Contents

Editorial

Articles

From the Field

Miscellany

Editorial

Research, Service, and Reflection

As I conclude the eighth year of my 5-year commitment as the Editor of the *Journal of Technology Education*, I find myself reflecting on the profession and my role as editor. As some of you in the profession know or will know after you read this editorial, I have decided to step down as editor as soon as a new editor is named. I will be turning my attention to other initiatives in technology and engineering education. Over the past eight years, I have read thousands of pages related to our discipline, as well as a lot manuscripts that did not represent the scope and readership of the *JTE*. In all, I could not be more pleased with the profession both within and outside of the United States. I am sure that Mark Sanders, the founding editor of the *JTE*, and James LaPorte, the second editor of the *JTE*, will likely feel the same as I in regard to the profession's research.

Across the globe, technology and engineering education is a very small discipline in comparison to others, and we have a shrinking base of professionals both domestically and internationally. However, our research, research partners, and submitted manuscripts for potential publication are not shrinking but rather growing stronger, especially as technology and engineering education becomes more focused within STEM education.

Over the past eight years, I have been able to work with a group of *JTE* editorial review board members and other invited reviewers that are second to none. If you have submitted a manuscript to the *JTE*, you know that the quality and quantity of feedback provided to you is thorough. The current editorial review members and the institutions that they represent are printed on the inside cover of the journal as well as at the end of the journal—**these are extraordinary professionals**. Second, the Technical Editor, Ms. Amanda Fain, may be the most thorough technical editor one could ask for in the profession. Amanda is so detail oriented that her edits go beyond looking for punctuation and grammar; her efforts reside at the heart of the manuscript, helping to craft a readable piece that is structurally sound and professionally delivered.

I want to thank all of you for making the *JTE* the flagship research journal in technology and engineering education.

Chris Merrill
JTE Editor, 2010–2018

Don't Ask Me Why: Preschool Teachers' Knowledge in Technology as a Determinant of Leadership Behavior

Anna Öqvist & Per Högström

Abstract

In the Swedish preschool curriculum, technology education is emphasized as one of the most significant pedagogical areas. Particularly, the teacher's role is emphasized: It is the preschool teacher's responsibility to stimulate and challenge children's interest in science and technology. Unfortunately, prior research indicates that preschool teachers feel uncertain about what technology is and the extent of their knowledge on the topic. Based on the path–goal theory, this article will explore how preschool teachers' knowledge of technology influence how they act toward children in different learning activities. Using a qualitative research design, this study collected data comprising 15 interviews with preschool teachers. The result provide insights for how teachers limited knowledge in technology influence their leadership behavior toward children both in planned activities initiated by teachers and in unplanned activities initiated by children during free play. The core of how teachers' knowledge in technology influences their leadership behavior in these two types of activities is their ability to deal with children's *why* questions. The results also show that a compensatory approach becomes evident in teachers' leadership behavior toward children in planned activities and that an avoidance approach is evident in unplanned activities. Our findings suggest that the development of a problem-solving approach in unplanned activities could enable teachers to create learning environments for children in which technology becomes something natural. Moreover, enhanced knowledge and understanding of technology will in turn make teachers better able to explain and clarify concepts and various technical phenomena.

Keywords: Leadership, path–goal theory, preschool, technology

Today, children are growing up in an environment in which everyday technologies and advanced technologies are evolving at a rapid pace. Computers, mobile phones, and other advanced technologies are available in almost every home and workplace. The ability to communicate and apply new knowledge is necessary in a society characterized by a huge flow of information (Williams, 2002). To embrace and facilitate the use of all the technologies that children encounter in everyday life, it is essential that they have a basic understanding technology. In Sweden, the preschool educational mission addresses the importance and significance of integrating technology in the education of young children. In the new Swedish preschool curriculum, technology education is emphasized as one of the most significant pedagogical areas. It puts particular emphasis on the teacher's role, emphasizing that it is the preschool teacher's responsibility to stimulate and challenge children's interest in science and technology (Skolverket, 2016). Thus, as part of their leadership, it is crucial for preschool teachers to have the appropriate knowledge to distinguish and highlight technology in children's everyday lives to facilitate children's learning. Unfortunately, prior research has shown that many preschool teachers feel uncertain about what technology is and the extent of their knowledge on the topic (Plowman, Stephen, & McPake, 2010; Siu & Lam, 2005; Smith, 2001). According to a Swedish Schools Inspectorate quality report (Skolinspektionen, 2012), in-service preschool teachers express uncertainty and even fear regarding technology, viewing it as something unknown. For example, teachers seem to have different perceptions of what technology is and, in many cases, understand technology strictly as electrical equipment, such as computers and televisions (Skolinspektionen, 2012; Smith, 2001). Teachers commonly associate technology with high-tech artifacts and focus on the use of these artifacts rather than their structure or the process that led to their development (Siu & Lam, 2005). Furthermore, preschool teachers experience technology as complex and difficult to manage (Plowman et al., 2010; Siu & Lam, 2005; Skolinspektionen, 2012). This trend is worrisome. To date, prior research has focused on investigating preschool teachers' knowledge of technology. Less attention has been paid to the actual influence of preschool teachers' knowledge on their leadership behavior toward children, that is, how preschool teachers act toward children in technology-related activities and how this might affect learning outcomes for children. We propose that addressing this can provide new avenues through which to understand how to facilitate children's learning about technology. The aim of this article is to explore how preschool teachers' knowledge of, and approaches to, technology influence how they act toward children in different learning activities.

Technology is part of the preschool environment and provides the children with experiences of everyday phenomena. From there, children will have the opportunity to build their perceptions of how technology can be used, among other things, to facilitate and solve problems in everyday life (Skolverket, 2016). First and foremost, this includes their ability to discern the technical objects of everyday life and become acquainted with them. In this way, children are given opportunities to reflect on issues concerning the use, benefits, functions, materials, design, and construction of these objects (Skolverket, 2016). From a Swedish perspective, such situations are particularly interesting because the preschool curriculum considers creativity, play, and enjoyment in learning as the backbone of young children's education. A central activity in preschool is free play. Prior research has shown that through free play, children learn largely by participating. For example, studies concerning children's involvement and participation show that these contribute to their understanding of technology.

This highlights the importance of direct experience in stimulating children's learning (Turja, Endepohls-Ulpe, & Chatoney, 2009; Tu, 2006). Children have an innate curiosity that compels them to discover things for themselves, and when they do so, their first meeting with the science of technology occurs. By participating in technical activities, children develop their investigative skills and learn to discuss, reflect, and formulate thoughts and ideas (Tu, 2006).

However, it is worrisome when children's perceptions of technology are inadequate and their development of alternate perceptions do not change over time (Mawson, 2011). Preschool teachers' ability to enhance children's participation in technology use seems to largely depend on the teachers' own knowledge. Previous research indicates that the teacher's role and behavior are crucial in encouraging children in their learning about technology (Rohaan, Taconis, & Joechems, 2010; Siraj-Blatchford & MacLeod-Brudenell, 1999). Children who receive considerable support and guidance on how various phenomena work have more opportunities to develop technical skills (Mawson, 2011; Stables, 1997; Tu, 2006). In such situations, children need adults with the appropriate knowledge and experience to guide them further (Smith, 2001). Therefore, it is important that teachers get involved in activities controlled by children (e.g., free play) because it is in participating in such activities that children are driven by a strong motivation to achieve a specific goal (Parker-Rees, 1997). Turja, Endepohls-Ulpe, and Chatoney (2009) find that play prompts children to use their imaginations to experiment with alternative plans, solutions, and problem-solving and to combine things in new ways. Practices in which children are only offered materials (e.g., building blocks) without support and must decipher for themselves what these materials can be used for can be counterproductive. For example, if the children build something, the teacher usually does not ask the children if they really understand what they have done. Therefore, the visible result is the dominant criterion in the evaluation of successful technology education (Tu, 2006). Siu and Lam (2005) conclude that if children are to get a basic understanding of everyday technology, they must have an understanding of the process involved in, for example, the construction of a specific technical artifact. When the children need support or help in solving problems or in finding new ways to proceed, the teacher's role in encouraging and being supportive is crucial (Stables, 1997).

Altogether, previous research highlights the importance of introducing technology at an early age to offer children an advantage in school. An early introduction to technology can change children's perceptions of what technology is as they interact with it (Can-Yasar & Uyanik, 2012; Mawson, 2010; Milne & Edwards, 2013; Siraj-Blatchford, 2001; Siu & Lam, 2005). Teachers' knowledge of technology is crucial for encouraging and stimulating the development of children's knowledge of technology and their skills in its use. From a broader perspective, due to the growing need for technical skilled labor, it is important that preschool teachers are aware of how to challenge, stimulate, and motivate the children's learning of, and interest in, technology (Rohaan et al., 2010).

Theoretical Framework

The aim of the present study was to determine how preschool teachers' knowledge of, and approaches to, technology influence how they act toward children in different learning activities. To derive an understanding of how preschool teachers' actions contribute to children's learning about technology, the study used the path–goal theory framework (House, 1996). *Path–goal theory* is a theory of leader effectiveness that focuses on identifying the effects of the leader's behavior on the subordinates' outcomes. To the extent that subordinates lack support and resources required to accomplish goals, it is the leader's function to provide such support or resources (House, 1996). According to path–goal theory,

> The motivational functions of the leader consist of increasing personal pay-offs to subordinates for work-goal attainment, and making the path to these pay-offs easier to travel by clarifying it, reducing roadblocks and pitfalls, and increasing the opportunities for personal satisfaction en route. (House, 1971, p. 324)

Thus, an effective leader is one who assists subordinates with navigating paths that ultimately lead to organizationally desired and individually valued outcomes.

Path–goal theory has proven fruitful in the field of education. For example, Öqvist and Malmström (2016) employed the theory to expand the understanding of teachers' leadership behavior and its impact on students' educational motivation. From the students' point of view, the authors highlighted the usefulness of the theory to capture how levels of developmental leadership cause low levels of motivation among students. In the present study, path–goal theory helped to explain how preschool teachers' knowledge of technology influences their leadership behavior toward children in different learning activities. Accordingly, if the children need help with solving a problem to achieve a goal (e.g., a playful activity involving building something), the teacher needs to help, support, and motivate the children by clearing away obstacles and discussing possible solutions in order to improve their learning and performance. The children will be motivated to carry out the activity or task if they feel that they are competent and possess the right knowledge to take on and complete the activity. This presupposes that the preschool teacher, as the leader, provides a clear direction and gets involved in the children's goal achievement by supporting and helping the children in different ways. Through their leadership, preschool teachers can influence children's motivation and interest in solving a problem or completing a task (cf. Yukl, 2013). Csikszentmihalyi (1990) and

Dörnyei and Ushioda (2011) show that problem solving leads to motivation. For preschool teachers, then, the challenge is to exhibit behavior that best meets the needs of the children.

Methodology

Sample

The present study adopted a qualitative embedded multiple case-study research design inspired by Eisenhardt (1989) and Yin (2003). Cases of preschool teachers' experiences were used to explore their knowledge of technology and how this influences their actions. The sample included data from 15 interviews with preschool teachers in northern Sweden. The first step in identifying participants was to locate teachers working in preschools. Through a directory of the preschools in various districts in the same municipality, 15 teachers were identified. The age of the teachers ranged from 28 years to 62 years with a mean age of 36 years. The range of experience in the field was from 3 years to over 30 years. The teachers worked in eight different preschools in the municipality. Letters were sent to all 15 preschool teachers through their workplaces; in these letters, they were informed about the study and were invited to participate. The preschool teachers contacted the researchers via e-mail or phone to set up a time for the interview. The names presented in the results are pseudonyms.

Data Collection

In-depth interviews were used to capture the preschool teachers' experiences and their view of reality (Silverman, 2013). For the data collection, an interview guide was developed to guide the researchers in capturing the teachers' experiences. The interviews were conducted with the teacher at their preschool in a room in which only the teacher and researchers were present. On average, each interview lasted about 1 hour. The interviews were recorded using a digital recorder and then transcribed. The amount of data recorded increased the potential of identifying fragmented and complex patterns in the preschool teachers' self-experienced narratives of technology in preschool (Mezias & Scarselletta, 1994). The number of interviews was considered sufficient to meet the study's aims. In other words, saturation was reached, and patterns were clear and validated (Yin, 2003).

Data Analysis

The idea behind this analysis was that social groups construct their own reality (Mumby & Clair, 1997), which is expressed through their representations and experiences (Fairclough, 1992). The approach applied presupposed that socially constructed institutions are produced and made real by the preschool teachers' storytelling and are reproduced in narrative form.

The data analysis was performed in a four-step interpretative process (see Figure 1) inspired by a microanalysis approach proposed by Corbin and Strauss (2015). The first step entailed interviewing the preschool teachers and transcribing the interviews. This involved gaining an initial understanding of the content, which facilitated the next step. The second step entailed manually coding the transcribed data. The coding followed an interpretive approach with repeated feedback between the theoretical framework and empirical data. Inspired by Corbin and Strauss (2015), words and phrases expressed in the preschool teachers' narratives were scanned. To help make sense of the data, a search was undertaken for statements and expressions related to technology that were associated with a set of guiding questions: (a) What are the main arguments about preschool teachers' knowledge of technology, (b) what kinds of technology-related activities are described, and (c) what actions toward children are described? The coding was subsequently grouped into patterns. The third step involved defining categories through the repeated analysis of patterns. The researchers met frequently to compare the emerging categories. Categories were identified with repetitive feedback between categories and patterns, thus following the recommendations of Denzin and Lincoln (2000) and Miles and Huberman (1994). In the fourth and final step, the categories were grouped to generate the basis for three different themes: *knowledge*, *planned activities*, and *unplanned activities* (see Figure 1). Consequently, typical aspects of the preschool teachers' statements were highlighted, illustrating the various themes. In this interpretive process, investigative triangulation between patterns, categories, and themes was used. To establish construct validity, narrative stories and quotes were used to present and illustrate these inductively generated results (Gibbert, Ruigrok, & Wicki, 2008; Yin, 2003). In this way, the researchers observed a high degree of consistency, which can underpin the internal validity of the results.

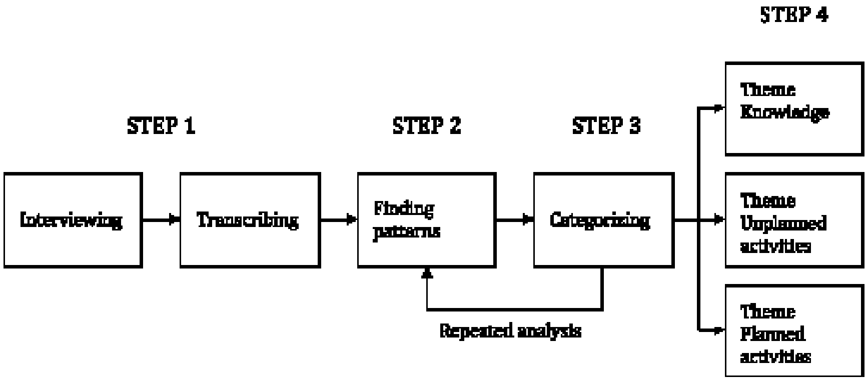

Figure 1. Process of analysis.

Results

The results describe the preschool teachers' knowledge of technology and how this influenced their actions toward children in planned and unplanned activities.

Limited Knowledge of Technology

Within the theme of *knowledge*, the preschool teachers' statements show their views on technology in relation to themselves and their profession. They faced difficulties in defining technology, with many relating it to computers, television, and other technical equipment. As to defining technology in preschool, they expressed that it is about solving problems of various kinds. Maria expressed the following:

> Technology is solving problems. I see a child in front of me who sits and builds a tower, and so it collapses, and everything is all about building the tower right. They need to know how to build it right. Problem solving.

The preschool teachers expressed that the goal of problem solving is that children should learn various technical skills to solve various problems. In problem solving, the child learns a skill, without the involvement of the teacher, explores, and tries out different procedures to finally reach a solution. The teachers also emphasized that the preschool environment offers, through a variety of materials, many challenges for children to work with different kinds of problem solving, both indoors and outdoors.

Besides problem solving, the preschool teachers defined technology as something that exists in everyday life in a substantial way and permeates the most basic needs. Sarah described the situation as follows:

> Technology in preschool exists everywhere in everyday life. When children wash their hands, I say to them that this is technology, and they learn what technology is. If I open the tap, the water comes out, and when I close the tap, the water stops. It is technology.

Sarah emphasized that technology appears in everyday situations. A common way of working with technology is by paying attention to the technology around the students, such as when they open the tap and water flows or when they close the tap and water stops flowing. Thus, focusing on such phenomena and attaching the word *technology* to them has become a strategy that the preschool teachers use when working with children to give them a basic understanding of technology in preschool.

