freedom prompts them to imagine how the space would look like, and create 3D mental visualizations and walkthroughs. Thus, it is important that educators emphasize the development of visualization skills.

Beginning level students' skills in technical drafting, mental visualizations of 2D views of objects and interior settings, and correctly drafting furniture in scale can be improved by revising the existing technical drafting courses, by encouraging students to seek help in their design studio classes, and by encouraging students to use their observation and research skills. The existing technical drafting course in the program is focused on draftsmanship and drawing small objects. This course can be revised to include more architectural drawings such as plans and elevations, and drawings of actual pieces of furniture. Students can measure and create 2D drawings of furniture that they can touch and feel. This would help them develop a better understanding of the relationship between the 2D drawings of furniture and what they actually represent.

Our second research question was about exploring how model making and CAD influence students' 3D visualization skills. The students were better at perceiving the space with the help of models and CAD. Digital and physical models allowed them to see some aspects of design that they could not visualize on their own and improved the accuracy of their drawings and designs. We believe that beginner-level students, especially those with lower mental visualization abilities benefit considerably from the use of computer generated and physical models. This also supports that students benefit from inter-connectedness of different courses.

Despite their usefulness for developing visualization skills, we believe that beginning-level students should not just rely on computer generated models in their design process. The participants of this study were required to use CAD only after they finished their initial 2D hand-drafted drawings. Over-reliance of physical and digital models can impede the creativity of the students as they spend most of their time creating those models instead of creating design ideas (Yagmur-Kilimci, 2010), or the capabilities of the computer drafting program might impede their creativity.

The student testimonials support that they struggled with the mental visualization skills. The technical drawing instruction and training was alone was not instrumental in the development of those skills. Mental visualization and drafting skills are essential parts of design, and new tools and instruments can be implemented to develop students' 3D spatial perception skills. Potter and Van der Merwe (2001) found that those skills were significantly improved after students were trained in "modeling, sketching, visualization, and three-dimensional representation using conventions of engineering drawing" (p. 7B5-3). As explained earlier, a body of literature (Khairulanuar & Azniah, 2004; Olkun, 2003; Potter, et. al., 2009; Rafi, Khairulanuar & Che Soh, 2008; Sorby et al., 2005) also suggests that spatial visualization skills can be developed through training.

Despite the relationship between spatial visualization skills, academic performance, and technical drawing skills as found by some researchers in the field of engineering and science (Potter & Van der Merwe, 2001; Sorby et. al., 2005), there is a lack of support in the architectural education literature regarding the relationship between mental rotation, academic performance (e.g., Akin, 2003; Ho, 2006; Yukhina, 2007) and mental visualization of large scale environments (Hegarty & Waller, 2004; Yagmur-Kilimci, 2010). Our findings support that an engineering style technical drawing course with a focus on drafting small geometric objects did not help interior architecture students develop their visualization skills of interior settings in the "Interior Design I" class. Despite the uncertainty whether training and testing in spatial visualization abilities can improve or measure skills to visualize large scale environments, implementing improved technical drawing and spatial visualization exercises may enhance interior architecture students' communication skills using technical drawings, which in turn, can improve their skills in communicating their design ideas through those drawings.

The findings of this study shed light on the student learning process in the Interior Architecture education. Those findings may also be used in other disciplines that rely on students to visualize and mentally manipulate 2D and 3D representations of objects. The findings provided insight on not only what kind of difficulties students experienced during their learning process but also how they overcame those difficulties. More research needs to be conducted with a larger and more diverse sample size to further investigate students' process of mental 3D visualizations. Future research can benefit from using mental rotation tests and spatial skill exercises to investigate the influence of spatial skills on beginner-level interior architecture students' technical drawing and mental visualization skills.

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