Even when using such strategies and seeming pleased with them, the teachers also discovered problems with this way of teaching children about what technology is. Several preschool teachers expressed concerns about whether they were challenging the children in their learning process in everyday situations. Helen described the following:

> I cannot explain to the children what happens when we switch the light on and off more than simply to say that it is so. I don't have enough knowledge for that, so I do not know what the children learn from this. I cannot answer their questions about *why*. But I do highlight that it is technology even if I can't explain *why*.

The preschool teachers pinpointed that to create a learning situation, the teacher needs the knowledge and ability to explain and discuss different processes of how everyday technology works. They all experienced a lack of this ability, for instance, when Helen described not being able to explain what happens to make the light turns on and off when one presses a button on the wall or when Sarah described what happens when one opens and closes the tap. The awareness of trouble with handling the *why* question is an issue they considered to be a problem in children's learning of technology. For children to gain an understanding of what technology is and how it can be used to explain how things work, it is important to discuss the *why* issue.

In the preschool curriculum, technology is emphasized as one of the most significant pedagogical areas. All of the preschool teachers were aware of that but expressed frustration over their limited knowledge and the fact that they could not live up to expectations. Anne described this as follows:

> The curriculum states that one should distinguish technology in everyday life and explore how simple technology works. If we don't understand what technology is, how do we get children to understand what it is?

Although the preschool curriculum has been strengthened and the teacher's mission has expanded, the preschool teachers found it difficult, and hence challenging, because they do not have sufficient knowledge of technology. If they cannot explain, or even have knowledge of, how a simple technology works, they cannot challenge children and help them understand how it works. This lack of knowledge in dealing with the *why* issue will impact how they act toward the children in technology-related activities that are either planned by them or unplanned and initiated by the children in their free play.

Planned Activities Initiated by the Teacher

Planned activities are activities planned by the preschool teacher. However, the preschool teachers described such activities as being unusual. Planned activities are activities that include teaching materials that provide step-by-step instructions on how to carry out the activity. Issues that may be addressed with the children during and after the activity are included in these instructions. Despite being unusual, the preschool teachers emphasized that these planned activities are the best way for children to learn about technology. Maria stated the following:

> It is important to have planned activities in technology because we challenge the children's learning process by preparing questions for them based on the teaching materials. It is the best way for the children's learning.

A crucial factor for choosing to work with technology in planned activities is the safeness of relying on teaching materials. As Maria highlighted, it provides opportunities to be involved in the activity, and that it is the best way of challenging the children in their learning. This is because the teaching materials often have detailed instructions and describe what happens in every exercise. This enables the preschool teacher to answer the *why* questions.

The guidelines that these materials provide regarding, for example, prepared questions, enable the preschool teachers to handle the *why* issue. Emmy described the benefit of these materials:

> A good thing is that the teaching materials make us active and have prepared answers that we give the children, so they understand how things work. The materials not only give instructions on what to do but also explain what happens, so we can tell the children how to understand the phenomena. This is the key.

The preschool teachers pinpointed that the teaching materials create good conditions for working with technology in preschool. The key in planned activities is that the teaching materials enable the preschool teachers to take an active approach in working and interacting with the children. The materials provide facts to help the teachers address the *why* issue or, more specifically, to explain what and how different phenomena appear. Thus, it is the teacher who poses questions to the children, not vice versa, and above all, they have the answers to the questions and are able to answer the children's *why* questions. The preschool teachers' experience of the materials is that they enable them to exert control over the situation, especially because they feel prepared and confident to address the children's questions. They highly value this approach to working with technology when they see the learning opportunities that it provides.

Unplanned Activities Initiated by the Children

Unplanned activities in technology are activities that are initiated and carried out by children during free play. Opportunities for free play allow space for children's innate curiosity to discover, solve problems, and create an understanding of the world around them. The preschool teachers pinpointed that preschool should provide children with a safe environment that simultaneously challenges and encourages play and activities related to technology. Furthermore, children should be challenged to explore the world around them, and the activities should provide space for the children to execute their own plans, fantasies, and creativity in play and learning. The preschool teachers also emphasized that children are offered a variety of technical tools in the preschool environment. Elisa described the following:

> Our environments offer building blocks and Lego. We also offer hammers, nails, and pieces of wood collected outdoors that they can build with. But mostly they play with technical material that we have indoors.

Many of the preschool teachers' statements concerned, as Elisa expressed, materials that they connect to construction play and activities that take place indoors. They all expressed that children show curiosity about using technical materials and tools.

Building activities are based on children's natural curiosity and joy of discovery. The children initiate technical activities every day when they, by nature, use play, fantasy, and creativity, especially in construction play. For example, Jennifer described the following:

> It happens every day that children sit and build with blocks and construct houses and towers of various kinds. They are so creative and full of fantasy. Sometimes they have even drawn on paper an outline of what they want their building to look like. They sit and discuss different possibilities and

> solutions to build, for example, a tower, in the best way so that it will not collapse. I mean, that's very creative.

Jennifer described a common unplanned activity in technology initiated by children with a focus on building things. The children sometimes start the activity by drawing a sketch to clarify their thoughts and ideas and what the goal, or final product, is. Based on the sketch, they start to construct. The preschool teachers described how the children use their creativity and fantasy to develop technical solutions and show a natural interest in creating things. A cornerstone of technical skills is being able to express oneself using speech, models, or drawings. In this process, they develop and make comparisons of their own and other constructions, which increases their understanding of the technological possibilities. In working with their own constructions, they learn to detect similar technological solutions in their environment.

Unfortunately, the preschool teachers' limited knowledge of technology influences their actions toward the children in the activities that the children initiate. Sofia stated the following:

> The children get frustrated when it collapses and do not know how to place blocks to build as planned. They often ask us teachers why it collapses and how to build successfully. It often ends with us saying we don't know and that they should try again, and we walk away. We do not know how to explain to the children why it collapses or how to construct the building for it to stand. We don't have the technical knowledge to answer their question. It might sound silly, but it is like this. It often ends with the children becoming bored and switching activities.

The children show an interest in something and are stimulated and challenged through play, environment, materials, and other children. Unfortunately, the preschool teacher's actions do not encourage the children in their activities. Consequently, they do not stimulate the children's learning about technology. When the children's buildings collapse, they ask for support and help from the preschool teachers to get deeper knowledge to continue with the activity. Instead of giving support and encouragement by engaging in discussions with the children to find solutions, the teachers fail to stimulate the children's interest, curiosity, creativity, and motivation to go further. A possible approach is to encourage children to develop and make comparisons between their own and others' construction to increase their understanding of the technological possibilities. In working with their own constructions, they could also learn to detect similar technological solutions in their environment. The situation that Sofia described could be turned into an excellent learning moment; instead, her experience has been that the children stop and switch activities.

Discussion

The aim of this study was to investigate how preschool teachers' knowledge of, and approaches to, technology influence how they act in different learning activities with children. In line with prior research (e.g., Plowman et al., 2010; Siu & Lam, 2005; Smith, 2001), the results show that preschool teachers' knowledge of technology is limited. Moreover, the excerpts from our interviews with preschool teachers indicate how this limited knowledge influences the teachers' leadership behavior toward the children in technology-related activities. Our results provide insights for both planned activities initiated by teachers and unplanned activities initiated by children during free play. The results also show that the core of how the teachers' knowledge of technology influences their leadership behavior in these two types of activities is their ability to deal with children's *why* questions.

A compensatory approach is evident in the teachers' leadership behavior toward the children. It is visible in planned activities initiated by the teachers in which they rely on prepared teaching materials to compensate for their lack of knowledge of technology. These materials also provide tools for dealing with children's *why* questions, such as step-by-step instructions on how certain activities can be carried out and examples of issues to address with the children. Such compensation causes the teachers to prefer working with technology in planned activities, even if such activities are unusual. In unplanned activities initiated by the children during free play, the compensatory approach is replaced with an avoidance approach, evinced in the teachers' leadership behavior toward the children. It is visible, for example, when the preschool teachers are invited to participate in the activity because a child needs support or wants to discuss solutions to go further in the activity. In such an instance, the teacher cannot rely on any teaching materials and has neither the tools nor the knowledge to deal with the child's *why* questions. Instead of support with problem solving to motivate the children, the teachers walk away and avoid interaction while the children carry out these activities.

According to path–goal theory (House, 1971, 1996), preschool teachers' behavior strongly affects their ability to be supportive, motivating, and challenging. Our results show that the teachers' knowledge of technology is crucial because it influences their leadership behavior toward the children. Consequently, such a direction sets limitations for the children's outcomes, such as learning, and one can question how discovery, creativity, fantasy, and problem solving can be motivated in this case. Aligned with Senesi (1998), this implies that an enhanced understanding of technology affects how learning processes aimed at achieving certain goals can be pursued in activities related to technology. This also affects how children are being helped to develop knowledge of technology and technological skills within the preschool environment.

Despite the preschool teachers' experienced inability to challenge children's learning about technology, they are aware of the importance of the children receiving support from their teachers. Thus, to further children's thinking in finding possible solutions to problems, preschool teachers must understand what is required of leadership behavior and must consciously reflect on what is happening in the process. When children are challenged by the preschool teacher with open questions focused on the *why* issue, they get the opportunity to reflect on what is happening which can be compared with being encouraging and supportive (Stables, 1997). The preschool teachers highlighted that their view and knowledge of technology result in them influencing the children's learning negatively by their actions. This leadership behavior is a consequence of the teachers' self-expressed limited knowledge of technology, which further influences their inability to answer the children's *why* questions. Enabling learning requires that the preschool teacher to be aware of the goal of an activity. Therefore, they provide planned activities, in which they have control, that open up opportunities for learning in a more profound way than what takes place during unplanned activities.

According to previous research (e.g., Siraj-Blatchford, 2001; Siu & Lam, 2005), preschool teachers should offer children a chance to develop an understanding of the world around them at an early stage. Because young children have an innate curiosity to discover and solve problems, activities involving technology could be welcomed in the preschool environment. This would require that the preschool teachers capture such possibilities by gaining knowledge of how a preschool environment can be equipped to encourage and develop children's discovery of technology. We have identified that preschool teachers may be prone to compensatory and avoidance approaches. However, in line with Csikszentmihalyi (1990) and Dörnyei and Ushioda (2011), we argue that a problem-solving approach may be fruitful in preschool teachers' leadership behavior toward children and that such an approach can be valuable both in planned and unplanned activities. Such an approach will allow the teachers to pay attention to the technology, thereby making it visible to the children. In turn, this can create opportunities for the teachers to experience and handle situations that motivate learning.

Conclusion

The results highlight the importance of developing preschool teachers' knowledge and understanding of technology, which will also enable them to develop their ability to explain and clarify concepts and various technical phenomena. Moreover, such development will enable the preschool teachers to create learning environments for children in which technology becomes something natural. It will also help the preschool teachers become proficient, for example, in problem solving and asking reflective questions—thus enabling them to adopt a problem-solving approach. The development of possibilities for children's learning about technology will be affected in both planned activities initiated by teachers and, most importantly, in unplanned activities initiated by the children during free play.

For children's learning, interest, and motivation to be strengthened, it is not sufficient to equip the physical environment of the preschool in such a way that it encourages and develops children's interest in discovering technical phenomena. Preschool teachers need to take advantage of the unplanned experiences and capitalize on teachable moments when any opportunities for instruction present themselves by chance, for example, by reflecting on problem solving with the children. Preschool teachers should exploit children's natural curiosity for learning and their problem-solving approach. In this way, the teachers can support the children in discerning what technology is in everyday situations instead of making technology invisible.

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Effectiveness of Small-Group Learning Pedagogies in Engineering and Technology Education: A Meta-Analysis

Sema A. Kalaian, Rafa M. Kasim, & Julia K. Nims

Abstract

This study reports the results of a meta-analysis synthesizing the available literature on the effectiveness of various forms of small-group learning methods on the academic achievement of college students in undergraduate engineering and technology classrooms. The meta-analytic results showed that cooperative learning, collaborative learning, problem-based learning, and peer-led team learning pedagogies were studied in college technology and engineering classrooms. The results also revealed that most of the primary studies supported the effectiveness of the small-group learning methods in improving students' academic achievement with an overall positive weighted average effect size of 0.45 in standard deviation units favoring small-group learning methods. The findings might help engineering and technology instructors and educators by providing guidance in identifying the conditions under which various forms of innovative small-group pedagogies are more effective than the traditional lecture-based teaching and individualized instruction.

***Keywords*:** cooperative learning, collaborative learning, engineering education, problem-based learning, small-group learning, STEM, technology education

For the last three decades, there have been numerous and consistent calls for instructional reforms and innovations in science, technology, engineering, and mathematics (STEM) education by national and federal agencies as well as national organizations such as the Accreditation Board for Engineering and Technology (Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology, 1997), the American Association for the Advancement of Science (1989, 2004), the National Science Board (2003, 2010, 2015), the National Science Foundation (1996), the National Academy of Engineering (2004, 2005), the National Research Council (1996), and the Domestic Policy Council and Office of Science and Technology Policy (2006). In their publications and recommendations, they have emphasized the need to examine and explore the teaching practices and student-learning processes that require various forms of innovative small-group pedagogies in STEM college classrooms. In addition, these calls have stressed the requirement for graduates from the various STEM disciplines and programs to have the ability to communicate effectively, think reflectively and critically, and function effectively in cooperative and collaborative multidisciplinary diverse team-based educational and workplace settings (Engineering Accreditation

Commission of the Accreditation Board for Engineering and Technology, 1997; Jamieson & Lohmann, 2009). These desired educational goals might be accomplished by adopting active small-group learning pedagogies that stress experiential methods, which simulate real team-based workplace environments and provide real-life learning experiences (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2005; National Academy of Engineering, 2004).

In response to these numerous calls and recommendations, many STEM educators and instructors across all levels of schooling have been developing, studying, and adopting various innovative forms of active small-group learning methods in their classrooms as alternative pedagogies for traditional lecture-based and individualized instruction. Cooperative learning, collaborative learning, problem-based learning, peer-led learning, peer-learning, inquiry-based learning, and team-based learning are examples of such innovative systematic forms of small-group learning methods. In small-group learning, students in the classroom are divided into groups to work together collaboratively on classroom activities to accomplish a common learning goal.

Consequently, many empirical primary studies have been conducted to examine the effectiveness of these innovative small-group learning methods in comparison to lecture-based instruction across all levels of schooling. As far as we know, no meta-analytic review has been conducted to examine the impact of the various forms of small-group learning pedagogies on students' achievement in technology and engineering undergraduate college classrooms. Therefore, there is a need to survey, review, integrate, and synthesize the existing research on the impact of the different small-group learning pedagogies compared to lecture-based and individualized instruction in STEM undergraduate courses across technology and engineering disciplines. The main objectives of the meta-analytic study were to: (a) determine how much empirical primary research has been conducted and evaluated on the use of each of the various forms of small-group learning methods in undergraduate technology and engineering classrooms and (b) determine if each of the evaluated innovative small-group methods is effective in maximizing student achievement in technology and engineering college courses.

Meta-Analysis Methodology

Meta-analysis is a quantitative statistical method for synthesizing and integrating the research findings from the accumulated scientific literature on a specific research topic that address and test the same fundamental research question and hypothesis (Hedges & Olkin, 1985). In this section, we describe how we conducted the meta-analytic review for this study.

Identification of the Relevant Studies

We used extensive library search procedures to identify published and unpublished primary studies that focused on the effectiveness of small group learning instruction compared to lecture-based and individualized instruction in technology and engineering college classrooms. Library searches were conducted through (a) searching electronic databases, such as the ProQuest Dissertations and Theses database, searching electronic technology and engineering journals, such as the *Journal of Technology Education* and the *Journal of Engineering Education*, and (b) examining the references of these studies to identify other potential relevant primary studies in engineering and technology.

The keywords used in this study included: “cooperative learning,” “collaborative learning,” “problem-based learning,” “small-group learning,” “peer-led group learning,” “peer learning,” and “team-based learning.” These keywords represented the key small-group learning pedagogies and were combined with “technology” or “engineering” subject matter descriptors in “college” and “university” settings.

Inclusion or Exclusion Criteria of the Primary Studies

Stringent inclusion criteria were established and used to determine whether a primary study was qualified to be included in the present meta-analytic review. A study was included in the meta-analysis if it met the following criteria: (a) used two-group research designs (experimental, quasiexperimental, or comparative) that focused on comparing one of the various forms of small-group learning pedagogies to the traditional lecture-based and individualized instruction on college students’ achievement, (b) involved undergraduate technology and engineering college classes, and (c) reported the necessary descriptive summary statistics such as the means and standard deviations of the achievement scores for the two comparison groups. With these preset criteria, we identified 18 technology and engineering primary studies.

Coding of Study Features

Based on a careful review of the collected literature, a coding instrument was constructed to cover the methodological and substantive features of each of the 18 primary studies. The coding of the study features was based on the reported information in the primary studies. Publication year, publication type, and instructional duration are examples of the coded characteristics of the primary studies.

Estimating and Calculating the Effect Sizes

In this meta-analytic study, 26 independent effect sizes, based on independent samples of students, were extracted from 18 primary studies. The 26 independent effect sizes (standardized mean differences) were calculated to measure the effectiveness of each of the various forms of small group learning instruction compared to either a lecture-based instruction or an individualized instruction in evaluating students' achievement scores in technology and engineering college courses. The effect-size index for each primary study was calculated by taking the difference between the means of achievement scores of the students who were instructed by the small-groups methods and the lecture-based groups and dividing the difference by the two groups' pooled standard deviation, known as *Hedges's g* (Hedges & Olkin, 1985; Kalaian & Kasim, 2014). To obtain the weighted average effect size, which is referred to in this study as *d*, each of the effect sizes was weighted by its inverse of the combined sampling and random errors.

Integrating and Modeling Effect Sizes

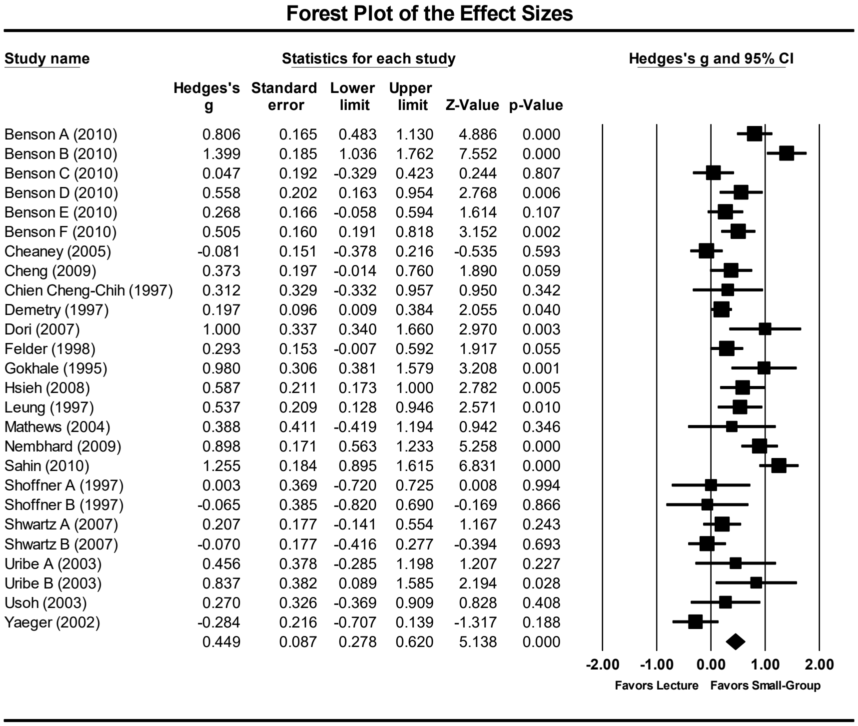
The meta-analytic results of this study were obtained by using the Comprehensive Meta-Analysis (Version 2.0) software package. The random-effects approach for meta-analysis was used to synthesize and integrate the accumulated technology and engineering literature on the effectiveness of the various forms of small-group learning pedagogies on college students' achievement in technology and engineering college classrooms. Moderator analyses involving the categorical and continuous coded characteristics of the primary studies (e.g., publication year, instructional duration) were also performed to investigate the conditions under which the various forms of small-group learning methods may have different effects.

Results

The results of this study are organized into three main sections. The first section lists and describes the characteristics of the primary studies, the weighted effect sizes. The second section reports the results of the subgroup analysis for the major subgroup characteristics of the primary studies (study design characteristics, instructional characteristics, and student grouping characteristics) and includes the categories of the moderator variables. Finally, the third section reports the results of the metaregression analysis to explain the variations among the effect sizes using the coded continuous variables of the primary studies as moderators (predictors) in the regression model.

Overall Meta-Analysis Results

Figure 1 shows the forest plot of the effect sizes, which includes the first author's name, publication year, the effect size (Hedges's g), *p*-value, and the weighted average effect size of the 26 independent effect sizes using the random-effects model. As shown in Figure 1, the primary studies were published between 1995 and 2010. The 26 independent effect sizes, which were extracted from the 18 primary studies, ranged in value from -0.28 to +1.40. Out of the 26 effect sizes, 22 had positive effects in favor of small-group learning, whereas the remaining four had negative effects in favor of lecture-based and individualized instruction.



Forest Plot of the Effect Sizes

Study name	Hedges's g	Standard error	Lower limit	Upper limit	Z-Value	p-Value
Benson A (2010)	0.806	0.165	0.483	1.130	4.886	0.000
Benson B (2010)	1.399	0.185	1.036	1.762	7.552	0.000
Benson C (2010)	0.047	0.192	-0.329	0.423	0.244	0.807
Benson D (2010)	0.558	0.202	0.163	0.954	2.768	0.006
Benson E (2010)	0.268	0.166	-0.058	0.594	1.614	0.107
Benson F (2010)	0.505	0.160	0.191	0.818	3.152	0.002
Cheaney (2005)	-0.081	0.151	-0.378	0.216	-0.535	0.593
Cheng (2009)	0.373	0.197	-0.014	0.760	1.890	0.059
Chien Cheng-Chih (1997)	0.312	0.329	-0.332	0.957	0.950	0.342
Demetry (1997)	0.197	0.096	0.009	0.384	2.055	0.040
Dori (2007)	1.000	0.337	0.340	1.660	2.970	0.003
Felder (1998)	0.293	0.153	-0.007	0.592	1.917	0.055
Gokhale (1995)	0.980	0.306	0.381	1.579	3.208	0.001
Hsieh (2008)	0.587	0.211	0.173	1.000	2.782	0.005
Leung (1997)	0.537	0.209	0.128	0.946	2.571	0.010
Mathews (2004)	0.388	0.411	-0.419	1.194	0.942	0.346
Nembhard (2009)	0.898	0.171	0.563	1.233	5.258	0.000
Sahin (2010)	1.255	0.184	0.895	1.615	6.831	0.000
Shoffner A (1997)	0.003	0.369	-0.720	0.725	0.008	0.994
Shoffner B (1997)	-0.065	0.385	-0.820	0.690	-0.169	0.866
Shwartz A (2007)	0.207	0.177	-0.141	0.554	1.167	0.243
Shwartz B (2007)	-0.070	0.177	-0.416	0.277	-0.394	0.693
Uribe A (2003)	0.456	0.378	-0.285	1.198	1.207	0.227
Uribe B (2003)	0.837	0.382	0.089	1.585	2.194	0.028
Usoh (2003)	0.270	0.326	-0.369	0.909	0.828	0.408
Yaeger (2002)	-0.284	0.216	-0.707	0.139	-1.317	0.188
	0.449	0.087	0.278	0.620	5.138	0.000

Figure 1. Forest plot of the effect sizes of the primary studies.

The overall homogeneity test results revealed that the 26 effect sizes of the primary studies were heterogeneous ($Q = 115.81$, $p < 0.00$), indicating that there was significant heterogeneity among the effect sizes of the primary studies and that these differences may be explained by the coded characteristics of the studies. Also, the results of the random-effects model revealed that the overall weighted average of the 26 effect sizes was positive and significant ($d = 0.45$, $p < 0.00$).

Subgroup Analysis of the Categorical Moderator Variables

Based on the homogeneity test results, which indicated that the 26 effect sizes were significantly heterogeneous, we conducted subgroup analyses for the coded categorical variables using the random-effects methods. This analysis was performed in order to identify both the source of variability among the effect sizes and the differences among the subgroups. The following are the results of the subgroup analyses for the three major subgroup characteristics: study design characteristics, instructional characteristics, and student grouping characteristics.

Subgroup results of the study design characteristics. The subgroup results of the random-effects categorical analysis for the categories of the major coded study characteristics of the primary studies are shown in Table 1. As shown in Table 1, seven effect sizes were extracted from the primary studies that had been published in 2000 or earlier with a *d*-value of 0.32. The remaining 18 effect sizes were extracted from the primary studies that had been published in 2001 or later with a *d*-value of 0.49, which was much larger than the average effect size of the primary studies that were published in 2000 or earlier.

The results also show that 18 effect sizes were extracted from articles published in peer-reviewed journals with a significant and positive *d*-value of 0.58. This average effect size was much larger than the average effect size of the remaining eight effect sizes that were extracted from PhD dissertations with a nonsignificant *d*-value of 0.05. Regarding the research design that is used in the primary studies, the quasiexperimental studies (two-group pre–post research design) produced much larger effect sizes with a significant *d*-value of 0.52 than the nonexperimental (comparative post-only) studies with a significant *d*-value of 0.40.

In addition, the results show that the engineering primary studies in this review produced larger effect sizes (18 effect sizes with a *d*-value of 0.48) than the technology primary studies (eight effect sizes with a *d*-value of 0.38). In regards to college classroom level, the effect sizes for first-year freshmen classrooms were much larger ($d = 0.84$) than the effect sizes of the higher level college classrooms (sophomores, juniors, and seniors; $d = 0.38$). These results indicate that the various small-group learning methods were much more effective in the freshmen level of college than the higher levels.

Furthermore, the results show that the majority of the primary studies were conducted at universities and colleges in the United States and 24 effect sizes were extracted from these primary studies. The *d*-value of these 24 effect sizes was positive and statistically significant. The remaining two effect sizes were extracted from the primary studies that had been conducted in China and Turkey and had much larger effect sizes with a significant positive *d*-value of 0.90.

Table 1
Subgroup Analysis of the Study Characteristics

Study characteristics	# of *d*	*d*-value	*p*-value
Publication year			
2000 or earlier	7	0.32	0.00
2001 or later	19	0.49	0.00
Publication type			
Published articles	18	0.58	0.00
Theses and dissertations	8	0.05	0.62
Research design			
Quasi-experimental	10	0.52	0.00
Non-experimental	16	0.40	0.00
Classroom level			
First year class	4	0.84	0.00
Higher classes	22	0.38	0.00
Study location			
United States	24	0.41	0.00
Other countries	2	0.90	0.01
Discipline			
Engineering	18	0.48	0.00
Technology	8	0.37	0.02

Subgroup results of the instructional characteristics. The results of the subgroup analyses that are related to the instructional characteristics of the engineering and technology primary studies are shown in Table 2. The results show that during the last 3 decades, four different methods of small-group learning (cooperative, collaborative, problem-based, or peer-led team learning pedagogies) have been used and evaluated in the technology and engineering college classrooms. The results also show that both cooperative and collaborative learning methods promoted larger effects in increasing students' achievement with *d*-values of about 0.51 and 0.46, respectively, and followed by problem-based learning with a *d*-value of 0.36. Only one primary study implemented peer-led team learning and had the lowest effect size of 0.20.

About 25% of the effect sizes that were extracted from six primary studies had much shorter instructional durations (20 hours or less) with a *d*-value of 0.41. The other 75% of the effect sizes had instructional durations of 30 hours or more ($d = 0.45$), which is almost similar to the shorter instructional duration. None of the primary studies in this review had instructional durations between 21 and 29 hours.

Courses that used computers as an instructional aid in the classrooms had larger effects sizes with a significant positive *d*-value of 0.50 than courses that did not use computer-aided instruction with a significant positive *d*-value of 0.42. The results also show that the primary studies had about similar effect sizes when the instructional intervention was delivered by either the researcher (author) of the primary study or another instructor who was not the researcher of the primary study with *d*-values of 0.44 and 0.45, respectively.

Regarding the ethnic diversity of the students: None of the studies had predominately minority students in the classrooms. Five effect sizes were extracted from the primary studies that were predominately White (more than 60%) with a *d*-value of 0.26, and the majority of the primary studies did not report the ethnic diversity of the classrooms. These studies had a much higher effect sizes ($d = 0.49$) than the studies that reported the ethnic diversity of the students.

Similar to the ethnic diversity of the students in the classrooms, the results show that the 13 effect sizes were extracted from the primary studies that did not report the gender diversity of the students in the engineering and technology classrooms and had a *d*-value of 0.53. Ten effect sizes were extracted from the primary studies with male dominated classrooms (more than 60%) and had a *d*-value of 0.42. The remaining three effect sizes were extracted from the primary studies with female-dominated classrooms (more than 60%) and had much lower *d*-value of 0.23 than the studies that did not report the gender composition of the classrooms.

Finally, our results show that the majority of the primary studies had used teacher-made tests to assess students' achievement in engineering and technology classrooms with a significant positive *d*-value of 0.44. The remaining two studies used standardized tests and produced a significant positive *d*-value of 0.65.

Table 2
Subgroup Analysis of the Instructional Characteristics of the Studies

Instructional characteristics	# of *d*	*d*-value	*p*-value
Learning method			
Cooperative learning	12	0.51	0.00
Collaborative learning	7	0.46	0.00
Problem-based learning	6	0.36	0.18
Peer-led learning	1	0.20	0.04
Instructional duration			
20 hours or less	6	0.41	0.00
21 hours or more	20	0.45	0.00
Classroom computer use			
Yes	9	0.50	0.00
No	17	0.42	0.00
Classroom instructor			
Investigator	17	0.44	0.00
Other	9	0.45	0.00
Classroom ethnic diversity			
Predominately minority	0	--	--
Predominately White	5	0.26	0.08
Not reported	21	0.49	0.00
Classroom gender diversity			
Predominately female	3	0.23	0.15
Predominately male	10	0.42	0.01
Not reported	13	0.53	0.00
Type of exam			
Teacher made test	24	0.44	0.00
Standardized test	2	0.65	0.06

Subgroup Results of the Student Grouping Characteristics

As shown in Table 3, the primary studies that placed the students into small groups by students' selecting their own groups produced much higher effect sizes ($d = 0.51$) than the studies that placed students in the groups by random selection ($d = 0.46$) and much less than the studies that placed the students in groups based on abilities such as their Grade Point Average (GPA) and Scholastic Aptitude Test (SAT) scores ($d = 0.21$). The results also show that the primary studies with small groups of three to five students produced larger effect sizes ($d = 0.49$) than the studies with groups of two students ($d = 0.31$).

Table 3
Subgroup Analysis of the Grouping Characteristics of the Studies

Grouping characteristics	# of *d*	*d*-value	*p*-value
Placement of students into small groups			
Random selection	11	0.46	0.001
Ability grouping	4	0.21	0.29
Self-selected groups	11	0.51	0.00
Group size			
2 students	6	0.31	0.22
3 students	12	0.48	0.00
4 students	6	0.49	0.01
5 students	2	0.49	0.01

Random-Effects Regression Analysis Results of the Continuous Predictors

Based on the homogeneity test results, which indicated that the 26 effect sizes were heterogeneous, we conducted random-effects metaregression analyses for each of the coded continuous moderator variables. The metaregression analyses were performed to: (a) determine the ways in which the coded continuous predictor variables impacted the effect sizes and (b) explain some of the variability among the effect sizes. The two coded continuous moderator variables were publication year and instructional duration (in hours) of each of the primary studies in this review. Table 4 shows that the regression coefficients (slopes) for the publication year and instructional duration of the primary studies were 0.03 and -0.004, respectively. These regression coefficients were close to not significant.

Table 4
Random Effects Meta-Regression Analysis of the Predictors

Predictor	Regression coefficient	Standard error	*p*-value
Publication year			
Intercept	-50.35	32.30	0.20
Slope	0.03	0.02	0.12
Instructional duration in hours			
Intercept	0.58	0.25	0.02
Slope	-0.004	0.007	0.58

Conclusion

This meta-analytic study aimed to survey the engineering and technology literature and investigate the effectiveness of the various forms of small-group learning methods in comparison to the traditional lecture-based and individualized instruction in maximizing college students' achievement scores in undergraduate engineering and technology classes. As far as we know, this is the only comprehensive meta-analysis of the undergraduate technology and engineering education literature.

The results showed that, collectively, the small-group learning methods were more effective on average than the traditional lecture-based instruction with a significant positive overall *d*-value of 0.45 in standard deviation units favoring small-group learning methods. This means that using small-group learning in technology and engineering classrooms could positively affect student achievement, moving the students' scores from the 50th percentile, which is the percentile score of the students in the lecture-based and individualized instructed classrooms, to the 69th percentile in the small-group classrooms. In other words, instead of scoring better than 50% of the students in a lecture-based class, the same student would score better than 69% of the students in a small-group classroom. The results also showed that during the last 3 decades, four different methods of small-group learning (cooperative, collaborative, problem-based, or peer-led team learning pedagogies) have been used and evaluated in the technology and engineering college classrooms.

In addition to exploring the scope and magnitude of the effects of the various forms of small-group learning methods, this study examined the subgroups for whom small-group learning methods are effective. Although the innovative and reform-based small-group learning methods produced positive and significant effects across the subgroup categories, educators and policy makers should note that the various small-group learning interventions appeared to be significantly more effective for freshmen students, students in countries other than the United States, students in groups of three to five, students who chose their own groups, and engineering students. The small-group learning interventions also appeared to be significantly more effective in recently published studies.

The results of this quantitative meta-analytic study are based on 18 technology and engineering primary studies that were conducted since 1997 and met the established inclusion or exclusion criteria. Based on these results, we believe that pedagogical research in engineering and technology education is limited and that there is a need to conduct more primary studies to examine the effectiveness of small-group learning methods in college engineering and technology classrooms. Also, there is a need for better reporting of the small-group instructional processes, activities, and the results of the effects of the various forms of small-group learning research.

In conclusion, this meta-analytic study had shed some light on the accumulated pedagogical literature of the effectiveness of the various methods of small-group learning compared to lecture-based and individualized instruction in college engineering and technology classes. Also, the results of this study added to already converging evidence from other domains such as STEM (Springer, Stanne, & Donovan, 1999), statistics (Kalaian & Kasim, 2014), and computer science (Kalaian & Kasim, 2015) that each form of the small-group learning pedagogies appear to be a promising mechanism for promoting academic success. In other words, we learned that if college students who are taking college engineering and technology classes are placed in an environment in which they have an opportunity to experience peer-supported collaborative and cooperative scientific inquiry, the academic achievement of these students will be improved and accelerated. The evidence-based findings that emerged from this quantitative review can contribute significantly to the current pedagogical knowledge concerning technology and engineering education. The findings also have significant institutional policy implications in undergraduate technology and engineering education as well as being of great interest to instructors and educators who are interested in the pedagogical knowledge to improve students' success, motivation, and persistence in the colleges of technology and engineering throughout the nation and worldwide.

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A Comparative Analysis of Holographic, 3D-Printed, and Computer-Generated Models: Implications for Engineering Technology Students' Spatial Visualization Ability

Petros J. Katsioloudis & Mildred V. Jones

Abstract

A number of studies indicate that the use of holographic displays can influence spatial visualization ability; however, research provides inconsistent results. Considering this, a quasi-experimental study was conducted to identify the existence of statistically significant effects on sectional view drawing ability due to the impacts of holographic displays. In particular, the study compared the use of three different types of displays: 3D printed model, computer generated model, and holographic model to determine whether a significant difference exists towards sectional view drawing ability, among engineering technology students. According to the results of this study, it is suggested that the impact of the display type provides no statistically significant differences.

Keywords: Holographic, spatial visualization, 3-D printed, spatial ability

Generating holographic projections "of medical images and engineering data is a recent topic in visualization" studies (Sheet et al., 2014, p. 103). Complex visualizations require high computer configuration and optical specification, which can be quite difficult and expensive to obtain. However, recent developments in technology have created a growing demand for mature 3D displays and other types of holographic visualization (Gao, Zhang, & Liu, 2010). According to Luévano, López de Lara, and Castro (2015), "recent research on holography . . . [at] the University of Arizona has shown that the development of computer capacities will allow the construction of a three-dimensional presence by the year 2018" (p. 340).

In recent years, 3D holographic technology has been used in communication, military training, entertainment, virtual augmented reality, and medical training (Lee, 2013). Even though holographic technology is mainly developed and used outside educational settings, there is certainly educational potential (Lee, 2013). Holographic technology as a learning tool has the potential to promote a student-centered learning environment, placing students in an interactive environment that allows them to construct knowledge based on their individual learning experiences (Lee, 2013). Sudeep (2013) notes the importance of 3D hologram technology, specifically in engineering education. Coursework, such as engineering design and graphics, require various types of study, including projection of solids and planes, sectional views of solids, and orthographic projection.

According to Liarokapis et al. (2004), virtual and augmented reality in education " can provide a rewarding learning experience that would be otherwise difficult to obtain" (p. 14), especially for disciplines like engineering education that utilize large and complex data sets (Sudeep, 2013).

However, as with many technological applications in education, 3D holographic technology faces several challenges, such as the quality of 3D renderings, visual fatigue, effectiveness of instructional media, and planning of applications (Lee, 2013). Even though the topic has been under research for 2 decades, no significant achievements had been made until the last 5 years (Sheet et al., 2014). The purpose of the current study is to identify whether the use of holographic technology models versus other traditional types of models can increase or decrease spatial ability performance for engineering technology students.

The following was the primary research question:

> Is there an effect on students' (a) spatial visualization ability, as measured by the Mental Cutting Test, and (b) ability to sketch a sectional view drawing, due to the impacts of holographic, 3D-printed, and computer-generated models?

The following hypotheses were analyzed in an attempt to find a solution to the research question:

> H_0: There is no effect on students' (a) spatial visualization ability, as measured by the Mental Cutting Test, and (b) ability to sketch a sectional view drawing due to the impacts of holographic, 3D-printed, and computer-generated models.
>
> H_1: There is an identifiable effect on students' (a) spatial visualization ability, as measured by the Mental Cutting Test, and (b) ability to sketch a sectional view drawing due to the impacts holographic, 3D-printed, and computer-generated models.

Review of Literature

Spatial Visualization

According to Strong and Smith (2001), "spatial visualization is the ability to manipulate an object in an imaginary 3-D space and create a representation of the object from a new viewpoint" (p. 2). Although visualization in a 3D computer graphics context is not new, the evolution of technology has revealed an increasingly significant focus of visualization as a dominant tool in many different disciplines (Ferri, 2001). In 3D computer graphics, the depth perception of an image develops from monocular depth cues (e.g., retinal image size, texture gradients, shading, shadowing, overlapping, motion, linear, and aerial perspective), which "create the illusion of volume and depth on flat image surfaces" (Ferri, 2001, p. 309). Research studies have suggested that as many as 84 career fields require well-developed spatial skills (spatial visualization and rotation abilities, in particular) and play a significant role in success and retention in engineering majors (Maier, 1994; Sorby, Nevin, Mageean, Sheridan, & Behan, 2014; Smith, 1964).

Augmented Reality vs. Virtual Reality vs. Holograms

To alleviate any confusion among types of interactive technologies, it is important to distinguish here that there is a difference between augmented and virtual realities and holograms. Using the same hardware technologies, augmented reality (AR) and virtual reality (VR) both share computer-generated virtual scenes, 3D objects, and interactive components. The difference between these two technologies lies in the way that they are used: "Virtual reality aims to replace the real world while augmented reality respectfully supplements it" (Kesim & Ozarslan, 2012, p. 298), layering enhancements atop an existing reality (see also, García Domínguez, Martín-Gutiérrez, González, & Mato Corredeaguas, 2012). According to Kesim and Ozarslan (2012), augmented reality (AR) "brings virtual information or object to any indirect view of user's real-world environment to enhance the user's perception and interaction with the real world" (p. 298). Azuma (1997) defined "AR as any system that": (a) "combines real and virtual," (b) "is interactive in real time," and (c) "is registered in three dimensions" (p. 356). VR is comprised of an environment that has been made up by a computer.

Holography is neither AR nor VR; rather, it is a way of presenting pictures that you can "walk around." It is a technique that allows an image system (camera or eye), directed at the reconstructed beam, to continue seeing an image even when it is no longer present. Holography uses the same technologies as AR and VR; however, it is completely different from AR and VR technology.

Hologram

Like digital photographs, holograms take light around an object and encrypt it onto a chip. Photographs record the intensity of light; however, holograms capture the "phase" of the light, which gives it a three-dimensional appearance (Khorasaninejad, Ambrosio, Kanhaiya, & Capasso, 2016). According to Sudeep (2013), "the word, hologram is composed of the Greek terms, 'holos' for 'whole view'; and gram meaning 'written'. A hologram is a three-dimensional record of the positive interference of laser light waves" (p. 63). Mature 3D displays can add value to a broad scope of visualizations used in many fields, such as remote-sensing satellites (aerospace engineering), medical imaging devices (biomedical engineering), engineering design, art, advertising, and geological exploration (civil and geological; Khan, 2013, Gao et al., 2010). Holograms are advanced enough for commercialized use in many fields today. Holograms are also embedded in current technologies, such as credit card chips, paper currencies, retail scanners, and even biomedical devices (Khorasaninejad et al., 2016; Khan, 2013).

Static analog holograms were popular during the 1980s and 1990s; however, the technology had not yet evolved into a 3D dynamic holographic technology (Khan, 2013). Today, the resurgence of 3D technologies from sources like geographical data, medical scanning, CAD design, simulations, low-cost depth scanners, cinema or TV, and 3D printing have allowed for the development of enriched 3D dynamic holographic content (Khan, 2013).

Holographic Memory

The human brain may hold memories in a holographic manner, as suggested by Pribram's Holographic Brain Theory (Pribram, 1971, 1991). This theoretical approach to the cognitive processes in the brain suggests that holographic data is distributed rather than localized, such as in plain pictures. According to Berend, Doley, Frenkel, and Hanemann (2016) "each part of the memory (a neuron or a group of neurons) contains some information regarding the entire data" (p. 87). Living systems require not only the intellectual ability to memorize but also the associative property in which the brain establishes connections "between information units (images and concepts) that are not linked during learning," or cognitive processing (Orlov & Pavlov, 2015, p. 628).

Holographic Technology and Uses in Education

Typically, 2D media has been used in educational settings because it is convenient, familiar, flexible, portable, and inexpensive. However, 2D static representation does not reflect the natural world, which is three-dimensional (Kesim & Ozarslan, 2012). Today, virtual 3D environments are more appropriate for learning because the student is submerged in a virtual world representative of the natural world. Known as augmented reality, this "allows the user to see the real world and aim to supplement reality without completely immersing [the] user inside a synthetic environment" (Kesim & Ozarslan, 2012, p. 298). Although holographic technology is typically developed and implemented outside of the academic arena, the potential in educational settings could be the next step in enhancing the experiences of both the learner and the instructor. As educational paradigms shift from teacher-centered to more student-center models, it is important to consider the tools that enhance the transfer of knowledge (Contero, Naya, Company, & Saorín, 2006).

According to Lee (2013), "3D holographic technology can find its roots in the illusion known as 'Pepper's ghost' used in Victorian theaters in the 1860s to produce realistic ghosts through a series of optical projections" (p. 34). In the 1960s, the first static 3D holograms were created (Lee, 2013). In 2008, at the

World Congress on Information Technology, Bill Gates of Microsoft recorded a presentation that was shown as a holographic image in Malaysia. More recently, Cisco Systems and Musion integrated the technology between 3D holographic imaging and real-time virtual communication, allowing Cisco CEO Johan Chambers to appear with presenters who were "beamed" from San Jose to Bangalore, India (Lee, 2013, p. 35).

Although 3D holographic technology could offer enrichment in learning environments, there are also challenges that may hinder implementation in many educational environments. The quality of 3D renderings is a significant concern in instructional effectiveness in many disciplines, including engineering and medicine. For, example, BioDigital Human is "an online 3D interactive medical visualization program" for understanding anatomy and physiology (Lee, 2013, p. 36). Holographic 3D technology "renderings look 'a little cartoonish'" (Hernandez, 2012, para. 14) compared with other mediums like computer renderings and 3D-printed models.

In addition, visual fatigue has been known to occur following viewings of 3D images (Yano, Ide, Mitsuhashi, & Thwaitse, 2002). VR-induced sickness, also known as "cybersickness," has been extensively covered in research (Nichols & Patel, 2002). Educators also need to consider the need for learning activities and student learning outcomes that enhance student-teacher interactions as well as employing student-centered learning approaches for overall effectiveness.

According to Lee (2013), these new technologies also raise concerns regarding cost. Because 3D holographic technology is not fully developed and still needs to be assessed for cost effectiveness, many educational institutions may be uncertain if the cost is worth the investment at this stage.

Methodology

A quasi-experimental study was used as a means to perform the comparative analysis of rotational view drawing ability during the summer of 2016. The study compared the exposure of engineering technology students to three different kinds of spatial visualization models in order to determine whether a significant difference existed towards sectional view drawing ability. The research protocol was generated and submitted for approval to the College's Human Subjects Review Committee, where it was approved and received exempt status. Data was tested for normality of distribution using the Shapiro–Wilk test. The data was analyzed by a three-way repeated measures analysis of variance (ANOVA), with motion as the stimulus and the type of stimulus (3D-printed model, computer-generated model, and a holographic model) as subject factors. Tukey's post hoc analyses were performed to account for multiple comparisons and sample size effect. All data was analyzed using SPSS (Version 25.0). For the analyses, $p < 0.01$ was used to establish significant differences.

The study was conducted in an engineering graphics course, as part of the Engineering Technology program, during the summer semester of 2016. The participants were sophomores and enrolled in the Engineering Technology program. Using a convenience sampling technique, the participants, who were from three different sections of the same course, were assigned into one of three treatment groups. Each group of students was then assigned into a different classroom in which the treatment took place. A common core for all students was the fact that they all previously completed two required mathematics courses (MAT 102: College Algebra and MAT 302: Geometry). As described above, research supports that a positive correlation between mathematics and spatial visualization exists.

The engineering graphics course emphasized hands-on practice using 3D drafting software (Autodesk Inventor) in the computer lab, along with various methods of editing, manipulation, visualization, and presentation of technical drawings. In addition, the course included the basic principles of engineering drawing or hand sketching, dimensions, and tolerance principles. Table 1 shows the participants from the study. Using a convenience sample, there was a near equal distribution of the participants between the three groups. The three groups ($n_1 = 44$, $n_2 = 41$, and $n_3 = 43$), with an overall population of $N = 128$, were presented with the same model (dodecahedron) in a 3D-printed format (see Figure 2), a computer-generated model (see Figure 3), and as a hologram (created by using a free iTunes© application called Holapex© and projected using a Holapex projection pyramid; see Figures 4 and 5) and were asked to create a sectional view drawing of it. The type of visualization model was the independent variable in this study. Each group member received 60 seconds to observe the model. Upon observation, each student had to create a sectional view of the respective model. To create the sectional view of the model, students had to mentally section the dodecahedron; therefore, this process takes into consideration a learner's visualization ability and level of proficiency. Prior to attending the graphics course in which testing took place, all students had to complete two sections of mathematics (MAT 102: College Algebra and MAT 302: Geometry). Research has shown a positive correlation between mathematics and the spatial visualization ability, and "individual differences in spatial and mathematical abilities are correlated (~.5, e.g. Hegarty & Kozhevnikov, 1999), and rely on partly overlapping neural networks (Hubbard, Piazza, Pinel, & Dehaene, 2005)" (Tosto et al., 2014, p. 462). Research suggests these factors can easily be determined through sketching and drawing techniques.

The engineering drawing used in this research was a sectional view of the dodecahedron (see Figure 6). Sectional views are very useful engineering graphics tools, especially for parts that have complex interior geometry because the sections are used to clarify the interior construction of a part that cannot be described by hidden lines in exterior views (Plantenberg, 2013). By taking an imaginary cut through the object and removing a portion, the inside features can be seen more clearly. Students had to mentally discard the unwanted portion of the part and draw the remaining portion. The rubric used included the following parts: (a) section view labels, (b) correct hatching style for cut materials, (c) accurate indication of cutting plane, (d) appropriate use of cutting plane lines, and (e) appropriate drawing of omitted hidden features. The maximum score for the drawing was 6 points.

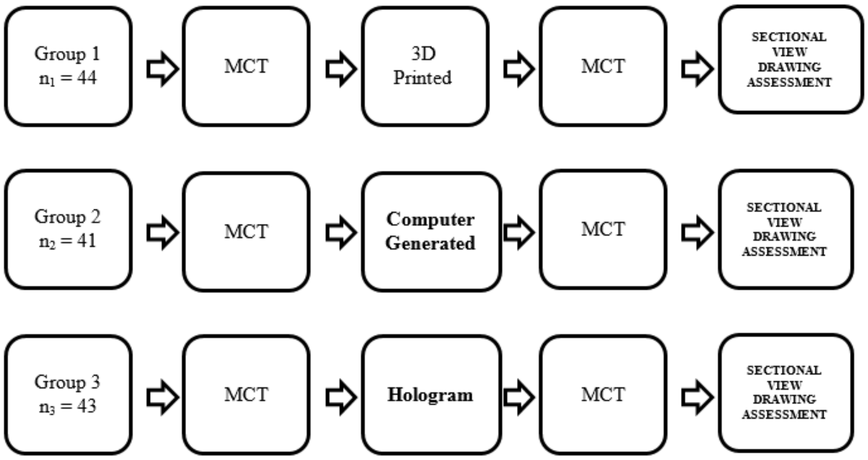

Figure 1. Research design methodology.

In addition, all groups were asked to complete the Mental Cutting Test (MCT; College Entrance Examination Board [CEEB], 1939) instrument 2 days prior to the completion of the sectional view drawing in order to identify the level of visual ability and show equality between the three groups. In this study, the MCT was not used to account for spatial visualization skills. Its only purpose was to establish a near to equal group dynamic based on visual ability, as it relates to mental cutting ability. According to Németh and Hoffman (2006), the MCT (CEEB, 1939) has been widely used in all age groups, making it a good choice for a well-rounded visual ability test. The Standard MCT consists of 25 problems. “The *Mental Cutting Test* . . ., a sub-set of the CEEB Special Aptitude Test in Spatial Relations . . . (1939), has also been used by Suzuki et al. . . . [1990] to measure spatial abilities in relation to graphics curricula” (Tsutsumi, 2004, p. 117).

> In each problem, subjects are given a perspective drawing of a test solid, which is to be cut with a hypothetical cutting plane. Subjects are then asked to choose one correct cross section from among 5 alternatives. There are

> two categories of problems in the MCT . . . [(Suzuki et al., 1990)]. Those of the first category are called '*pattern recognition problems*', in which the correct answer is determined by identifying only the pattern of the section. The others are called '*quantity problems*' or '*dimension specification problems*', in which the correct answer is determined by identifying, not only the correct pattern but also the quantity in the section, e.g., the length of the edges or the angles between the edges. (Tsutsumi, 2004, p. 117)

Data Analysis

Analysis of MCT Scores

The first method of data collection involved the completion of the MCT instrument prior to the treatment to show equality of spatial ability as predicted by similar scores between the three groups. Using convenience sampling instead of random assignment the researchers graded the MCT instrument as described in the guidelines by the MCT creators. A standard paper-and-pencil MCT pre- and post-test was conducted, in which the subjects were instructed to draw intersecting lines on the surface of a test solid with a green pencil before selecting alternatives. The maximum score that could be received on the MCT is 25. The pretest results can be seen in Table 1: $n1 = 23.726$, $n2 = 22.622$, and $n3 = 21.739$. Overall means were higher in the post-test: $n1 = 24.563$, $n2 = 23.478$, and $n3 = 22.631$. A noticeable difference was seen for the group that completed the treatment using the hologram. Respective means changed from 21.739 to 23.631. It can also be seen that the pretest MCT scores were relatively high. This is probably due to the fact that all students that participated in the study had completed two math courses (algebra and geometry) in previous semesters and were also sophomores in engineering technology. "Spatial ability at age 18 moderately correlates with raw SAT (Scholastic Assessment Test) mathematics scores, and remains a significant predictor of mathematical ability after controlling for general intelligence, processing speed and working memory (Rohde & Thompson, 2007)" (Tosto et al., 2014, p. 462).

In addition, after treatment was completed, a one-way ANOVA was run to compare mean scores between pre- and post-treatment, as measured through the MCT. There was significant F (6.181) = .0008, $p < 0.01$ difference between the three groups' level of spatial visualization ability between pre- and post-treatment, as measured by the MCT instrument (see Table 2). The result suggests that a significant difference occurred between the pre- and post-treatment MCT instrument for one of the groups. Research suggests that even a short intervention could increase someone's spatial ability.

Table 1
MCT Pre- and Post-Test Descriptive Results

						95% confidence interval for mean	
	n	Mean pretest	Mean posttest	*SD*	*SE*	Lower bound	Upper bound
Group 1	44	23.726	24.563	3.042	0.976	21.783	24.533
Group 2	41	22.622	23.478	2.631	0.756	22.983	23.431
Group 3	43	21.739	23.631	3.871	0.865	20.789	22.953
Total	128	22.695	23.173	3.181	0.865	21.851	23.639

Table 2
MCT Pre- and Post-Test ANOVA Results

Quiz	*SS*	*df*	*MS*	*F*	*p*
Between groups	1043.531	2	62.897	6.181	*0.008
Within groups	1014.306	98	10.823		
Total	2058.061	100			

* Denotes statistical significance

The second method of data collection involved the creation of a sectional view drawing (see Figure 2). One researcher graded all sketches using a rubric that included the following parts: (a) section view labels, (b) correct hatching style for cut materials, (c) accurate indication of cutting plane, (d) appropriate use of cutting plane lines, and (e) appropriate drawing of omitted hidden features. The maximum score for the drawing was 6 points. As shown in Table 3, the group that used the 3D-printed model as part of their treatment ($n = 44$) had a mean observation score of 4.421. The groups that used the computer-generated ($n = 41$) and holographic ($n = 43$) models had higher scores of 5.421 and 5.602, respectively. A one-way ANOVA was run to compare the mean scores for significant differences among the three groups. The result of the ANOVA test, shown in Table 4, was not significant: F (0.423) = 0.532, $p < 0.01$. The data was dissected further through the use of a post hoc Tukey's honest significant difference (HSD) test. As shown in Table 5, the post hoc analysis shows no statistically significant difference between the computer-generated vs. 3D-printed models ($p < 0.742$, $d = -.2532$), the computer-generated vs. holographic models (*p* = .987, *d* = -.03264), and the holographic vs. 3D-printed models (*p* = .542, *d* = -.3932*)*.

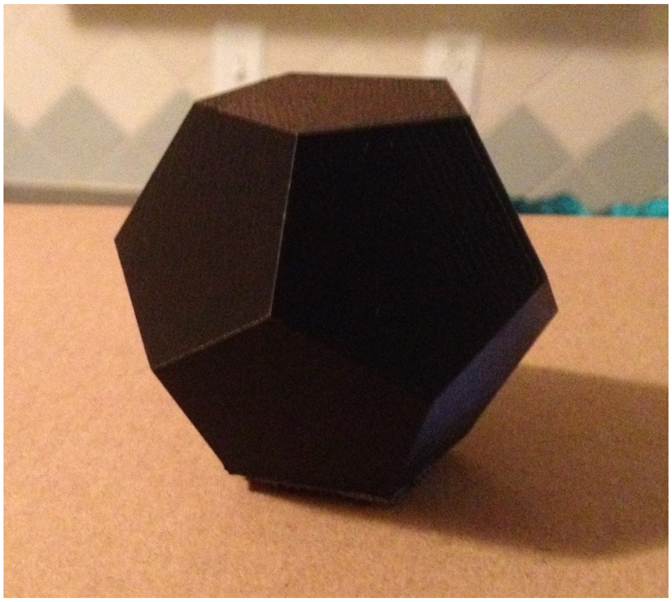

Figure 2. 3D-printed dodecahedron.

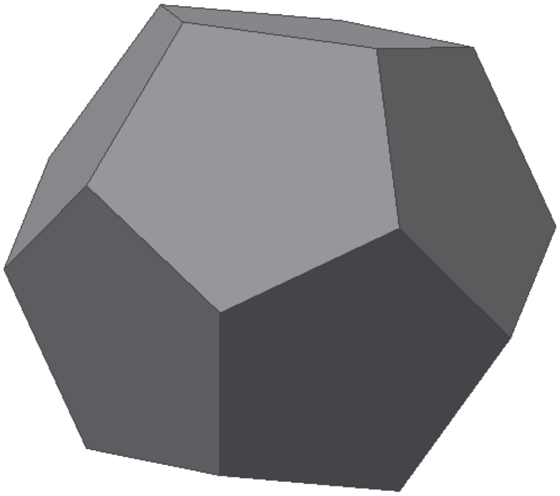

Figure 3. Computer-generated dodecahedron.

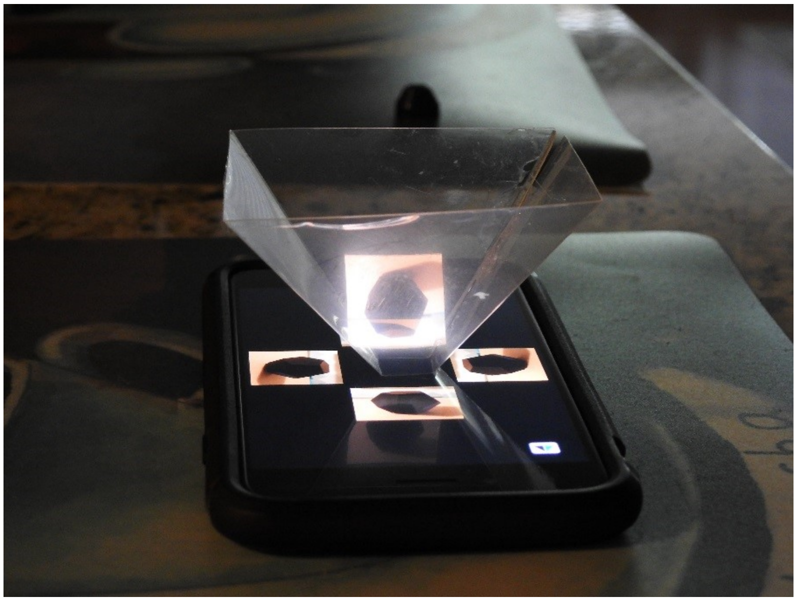

Figure 4. Set up for dodecahedron hologram.

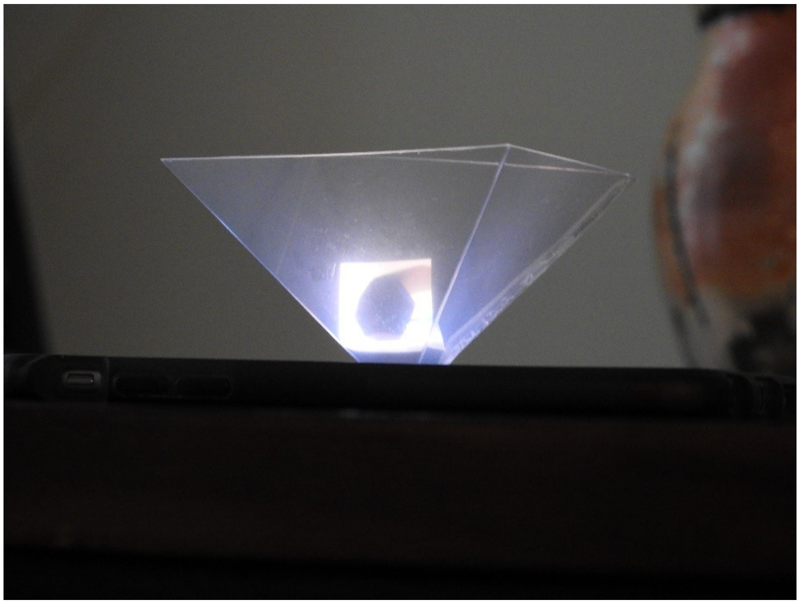

Figure 5. Hologram of dodecahedron.

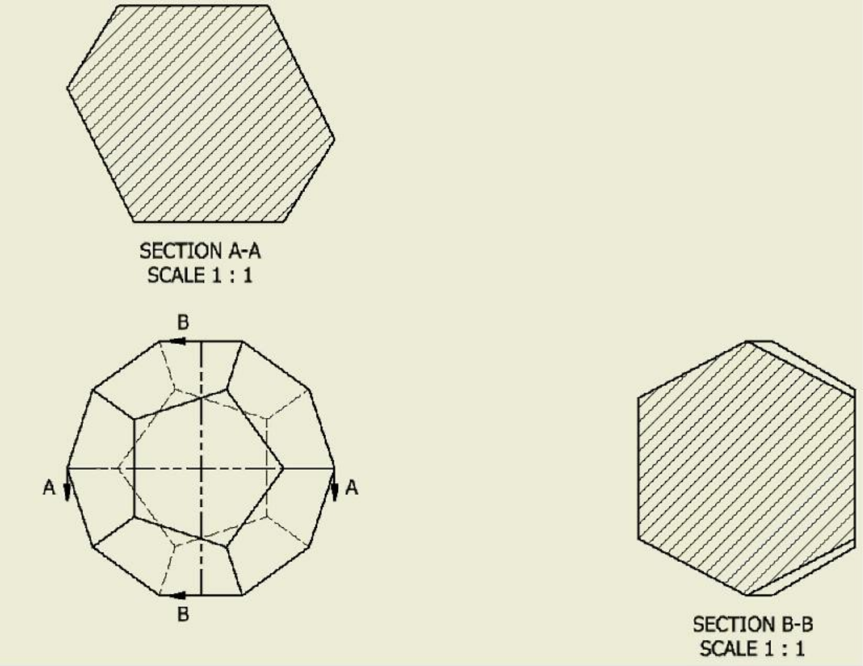

Figure 6. Dodecahedron sectional view.

Table 3
Sectional View Drawing Descriptive Results

					95% confidence interval for mean	
Groups	*n*	Mean	*SD*	*SE*	Lower bound	Upper bound
3D printed	44	4.421	1.422	.394	4.422	4.341
Computer generated	41	5.421	1.421	.301	4.322	5.332
Hologram	43	5.602	1.604	.294	4.042	5.503
Total	128	5.148	1.482	.329	2.262	5.058

Table 4
Sectional View Drawing ANOVA Results

Quiz	*SS*	*df*	*MS*	*F*	*p*
Between groups	1.432	2	0.544	0.423	0.532
Within groups	214.432	98	2.422		
Total	215.864	100			

Table 5
Sectional View Drawing Tukey HSD Results

	Visual Models (1 vs. 2 vs. 3)	Mean Diff. (1-2)	*SE*	*p*
2 vs 1	computer generated vs. 3D printed	-.2532	.3424	.742
2 vs 3	computer generated vs. hologram	-.0421	.3264	.987
3 vs 1	Hologram vs. 3D printed	-.3214	.3932	.542

Discussion

This study was done to determine significant positive effects related to sectional view drawing ability. In particular, the study compared the exposure of engineering technology students to three different kinds of treatments (different models for drafting) to determine whether a significant difference exists in sectional view drawing ability due to a specific kind of model.

The null hypothesis—that there is no significant effect on students' (a) spatial visualization ability, as measured by the MCT, and (b) ability to sketch a rotational view drawing, due to the impacts of holographic, 3D-printed, and computer-generate models—was accepted. Although not statistically significant, the students who received treatment using the hologram outperformed their peers who received treatment using 3D-printed and computer-generated models, respectively. In addition, a one-way ANOVA was run to compare mean scores between pre- and post-treatment, as measured through the MCT. There was a significant difference between the three groups' level of spatial visualization ability between pre- and post-treatment, F (6.181) = .0008, $p < 0.01$, as measured by the MCT instrument. The results of the one-way ANOVA suggest that after treatment, different groups of students showed a significant difference in their MCT scores. In their study, Liarokapis et al. (2004) found that holographic technology allows students "to understand more effectively through interactivity with multimedia content” and “can provide a rewarding learning experience that would be otherwise difficult to obtain” (p. 14). In addition, Eschenbrenner, Nah, and Siau (2008) identified that the benefits of VR in education include, but are not limited, to (a) conducting activities in a risk-free environment, (b) facilitating collaboration and communication, and (c) allowing visualization of abstract or difficult concepts or ideas. In addition, in a study conducted by Ghuloum (2010), 400 teachers from different levels of education in the United Kingdom were surveyed to evaluate the effectiveness of 3D hologram technology as an educational tool. According to the findings, the majority of respondents believed that the technology can enhance learning and constitutes an effective teaching tool.

As with the introduction of many tools in the classroom, implementing holographic technology also includes challenges (Lee, 2013). According to Lee (2013), “the quality of 3D renderings may be one of the most important factors in determining the instructional effectiveness of the technology” (p. 37). Medical students, for example, could receive additional benefits from using interactive 3D holographic models versus using 3D renderings that provide little or limited detail (Lee, 2013). Another issue is the adverse effects, such as visual fatigue (Yano et al., 2002) and cybersickness (Nichols & Patel, 2002), that have been observed after using 3D and VR technologies.

It is also important to understand that the effectiveness of a new instructional technology is not only strongly correlated with the abilities of the technology itself but also with the users. Kozma (1994) explains that the effectiveness of instructional technology, or media, lies in the capabilities of a particular media or technology in conjunction with the appropriate instructional methods in relation to the learners. For example, in a study conducted by Khooshabeh and Hegarty (2008), it was determined that different types of visual cues found in visual technologies affected the performance of participants with low spatial ability but did not show any significance difference in students who already possessed high spatial abilities, such as those in engineering courses. Learners with high spatial ability are able to use more schematic spatial mental representations, whereas learners with low spatial ability tend to use both visual and spatial information in performing tasks (Khooshabeh & Hegarty, 2008).

As shown in Table 4, the ANOVA test did not show any significant difference between the three groups, $F(0.423) = 0.532$, $p < 0.01$, when measuring the sectional view drawing results. Even though a positive difference in the mean of the hologram treatment was observed, it was not statistically significant enough to promote a stronger positive correlation. This article contributes to understanding the effects of using holograms as an instructional tool to enhance learning.

Limitations and Future Plans

In order to have a more thorough understanding of the effects of holograms as it relates to spatial visualization ability for engineering technology students, further research is needed. This study was limited to sophomore engineering technology students that completed two math courses. In addition, a convenience sampling process was used versus random sample assignment. Also, the treatment time was short, it might limit some students' ability to perform better.

Future plans to build on this study include but are not limited to:

- Verifying the results by using additional types of hologram treatments;
- Using a different population, such as technology education, science, or mathematics students;
- Comparing male versus female engineering technology students; and
- Increasing the treatment time.

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Using Teaching Portfolios to Revise Curriculum and Explore Instructional Practices of Technology and Engineering Education Teachers

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Abstract

This paper reports on the use of teaching portfolios to assist in curriculum revision and the exploration of instructional practices used by middle school technology and engineering education teachers. Two new middle school technology and engineering education units were developed through the Engineering for All (EfA) project. One EfA unit focused on addressing world food shortages via the design and construction of urban vertical hydroponic farming systems, and the other focused on providing safe drinking water through the design and construction of water filtration and purification systems (modeled to reflect needs of people in a developing nation, in this case, Bangladesh). To explore the implementation of the new EfA units by teachers and to help with their revision, a new teaching portfolio instrument was developed, validated, and used. The teaching portfolios that participating EfA teachers compiled were evaluated based on a set of Design Teaching Standards that were developed for the project, and which grew out of the informed design teaching and learning model. Findings from the review of the teaching portfolios were used to (a) revise the curriculum, (b) create design-based teaching performance rubrics, and (c) develop specific materials for the professional development of prospective EfA teachers. Findings from this research project were also used to explore the strengths of middle school technology and engineering teachers and the challenges that they face when supporting students in doing engineering design in a social context.

Keywords: Teaching portfolios, technology and engineering education, instructional practices, design-based teaching standards.

The Engineering for All (EfA) project was a five-year-long collaboration between Hofstra University and the International Technology and Engineering Educators Association (ITEEA), and was funded by the National Science Foundation's DRK-12 program.[1] The main goal of this project was to develop middle school technology and engineering (T&E) education units that emphasize the role of engineers in solving important global and community-based problems. The project developed two units that contain authentic design

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challenges appropriate for the experiences and capabilities of middle school students. The two developed units dealt with the global shortage of fresh food and clean water. Both challenges were cited as priorities for integration into technology education curriculum (Buelin, Clark, & Ernst, 2016) and related to the *Grand Challenges for Engineering* identified by the National Academy of Engineering (NAS, 2017). One unit, *Vertical Farming: Fresh Food for Cities*, is focused on the development of sustainable food sources for cities through the inclusion of urban vertical hydroponics farms. The second unit, *Water: The World in Crisis*, is focused on the development of water filtration systems to be used in countries afflicted with contaminated water sources. Both units incorporate the "informed design" curricular structure (Burghardt & Hacker, 2004), which first introduces students to the major design challenge, followed by a "progression of *knowledge and skill builders (KSBs)*" (p. 7), activities that provide the students with the prerequisite experiences, knowledge, and skills to deal with the design challenge from a STEM-informed knowledge and skill base with the aim of reducing the uses of craft-based and trial-and-error approaches to solving design challenges.

The units were developed by T&E teacher teams, led by experienced curriculum developers, and were subsequently tested by 22 middle school T&E teachers and 755 students. As preparation for testing the units, the teachers participated in professional development workshops in which they learned the content and tried out the hands-on activities included in the two EfA units. During a pilot study of the new units, participating teachers constructed teaching portfolios that contained a structured weekly log and student work. In addition, the teachers participated in monthly WebEx phone conferences in which they reported on specific challenges in implementing the curriculum. Based on these conversations and data gathered during the pilot study, the units were revised and improved, making them more accessible to both teachers and students. The curriculum materials are available from ITEEA.

The following sections include descriptions of the development of the project's instruments, including: EfA Design Teaching Standards, EfA Design Teaching Portfolio, and the EfA Design Teaching Performance Rubrics.

EfA Design Teaching Standards

Knowing how to teach engineering involves quite a different knowledge and skill set than knowing how to do engineering. Like engineers, teachers using design tasks need to have content knowledge and process skills, but they also need pedagogical content knowledge (PCK), which is domain-specific and contextualized to each content area (Ball, Lubienski, & Mewborn, 2001; Magnusson, Krajcik, & Borko, 1999; Shulman, 1986). The Design Teaching Standards (DTS) were developed to describe this elusive PCK by defining what middle school T&E teachers need to know and be able to do in order to support students' learning with design-based curriculum. Because there were no published teaching standards for the teaching of K–12 engineering design in the United States, the EfA research team had to develop these standards to guide the work of the participating teachers. The development of the *Design Teaching Standards* was informed by the scholarly experiences in science and technology education of the three authors. Other sources that informed the development process include the *Minimum Competences for Trainees to Teach Design and Technology in Secondary Schools* in the UK (Design and Technology Association, 2003), the *Standards for Preparation and Professional Development for Teachers of Engineering* (American Society for Engineering Education, 2014), the *National Science Education Standards* (National Research Council, 1996) in the United States, and frameworks for engineering design teaching and learning (Crismond & Adams, 2012; Cross, 2000; Hacker, 2014; Reimers, Farmer, & Klein-Gardner, 2015).

The final set of the EfA DTS (see Table 2) created for this project is organized around the following three dimensions.

- Dimension I: *Design Practices*—This standard describes different practices that are part of the “informed design” teaching.
- Dimension II: *Engineering Themes*—This standard identifies cross-cutting themes and concepts that consistently appear in the engineering design literature (i.e., design, modeling, systems, resources, and human values).
- Dimension III: *Classroom Instructional Practices*—This standard describes essential instructional practices that are commonly considered necessary to support student learning.

The DTS were examined and validated by K–12 science, engineering and technology education teachers, teacher trainers, curriculum developers, STEM education researchers, administrators, and policy makers. Some participants were asked to comment on the quality of the standards in face-to-face interviews, whereas others completed an online questionnaire. In this online survey, the educators were asked to read each standard and rate their level of agreement with the following statements.

- Survey Statement 1: “The standard is feasible for teaching in the technology classroom.”
- Survey Statement 2: “The standard is important for teaching engineering design.”
- Survey Statement 3: “The standard is clearly written.”

Statements were rated on a 5-point Likert scale from *strongly disagree* (1) to *strongly agree* (5).

Table 1 summarizes the results of the online validation survey of the DTS. As can be seen in Table 1, most of the 38 survey participants agreed that the standards are instructionally feasible (93%), important (97%), and clearly written (92%). These results add validity to the EfA Design Teaching Standards.

Table 1
Results from the Online Validation Survey of the DTS

	Percent agreement with survey statement [a] (n = 38)		
DTS dimension	Standards are feasible for classroom teaching	Standards are important for teaching engineering design	Standards are clearly written
I. Design Practices	92%	98%	94%
II. Engineering Themes	93%	96%	88%
III. Classroom Instruction	94%	97%	94%
Mean % for all dimensions	93%	97%	92%

[a] Includes the combined responses of *agree* (4) and *strongly agree* (5).

Table 2
The EfA Design Teaching Standards

Dimension I: Informed Design Practices	Dimension II: Engineering Themes	Dimension III: Classroom Instruction
When teaching engineering design, teachers facilitate students' development of engineering design thinking and practices. In doing this, teachers provide students with opportunities to:	When teaching engineering design, teachers facilitate students' learning of engineering themes. In doing this, teachers provide students with opportunities to:	When teaching engineering design, teachers use appropriate instructional strategies to engage and monitor the learning of all students. In doing this, teachers:
a. *Framing the Challenge:* Understand and frame the design	a. *Design:* Use knowledge, creativity, critical thinking and ethics	a. *STEM Concepts*: Integrate and explain science, technology,

challenge by identifying and specifying the expected design performances, criteria and constraints.	when exploring and developing informed design solutions.	engineering and mathematics (STEM) content concepts that are relevant to the design challenge.
b. *Doing Research:* Conduct research and use inquiry methods to gather relevant information about the challenge.	b. *Models:* Use a variety of modeling techniques to envision solutions, develop explanations and make predictions.	b. *Lesson Plans:* Set appropriate learning goals and adjust curricula to create lessons that address students' specific learning needs.
c. *Generating Alternatives:* Brainstorm a range of possible design solutions and use drawings or other graphics, when appropriate, to represent these ideas.	c. *Systems*: Use systems thinking to analyze the inputs, processes, outputs, controls and feedback loops of a product and its subsystems.	c. *Academic Learning*: Incorporate literacy, numeracy and information technology to advance students' design thinking and work.
d. *Making decisions:* Balance pros/cons and consider tradeoffs in choosing the optimal solution.	d. *Resources*: Understand the need to choose resources based on availability, appropriateness, cost, ease of use, and sustainability.	d. *Practical Learning:* Ensure the safe, efficient and skillful use of materials and tools by all students.

e. *Prototyping:* Create prototypes based on plans of possible solutions selected for testing.	e. *Needs, Impacts, & Human Values*: Explore and consider the design context, users' needs and values, and the impacts of the design solution on the environment.	e. *Team Work*: Encourage students to work collaboratively and share ideas and resources with peers.
f. *Testing*: Design and perform tests to determine how the prototypes work and how well they meet design criteria.		f. *Assessments*: Use assessments to gather evidence of students' learning and provide timely feedback.
g. *Iterating and Improving*: Use feedback from tests and ideas from others to refine and improve prototype.		
h. *Communicating and Reflecting:* Reflect on and share with peers the design work, the processes used and decisions made.		

EfA Design Teaching Portfolios

> Teaching portfolios have been used by educators for more than two decades. Teaching portfolios that include student work and teachers' reflections capture the complexities of the teaching practice better than written tests or classroom observations. Not only are portfolios an effective way to assess teaching quality, but they also provide teachers with unique opportunities for self-reflection and collegial interactions based on documented episodes of their own teaching. (Wolf, 1996, p. 34)

Typically, teacher portfolios are used as a tool for teacher evaluation. For example, teacher portfolios were used by the Connecticut State Department of

Education for 2 decades for the evaluation and support of beginning school teachers (Lomask, Pecheone, & Baron, 1995). Teaching portfolios are also used by the National Board for Professional Teaching Standards (Darling-Hammond, 1999) as a major component of their comprehensive assessment of quality teaching. Lately, many states have adopted the teaching portfolio, as in the edTPA national project, as a tool to assess the quality of preservice teacher performance (Sato, 2014). In all of these examples, the portfolios were designed to gather authentic data in order to evaluate the quality of the teachers.

During the EfA project, teaching portfolios were selected and primarily used to review and gather data about the implementation of the new curricula and about common instructional practices of the participating teachers. In addition, the portfolios were employed by the research team as a way to provide ongoing feedback to the developers of the two EfA units and as a source of materials for future professional development. For example, copies of student work and classroom videos from submitted portfolios became part of the training materials for interested teachers at the 2016 ITEEA national conference held in National Harbor, Maryland. The main entries in the EfA teaching portfolio are described in Figure 1.

EfA teaching portfolio entries and required materials:

1. **Instructional logs** written at the end of each KSB (5–6 entries per unit of instruction). These logs address the following issues:
   a. Main STEM concepts that were taught,
   b. Main engineering practices that were practiced by students,
   c. Findings about students' learning strengths and challenges during each KSB, and
   d. Challenges in teaching each instructional sequence within the EfA unit.
2. **Student work** from one male and one female student, done to complete each of the KSB's formative assessment tasks. Student work was reviewed and evaluated by each participating teacher.
3. Three unedited instructional **video clips**, each 5–10 minutes in length, and selected to depict the following:
   a. Teaching a STEM concept,
   b. Teaching an engineering design practice, and
   c. Students' oral presentations of their final project with oral feedback from the teacher.
4. Written **reflection** on the implementation of the curriculum and what revisions may be needed in order to improve the unit and enhance student learning.

Figure 1. An overview of the EfA Design Teaching Portfolio.

EfA Teaching Performance Rubrics

The development of the teaching performance rubrics was an iterative process in which portfolios were reviewed by three professional technology and science educators in light of the evolving DTS. The rubrics were designed to provide a framework for the research about teachers' design PCK and to provide feedback to the curriculum developers. Since the rubrics were not used for formal teacher evaluation, no attempt was done to explore the reliability of the rubrics as a scoring tool. Rather, the portfolio reviewers worked collaboratively to develop the rubrics and then applied them in their review of the submitted teachers' portfolios. Tables 3, 4, and 5 describe the three EfA Design Teaching Performance Rubrics, one for each of the DTS dimensions.

Table 3
EfA Teaching Performance Rubrics: Design Practices

Dimension I: Design Practices		Advanced	Progressing	Novice
a.	Framing the Challenge	Teacher helps students grasp the design challenge and its context, as well as the criteria and constraints for a successful design solution.	Teacher describes the design challenge and its context, as well as the criteria and constraints for a successful design solution.	Teacher describes the design challenge and reviews with the students the design criteria and constraints.
b.	Doing Research	Teacher requires students to conduct research and hands-on investigations to gather relevant data on the design challenge.	Teacher requires students to gather data on the design challenge, mainly through reading of relevant materials.	Teacher does not require students to gather relevant data before they start working on the design challenge.
c.	Generating Alternatives	Teacher encourages students to develop several different possible solutions to the design challenge.	Teacher encourages students to develop two different possible solutions to the design challenge.	Teacher accepts one possible solution early in the design process.
d.	Making Decisions	Teacher asks students to discuss the benefits and tradeoffs of the different solutions and to justify their selection of the solution they would develop into a prototype.	Teacher asks students to justify their selection of the solution they would develop into a prototype.	Teacher allows students to develop their chosen solutions into a prototype without explaining their design decisions.
e.	Prototyping	Teacher provides students with basic safety guidelines for	Teacher provides students with basic safety guidelines for	Teacher provides students with basic safety guidelines for the

		the use of materials and tools, and helps students achieve high standards of safety and craftsmanship.	the use of materials and tools, and makes sure students follow the guidelines.	use of materials and tools.
f.	Testing	Teacher asks students to test, document and evaluate the performance of the prototypes based on the given design criteria.	Teacher asks students to test and document the performance of the prototypes they develop.	Teacher doesn't require students to conduct tests of the performance of their prototypes.
g.	Iterating and Improving	Teacher provides students with time and materials to revise their prototypes based on evidence they collected during testing.	Teacher provides students with time and materials to revise and improve their prototypes.	Teacher doesn't require students to revise and improve their prototypes.
h.	Communi-cating and Reflecting	Teacher requires students to present their design work and provides them with formative feedback.	Teacher requires students to present their design work but doesn't provide them with formative feedback.	Teacher doesn't require students to present their design work.

Table 4
EfA Teaching Performance Rubrics: Engineering Themes

Dimension II: Engineering Themes		Advanced (5)	Progressing (3)	Novice (1)
a.	Design	Teacher enables students to do informed design thinking by supporting their use of concepts, practices, creativity, critical thinking and ethics when engaging in design challenges.	Teacher encourages selected aspects of informed design thinking, including students' use of concepts, practices, creativity, critical thinking and ethics when engaging in design challenges.	Teacher provides limited or no time for students' use of concepts, practices, creativity, critical thinking and ethics when designing.
b.	Models	Teacher encourages students to use drawings and models during the design process, and to discuss the models' strengths and limitations	Teacher encourages students to use drawings and models during the design process.	Teacher provides limited exposure to the use of drawings and models when designing.

		in representing more complex products and systems.		
c.	Systems	Teacher helps students to identify subsystems and the inputs, processes, and outputs in their designed system and to distinguish between open and closed-loop systems.	Teacher helps students to identify subsystems and the inputs, processes, and outputs in their designed system.	Teacher helps students to identify the parts that work together and makeup their designed system.
d.	Resources	Teacher helps students to explore the need to choose resources based on availability, appropriateness, cost, ease of use, and sustainability when making their design choices.	Teacher reviews the availability of resources and their use when making design decisions.	Teacher offers little or no support to students for considering the selection and rationales for use of particular resources.
e.	Needs, Impacts, and Human Values	Teacher encourages students to explore how the designed product may impact intended users and the environment.	Teacher encourages students to pay attention to the needs of those who will use the designed product.	Teacher provides limited attention to the design context and the users of the designed product.

Table 5
EfA Teaching Performance Rubrics: Classroom Instruction

Dimension III: Classroom Instruction		Advanced	Progressing	Novice
a.	STEM Focus	Teacher accurately explains and connects all the relevant STEM concepts to the design challenge.	Teacher accurately explains some of the design-relevant STEM concepts.	Teacher either does not explain relevant STEM concepts or makes mistakes when explaining these concepts.
b.	Lesson Plans	Teacher adapts the learning activities or creates new ones, and uses a variety of instructional strategies to accommodate the learning needs of all students in class.	Teacher changes the pace and/or sequence of the learning activities in the given curriculum to accommodate students in class.	Teacher teaches the given curriculum without any adaptations to the learning needs of students in class.

c.	Academic Learning	Teacher provides students with activities that require them to apply literacy and numeracy skills and provides them with specific feedback on their performance.	Teacher provides students with activities that require them to apply literacy and numeracy skills.	Teacher does not use activities that require application of literacy and numeracy skills.
d.	Practical Learning	Teacher demonstrates the safe, correct and efficient use of tools, materials, and equipment and ensures that all students follow the required safety protocols and regulation.	Teacher demonstrates the safe use of tools, materials, and equipment and ensures that all students follow the required safety protocols and regulations.	Teacher ensures that all students follow the required safety protocols and regulations.
e.	Team Work	Teacher encourages teamwork and sharing of ideas, and encourages individual accountability for the successful completion of the project.	Teacher encourages teamwork and sharing of ideas, but doesn't support individual accountability of team members.	Teacher let student work in teams, but doesn't encourage cooperation and sharing of ideas.
f.	Assess-ments	Teacher monitors student understanding through classroom Q&A and reviews of submitted work, and provides students with formative feedback.	Teacher monitors student understanding through classroom Q&A and reviews of submitted work, but provides students with limited feedback.	Teacher rarely monitors students' quality of work and provides limited formative feedback.

EfA Units in Light of Participating Teachers' Feedback

A total of 22 teachers participated in the EfA curriculum development study. In the study, half of the teachers taught the EfA water unit, and the other half taught the food unit. The teachers implemented the new units over an 8–10 week period of time with technology education students in Grades 6–9. After the teachers finished their teaching of the original EfA units (before the revision of the curricular materials), they were asked to express their opinions on the new curriculum by rating various aspects of their experience on a 5-point Likert scale in which 1 is *strongly disagree* and 5 is *strongly agree*. Results from this online survey are displayed in Table 6.

Table 6
Results from the Online Teacher Survey (Prior to Curriculum Revision)

		Agreement with survey statement [a]	
	Survey statement	Food unit (n = 9)	Water unit (n = 10)
	Aspects of the EfA Curricula		
1.	Content and activities are grade-appropriate.	89%	60%
2.	Content is gender neutral and does not use stereotypes.	100%	100%
3.	EfA adequately covers the topics it claims to cover.	89%	90%
4.	The design activities are aligned with the content.	89%	100%
5.	EfA promotes the potential of engineering as a social good.	78%	100%
6.	Content and activities address unifying engineering themes of design, modeling, systems, resources, and human values.	90%	90%
7.	The learning goals are clear.	100%	100%
8.	Content and activities are aligned with the NGSS	45%	70%
9.	Content and activities are aligned with the *Standards for Technological Literacy.*	89%	100%
10.	The informed design process is clearly evident in the materials.	78%	70%
11.	Curriculum provides adequate support to assess students.	44%	50%
12.	The materials designed to scaffold students' learning.	55%	90%
13.	The curriculum is "user ready" (i.e., it can be used as currently available.)	44%	50%
14.	EfA materials are innovative.	67%	60%
	Implementation of EfA Curricula		
15.	Teachers would require professional development prior to adopting the EfA materials.	100%	70%
16.	Administrative support would be important for teacher who wants to use EfA.	67%	70%
17.	The EfA content would fit with most technology teachers' curriculum.	44%	80%
18.	The materials needed to implement EfA are available to most teachers.	33%	50%
19.	Cost of materials for EfA would limit teachers being able to use curriculum.	44%	50%
20.	Most technology classrooms have adequate space to complete the design activities.	33%	70%

	Appropriateness to Students		
21.	The EfA content was interesting to my students.	89%	70%
22.	The EfA content was valued by my students.	78%	80%
23.	The EfA content was culturally relevant for my students.	78%	80%
24.	My students had the needed pre-knowledge.	11%	30%
25.	Social issues discussed in EfA are appropriate for middle school students.	33%	70%

[a] Includes the combined responses of *agree* (4) and *strongly agree* (5).

The results shown in Table 7 indicate that although most teachers had positive opinions about the new curriculum, they also found that the content of the unit required knowledge that students do not have (Item 24) and that it was above the ability of their students (Item 25). EfA teachers also were concerned about the readiness of the units for classroom instruction and the cost and availability of materials to implement these units on a regular basis (Items 11–13 and Items 17–20). The findings from this online survey, in addition to more detailed information that was gathered through the teachers' portfolio, were used to revise and improve the curriculum.

Findings from Review of Teachers' Portfolios and Implications for EfA Curricular Revisions

The participating EfA teachers submitted the requested portfolio logs and the three videotaped teaching vignettes while teaching the units. At the conclusion of the units, the teachers submitted student work with teacher annotations as well as personal reflections. Teachers' portfolio materials were submitted electronically via Dropbox or physically via regular mail. At the conclusion of the project all of the written materials were printed and bound and were also rendered as PDF files in order to make the portfolio review more accessible. Three trained researchers reviewed the teacher portfolios individually and then met to compare evaluations and explore patterns found in the data reviewed. Differing interpretations of teachers' performances were resolved through discussion.

The following describes findings from the review of the teaching portfolios and main curricular revisions. Findings are organized by the three dimensions of the design teaching standards and rubrics: Design Practices, Engineering Themes, and Classroom Instruction.

Dimension I: Design Practices

Review of teacher logs and videos showed that EfA teachers understood the steps of the informed design process and made references to them during instruction. Burghardt and Hacker's (2004) informed design model was introduced in the EfA's introductory materials for students and was used to structure the learning activities that students completed to address the Grand Design Challenge found at the end of the unit. Teachers noted that even though the informed design process was introduced to students at the outset of the unit, they had for the most part forgotten and had difficulties recalling and applying this model when addressing the culminating design challenge.

One difficulty that teachers encountered when implementing the first edition of the EfA materials revolved around the use of scientific inquiry during the design process. For example, lessons in which students attempted to design fair-test experiments that explored key factors influencing plant growth in the hydroponics systems that they were building (e.g., the makeup of the nutrient solution, its pH levels, and lighting conditions) required that EfA teachers be able to explain to students the notion of a controlled experiment, dependent and independent variables – common misconceptions that students have regarding the use of control-of-variables strategy (Schwichow, Croker, Zimmerman, Höffler, & Härtig, 2016; Klahr & Nigam, 2004), and ways to measure key outcomes in an experiment effectively. Videos of several EfA teachers conducting lessons in which students designed experiments showed that several were unfamiliar with the practices related to scientific experimentation. Others, who may have known the key elements of good experiments (e.g., Harlen, 2001), did not integrate them into their teaching. Instead of engaging their learners in building a better understanding of scientific inquiry and the practices of designing fair-test experiments, some teachers gave cookbook directions for their students to follow. Thus, their students did not plan their own investigations but rather followed the directions and did the tasks that their teachers gave them. Another set of difficulties that were noted involved the ways in which teachers did or did not help students develop and evaluate several alternative design solutions before letting them move on to building their prototypes. In addition, most of the EfA teachers, perhaps to save time, did not give their students opportunities to revise their prototypes, even when prior tests had revealed flaws in those prototypes.

Based on these findings, the revised units were shortened to include fewer KSB activities prior to the main design activities so that those remaining could be done in more depth before students took on the unit's Grand Design Challenge. In addition, the scientific inquiry was connected more directly to EfA design challenges and better scaffolding, which was done to clarify the essence of the scientific experimental method for both teachers and students.

Dimension II: Understanding the Engineering Themes

The grasp and depth of teachers' portrayal of EfA engineering themes (i.e., design, models, systems, resources, needs, impacts, and human values) and of working within given constraints when developing and optimizing, were varied. Videos of instruction included in EfA teaching portfolios revealed how some teachers engaged their learners in discussing key themes and addressing students' misconceptions. Other EfA teachers did not seem to know ways to engage and elicit students' understanding. These teachers therefore rarely noted and addressed students' shortcomings. In general, teachers did not emphasize the importance of the engineering themes as crosscutting (meaning that these themes are important in multiple design challenges) but rather discussed the themes as they related to the specific design challenge at hand. Although most of the participating technology teachers had difficulties with the concepts and the themes, some teachers revealed a deeper understanding of the EfA concepts. For example, one teacher infused instruction about other types of hydroponics systems in addition to the two systems highlighted in the EfA curriculum. Another teacher added just-in-time instruction on the periodic table when students were learning about types of water chemical contamination.

Based on these findings, the units' revisions focused on clarifying the thematic focus of each subunit and providing more explanations and examples to engage students in explorations of the relevant themes.

Dimension III: Classroom Instruction

Abundant evidence was found in teachers' portfolios that EfA teachers were capable and effective in the management of their classrooms and their use of general pedagogical skills in engaging students and managing instruction. Teachers were found to use whole-class and small-group settings when presenting and implementing EfA content and activities. They excelled when teaching procedural and practical knowledge relevant to the field of T&E education, including the appropriate use of tools for making prototypes and use of a computer-aided drawing system, such as Google's *Sketchup* program that was highlighted in the EfA materials.

However, teachers were lacking when it came to two major components of effective design instruction: understanding essential science concepts and using assessment to support learning. The design challenges in the EfA units had strong links to relevant science concepts. For example, in the food unit, in order to design functional vertical hydroponic urban farms, students needed to understand concepts such as plant physiology and growth, the function and performances of pumps in different hydroponic systems, and concepts related to building stable and strong structures, as with wall-mounted reservoirs or hydroponics growth beds. In the water filtration unit, students needed to understand various concepts related to physical, chemical, and biological sources of water contamination as well as the operation and maintenance of filters that are designed to meet important performance objectives. Most of the participating technology teachers faced challenges in engaging their students in learning these concepts. This shortcoming may be rooted in lack of proper content preparation of the teachers or lack of time to explain the content well.

The second instructional practice that was challenging for teachers was the use of assessment. The EfA predesign activities (e.g., the KSBs) included one performance-based assessment task each. Students' work on these assessment tasks were collected and annotated with instructor comments by the teachers as part of their portfolio submission. Teachers' annotations that were written on their student work showed that the EfA teachers are not accustomed to providing meaningful formative feedback to students about the quality of their performance. Most written feedback included praises and encouragements (e.g., "I love your answer," "good work," or illustrated "smiles"). Instances in which teachers overlooked student misconceptions or did not comment on a feature of a design that would not work if built (e.g., a gravity fed filtration system in which the source of water was lower in height than the filter itself) were also noted. In general, there was a high correlation between teachers' conceptual understanding and the quality of their feedback to students: Teachers who understood the units' science concepts well were able to provide appropriate feedback, and teachers who lacked familiarity with the design and science concepts provided only limited formative feedback to their students.

Based on these findings, the revised EfA units included content-based support materials for the teachers to strengthen their understanding of the relevant science. In addition, every KSB included one major performance task (e.g., drawing a model, providing explanations, reporting experimental data, or creating concept maps) and content-specific rubrics for the evaluation of student work on each task.

Use of Teaching Portfolios for Professional Development

At the start of the EfA project, the exposure of the teachers to the design teaching standards and the accompanying rubrics was limited because these materials were developed later in the life of the project; in fact, they occurred hand-in-hand with the review of the portfolios. However, the project's materials were used extensively later in the preparation of additional EfA teachers during professional development workshops. For example, during the 2017 ITEE conference, the project introduced the EfA units and used materials from submitted portfolios (e.g., video clips and annotated student work) to train prospective EfA technology teachers.

Teaching portfolios can also provide contexts for peer coaching and mentoring in which teachers analyze their own and others' classroom work via the portfolios that they create. A recent study of Harvard's Best Foot Forward program, a video-based teacher evaluation system, showed improved instruction as a result of peer review of shared videos (Quinn, Kane, Greenberg, & Thal, 2015).

Conclusions

In our EfA research, we found that the design teaching standards and rubrics were extremely useful in evaluating curricula under development and the learning opportunities they provide to students, similar to findings about the use of science content standards in evaluating published curricula in previous research (Kesidou & Roseman, 2002).

The teaching portfolios were found to be a rich and useful instrument for collecting and reviewing data about the ways in which the participating T&E teachers implemented the new EfA curriculum. In general, teachers see the portfolio development as an extra instructional load and would probably not develop portfolios on their own. However, if trained and paid for the effort, teachers will develop authentic teaching portfolios that can serve as an efficient substitute for actual classroom observations. The EfA teaching portfolios developed in this project were not intended to be evaluative measures of teacher performance; however, they provided valuable evidence and directed the necessary curriculum revision and changes. In addition, the teaching portfolios opened windows into the common instructional practices of middle school T&E teachers and increased our understanding of the needed professional development to improve current T&E instruction.

The standards and the accompanying rubrics that were developed in the project can be used for teachers' self-assessment as well as for professional development purposes. Because the standards and the rubrics are not content specific, they can be adapted and used with a wide range of engineering design-based K–12 STEM curricula. Providing teachers with teaching standards and performance rubrics can guide and improve instruction in T&E settings.

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Evaluating the Effectiveness of Integrative STEM Education: Teacher and Administrator Professional Development

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Abstract

The integration of science, technology, engineering, and mathematics (STEM) education, also referred to as integrative STEM education, is a relatively new interdisciplinary teaching technique that incorporates an engineering design-based learning approach with mathematics, science, technology, and engineering education (Sanders, 2010, 2012, 2013; Wells, 2010, 2013). Over the past 11 years, 475 teachers and administrators, representing kindergarten through eighth grade teachers and elementary school administrators from 7 school districts in South Carolina, have participated in an Integrative STEM Education Institute. In this Institute, participants developed knowledge and skills to create and implement integrative STEM education activities for use in their classrooms. Participants learned how to incorporate problem-based and project-based learning that helps students work in groups to develop cross-curriculum skills.

The purpose of this article was to evaluate the immediate and long-term effectiveness of the Institute. Quantitative survey data from pre–post surveys immediately revealed a statistically significant increase in self-efficacy regarding the Institute's learning objectives. In addition, a survey was sent to alumni from the 2012–2015 Institutes. The results from this survey revealed that a significant number of alumni felt empowered through the Institute to implement integrative STEM education in their classrooms and build sustainable integrative STEM education programs at their schools following attendance at the Institute.

Keywords: integrative STEM education, professional development, elementary education, teacher efficacy, problem-based learning, project-based learning

Introduction and Background

The world that we live in is complex and integrated; however, dating back to 1894 with the Harvard Committee of Ten, the very roots of K–12 curriculum in the United States have emphasized discrete disciplinary subject instruction (Honey, Pearson, & Schweingruber, 2014). Though education looks different today, the same sentiments of instruction being conducted in siloes still exists 120 years later. These siloes are especially prevalent with regards to the science, technology, engineering, and mathematics fields, known by the acronym STEM. Instruction in mathematics "has been a regular part of K–12 education in the

United States since the early 1900s (Stanic and Kilpatrick 1992)" (Honey et al., 2014, p. 16). Since 2001, the No Child Left Behind Act of 2001 has emphasized regular testing in mathematics and later on science, although "science was never part of the 'adequate yearly progress' requirement that holds schools accountable for students' progress from year to year" (Honey et al., 2014, p. 17). Engineering and technology disciplines have been adopted at slower rates through vocational education, instructional technology, and engineering software adoption (Honey et al., 2014).

Despite the philosophical origins of the term STEM dating back to 1958, STEM, as society knows it, is relatively new (Daugherty, 2013). At first, the National Science Foundation (NSF) used the acronym SMET (science, mathematics, engineering, and technology), which was eventually changed to STEM (science, technology, engineering, and mathematics) in the 1990s (Sanders, 2013). Even though NSF did not originally intend for the integration of all four disciplines, teachers started to provide opportunities for students to see the connections, usually between two of the four areas of science, technology, engineering, and mathematics.

Within the last decade, federal education policy has expanded its emphasis on the practice of teaching and learning in the science, mathematics, technology, and engineering disciplines (Honey et al., 2014). Legislation like the No Child Left Behind Act of 2001 prompted conversations that led to changes in testing, funding, and curriculum with the state-based Common Core legislation, first introduced in Kentucky and then throughout the United States (An Act Relating to Student Assessment, 2009). Additionally, the evolving job market had the country anticipating a significant increase in STEM jobs in comparison to non-STEM jobs (Burning Glass Technologies, 2014). In his 2005 book, *The World Is Flat*, Thomas Friedman encouraged U.S. citizens to realize that we were not preparing students for the job market. A national dialogue to rethink K-12 education began among administrators, teachers, communities, and businesses. During this time, government and communities began investing in STEM education in siloes, a subject-based process focusing attention on each individual disciplinary component (Sanders, 2013).

The release of the *Common Core State Standards for Mathematics* (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) and the *Next Generation Science Standards* (NGSS Lead States, 2013) focused attention on disciplinary instruction in the STEM fields. The development of engineering associations' precollege level education standards, such as the *Standards for Technological Literacy* (International Technology Education Association, 2007), further advocated for linking engineering and technology to improve science and mathematics knowledge acquisition (Honey et al., 2014).

Recently, the National Academy of Engineering and the Board on Science Education of the National Research Council convened a Committee on

Integrated STEM Education to research pedagogies that may result in positive goals of an integrated STEM instructional model. The committee crafted and debated a variety of instructional models and definitions, never coming to a unified consensus. However, the committee did highlight one approach, *integrative STEM education*, which serves as the theoretical focus of this research article (Honey et al., 2014). Integrative STEM education places the engineering and technological design at the center of instruction, which facilitates connections being made across science and mathematics concepts (Sanders, 2009). Within this model, educators intentionally teach science and mathematics material through the seamless application of technology and engineering design-based teaching and learning in real-world problem-, project-, and design-based tasks (Honey et al., 2014; International Technology and Engineering Educators Association, 2018; Sanders, 2010, 2012, 2013; Wells, 2010, 2013).

"'Integrative STEM education may be enhanced through further integration with other school subjects, such as language arts, social studies, art, etc.' (Sanders & Wells, 2010)" (Sanders, 2013, p. 6). Integrative STEM education provides children with opportunities for educational engagement and achievement. This approach to education involves problem-based and project-based learning that allows students the opportunity to explore real-world problems simultaneously developing cross-curriculum skills while working in small, collaborative groups. Children now expect real-world connections to what they are learning, or else they may completely disengage.

Some scholars and educators argue that an integrative STEM education approach will better prepare all students for the global market in meaningful ways (Chute, 2009; Daugherty, 2013; Sanders, 2012). Research studies have discovered that integrating mathematics and science instruction leads to individually higher achievement scores in those disciplinary assessments (Hurley, 2001; Lehrer & Schauble, 2006). In research on the introduction of engineering instruction, the effect on mathematics and science achievement has been promising (Katehi, Pearson, & Feder, 2009), but results have been mixed on achievement improvement (Tran & Nathan, 2010). As a result, the National Academy of Engineering and the National Research Council have concluded that the reason for the inconclusive evidence may not be associated with engineering instruction itself but how engineering instruction is integrated together with established instructional methods in mathematics and science (Honey et al., 2014). Greater emphasis should be placed on how teachers are trained to weave together STEM concepts in their classrooms.

What We Did

Shifting to an integrative STEM education approach cannot occur overnight and cannot occur without training for current and future teachers. The question at hand, however, was how effective is a professional development (PD) program in equipping teachers with the pedagogical tools necessary for the successful implementation of integrative STEM education concepts? The results of this study provide evidence to support the argument that a seven school district Integrative STEM Education Institute PD program, which has served 475 educators over 11 years, has been an effective experience for empowering teachers and school administrators to implement integrative STEM education.

Results from this study of the Institute showed that participants felt greater confidence in their understanding of integrative STEM education teaching techniques and the methods necessary to implement those teaching techniques into their schools and districts. Results also showed that a significant number of Institute alumni were able to utilize and sustain integrative STEM education in their classrooms in the academic years following the Institutes.

Using a standards-based approach to integrate teaching and learning in STEM concepts established by the International Technology Education Association (2007), the Institute was designed specifically for K–5 teachers and administrators. The main purpose of this Institute was to give teachers and administrators the tools and confidence to teach integrative STEM. Through content coaches, the Institute assisted school teams with developing an integrative STEM curriculum that solved real-world problems in their schools. Teams left the Institute with an action plan for school improvement around a STEM conceptual framework. The learning objectives for this Institute were for participants to exhibit increased confidence in teaching integrative STEM education content and to understand:

- the role and purpose of integrative STEM education,
- how to use STEM as a curricula organizer,
- how content standards can be delivered using an interdisciplinary teaching approach,
- how heuristics are used as a conceptual tool in delivering project- or problem-based learning,
- how integrative STEM lessons are developed and delivered in the classroom,
- how the narrative curricular approach is used to launch STEM learning, and
- how standards are integrated into the learning experiences delivered through STEM curricula.

This program evaluation was centered around the following questions: (1) How effective was the integrative STEM education PD program at teaching the core principles associated with that pedagogy, and (2) what were the immediate and long-term outcomes of the PD program on participants?

To address our program evaluation questions, we employed two different survey instruments. The first survey was a pre–post survey used to determine the immediate outcomes and effectiveness of the PD program instruction and the immediate self-confidence (self-efficacy) that participants gained regarding integrative STEM education pedagogy. This survey was distributed to participants in the 2015 and 2016 Integrative STEM Education Institutes. The second survey provided evidence of the long-term outcomes of the Integrative STEM Education Institute. The evaluation team defined long-term outcomes as alumni members' ability to implement and sustain the pedagogy taught within the Institute. This survey was distributed to alumni of the program who had completed their cohort experience during the 2012–2015 Institutes. More detail about each of these data collection methods follows below.

Immediate Outcomes of the Institutes: Pre–Post Surveys

As mentioned above, pre–post surveys measuring immediate outcomes data were gathered regarding the 2015 and 2016 summer Integrative STEM Education Institutes. All Institute participants (*N* = 42) participated in the pre-survey prior to the opening session of the Institutes. In 2015, all but one of the attendees (*n* = 18) completed the post-survey at the conclusion of the last session. Because of a logistical change with the 2016 program schedule, only 47.83% of the participants in that cohort (*n* = 11) completed the post-survey from a Qualtrics ™ distributed online survey after the Institute. Even though we had a smaller yield with the online post-survey than with the previous year's paper method, the data was large enough to be analyzed collectively when both cohorts of post-surveys were aggregated. Through all pre–post survey responses, participants reported their proficiency in the Institute's eight major learning outcomes through responses to a 5-point Likert scale survey. Knowledge options ranged from *not much* (1) to *a great deal* (5) of expertise in each area. The remainder of the survey afforded participants the opportunity to share demographic information about their teaching appointment and district placement for the academic year immediately following the Institute. Also, participants had the opportunity to share their perspectives on the overall quality of what they learned and the degree to which they would implement the teaching techniques in their classrooms and schools.

To determine participant perspectives about the Institute and its short-term influence on the educators' use of integrative STEM education pedagogy in the schools, our evaluation team calculated frequency statistics on various survey questions. To determine participant demographic information, we used frequency statistics.

Immediate Outcomes of the Institute: Participants

Over the two Institute cohorts involved in this evaluation, 42 teachers and school administrators participated in the Integrative STEM Education Institute and agreed to participate in this program evaluation. Because the cohorts were very similar in demographic makeup, the following is an aggregate description. Table 1 provides a detailed summary of participants' roles within the building, subject-matter instruction, and background characteristics. The majority of attendees, 78.57% ($n = 33$), were classroom teachers, either grade-specific, instructional coaches, or distributed multi-grade-level subject teachers. Of the remaining participants, 8 (19%) were school administrators, and 1 (2.38%) was an instructional technology (IT) staff member. Considering the instructional teachers and coaches present at the Institutes, 12 of those teachers (9%) taught one specific subject. Ten teachers (30.30%) were responsible for teaching science, technology, engineering, and mathematics subjects; however, that did not guarantee these individuals were utilizing an integrative STEM education pedagogy model prior to participating in the Institute. The remainder of the participants, 19 teachers (57.58%), were responsible for teaching more than one subject but not all four STEM disciplines. Within the two cohorts involved in the study's evaluation, six of the seven school districts sent teachers and school administrators to the Institute.

Table 1
2015–2016 Summer Cohorts of the Integrative STEM Institute: Demographic Details Relevant for Academic Year Immediately Following Institute

Demographic information	Number of participants ($N = 42$)	Percentage of cohort
Professional affiliation ($N = 42$)		
Kindergarten–first grade teacher	6	14.30%
Second–fifth grade teacher	21	49.90%
Instructional coach	2	4.80%
Multi-grade-level subject teacher	4	9.60%
School administrator	8	19.0%
IT staff	1	2.38%
Instructional areas (for classroom-based teachers) ($n = 33$)		
Mathematics	2	6.06%
Science	1	3.03%
Technology	1	3.03%
Engineering	0	0%
Mathematics, science, technology, and engineering	10	30.30%
More than one instructional discipline, but not all STEM fields	19	57.58%
Experience in K–12 Education ($N = 42$)		
0–3 years	10	23.80%
4–6 years	6	14.3%
7–9 years	2	4.80%
10 years or more	24	57.10%

Long-Term Outcomes of the Institute: Alumni Survey

The evaluation team created a survey to measure the long-term outcomes of the Institute. Our operational definition of the Institute's long-term impact was the degree to which alumni were capable of implementing integrative STEM education teaching pedagogy in their classrooms and buildings as well as the degree to which they could sustain those integrative STEM programs at their schools. The survey included seven binary questions asking participants to answer whether or not they were able to implement integrative STEM education. In addition, there were two 5-point Likert scale questions asking alumni to share their opinions of the impact of the Institute and their long-term confidence in implementing integrative STEM education.

Long-Term Outcomes of the Institute: Alumni Participants

During the fall 2015 semester, we surveyed 96 previous Integrative STEM Education Institute attendees (from the 2012–2015 Institute sessions). Forty-two alumni (43.75%) completed the survey. Frequency statistics through an online Qualtrics™ survey revealed the self-confidence and self-efficacy of alumni following the Institute in implementing the pedagogies involved in the Institute. The survey results also reported the degree to which alumni were able to implement the Institute principles and continue to sustain integrative STEM education in the years after their participation in the Institute. Survey participants also shared how valuable the Institute was as a PD program in comparison to their other continuing education activities.

Table 2 provides a detailed summary of the Institute alumni demographics at the time of the survey, with specific information about their roles within the building, subject matter instruction, and background characteristics. To summarize, all but 10 (*n* = 32) of the Institute alumni provided demographic information. Five alumni (15.63%) indicated at the time of the survey that they taught Kindergarten or Grade 1, 18 alumni (56.25%) taught elementary Grades 2 through 5, four alumni (12.50%) taught middle school Grades 6 through 8, and three alumni (9.38%) taught high school. The remaining two alumni (6.25%) served as district or building-level administrators or teachers of high school grades. Eleven (34.40%) of the participants indicated that they would teach mathematics in the upcoming academic year, 11 (34.04%) would teach science, four (12.50%) would teach a technology subject, and six (18.80%) would teach an engineering subject. Seventy-five percent of alumni (*n* = 24) had 10 or more years of experience teaching in K–12 schools, and 93.80% (*n* = 30) taught or worked in the same county or district as they had at the time of participating in the Institute.

Table 2
2012–2015 Alumni of the Integrative STEM Education Institute: Demographic Details

Demographic information	Number of participants (*n* = 32)	Percentage of alumni
Professional affiliation		
Kindergarten–first grade teacher	5	15.63%
Second–fifth grade teacher	18	56.25%
Sixth–eight grade teacher	4	12.50%
High school teacher	3	9.38%
School administrator	2	6.25%
Instructional areas (for classroom-based teachers)		
Mathematics	11	34.40%
Science	11	34.04%
Technology	4	12.50%
Engineering	6	18.80%
Experience in K–12 education		
0–3 years	3	9.40%
4–6 years	4	12.50%
7–9 years	1	3.10%
10 years or more	24	75.0%

What We Found

Immediate Outcomes of the Institute: Strengthening Self-Efficacy

Our team gathered pre–post survey data on the immediate outcomes of the 2015 and 2016 summer Integrative STEM Education Institutes by surveying participants at the beginning of each Institute and at the conclusion of each Institute. In all surveys, participants indicated their current level of knowledge on topics related to the program's eight learning outcomes. A summary of those learning outcomes and their self-reported average levels of expertise appears in Table 3.

Table 3
Knowledge in the Integrative STEM Education Institute Learning Outcomes: Self-Reported Pre–Post Survey Means of 2015–2016 Institutes

Integrative STEM Education Institute programmatic learning outcomes	Pre-Institute level of knowledge ($N = 42$)	Post-Institute level of knowledge ($n = 29$)	Mean difference of level of pre- and post-Institute levels of knowledge
The role and purpose of integrative STEM education.	2.88	4.41	1.53
How a teacher can use STEM as a curricula organizer.	2.38	4.21	1.83
How content standards can be delivered using an interdisciplinary teaching approach	3.05	4.34	1.30
How heuristics are used as a conceptual tool in delivering project/problem-based learning.	2.10	4.03	1.94
How integrated STEM lessons are developed and delivered in the classroom.	2.64	4.45	1.81
How the narrative curricular approach is used to launch STEM learning.	2.02	4.14	2.11
How standards are integrated into the learning experiences delivered through STEM curricula.	2.74	4.38	1.64
How one can teach STEM content to the age group he/she currently teaches.	2.56	4.38	1.82

Note. Level of self-reported expertise with the learning outcomes was determined on a 5-point Likert scale, with 1 indicating *not much* knowledge and 5 indicating *a great deal* of knowledge.

All participants reported higher levels of proficiency and expertise after the Institute than when they first arrived at the Institute. To find out if those differences were statistically significant, the average levels of expertise for each learning outcome at these two points in the participants' development were compared using independent-samples *t*-tests with SPSS. We originally expected differences across professional affiliation, grade level, or the subject one teaches; however, frequency statistics prior to mean difference comparisons revealed that the demographic subsamples were too small for robust regression or ANOVA statistical analysis. Taken in aggregate, we had enough data for broad mean comparisons if we examined the entire sample of pre- and post-Institute results.

Given that our α level was set to .05 with a confidence interval of 95, results of the *t*-test indicated that there was a statistically significant difference in all eight scores on the post-survey following the Institute ($N = 29$) compared to the pre-survey scores ($N = 42$). Table 4 summarizes the results from each learning objective *t*-test analysis. These results serve as an indication that participants believed the learning objectives for the program were met in both summer Institutes.

Table 4
Descriptive Statistics and t-Test Results for Self-Assessed Knowledge of Learning Objectives: Pre–Post Surveys for 2015–2016 Institutes

	Pre-institute level of expertise (*N* = 42)		Post-institute level of expertise (*n* = 29)		Mean difference of level of expertise	95% CI for mean difference	*t*	*df*
	M	*SD*	*M*	*SD*				
The role and purpose of integrative STEM education.	2.88	.993	4.41	.682	1.53	1.11, 1.96	7.21*	69
How a teacher can use STEM as a curricula organizer.	2.38	.962	4.21	.675	1.83	1.44, 2.21	9.40*	69
How content standards can be delivered using an interdisciplinary teaching approach	3.05	.882	4.34	.721	1.30	0.90, 1.69	6.55*	66.95
How heuristics are used as a conceptual tool in delivering project/problem-based learning.	2.10	1.044	4.03	.981	1.94	1.44, 2.43	7.84*	62.67
How integrated STEM lessons are developed and delivered in the classroom.	2.64	1.008	4.45	.870	1.81	1.35, 2.27	7.84*	65.53
How the narrative curricular approach is used to launch STEM learning.	2.02	.924	4.14	.915	2.11	1.67, 2.26	9.51*	60.73

How standards are integrated into the learning experiences delivered through STEM curricula.	2.74	.964	4.38	.775	1.64	1.21, 2.07	7.62*	67.31
How one can teach STEM content to the age group he/she currently teaches.	2.56	1.026	4.38	.862	1.82	1.35, 2.28	7.79*	65.89

Note. For all learning outcomes except for the second one, a Satterthwaite approximation was employed due to unequal group variances. Level of self-reported expertise with the learning outcomes was determined on a 5-point Likert scale, with 1 indicating *not much* knowledge and 5 indicating *a great deal* of knowledge.
* $p < .05$.

2015–2016 Participant Perspectives about the Institute

At the conclusion of each Institute, all 2015–2016 participants surveyed indicated that they found the program to be a worthwhile PD opportunity. The data analyzed for classroom-related outcomes included only grade-specific teachers, instructional coaches, and distributed-grade-level discipline teachers. Administrators were not considered in the frequency calculations because many may not have had classroom-based responsibilities in the academic year following the Institute. In addition, 95.83% (n = 23) of classroom-based teachers who participated expected to work independently to implement integrative STEM education activities in their individual classrooms, and 96.4% (n = 27) of attendees indicated that they expected to work with their instructional teams to implement integrative STEM education activities throughout their schools.

Furthermore, 89.3% (n = 25) of participants indicated that they had the ability and would seek out additional resources or opportunities to learn more about integrative STEM education activities. Sixty-eight percent (n = 17) of those participants demonstrated an understanding of what those resources or opportunities could be, noting that they would refer to sources introduced to them during the Institute. These sources could include peer elementary STEM teachers and administrators whose schools were utilizing this instructional model.

Long-Term Outcomes: Ability to Implement and Sustain Integrative STEM Education

According to the results of the alumni survey, 73.80% (n = 31) of alumni indicated that they were able to introduce integrative STEM education pedagogy in their classrooms. Of those 31 participants, 61.90% ($n = 26$) indicated that they were able to work with other faculty in their disciplinary teaching teams to introduce integrative STEM education activities at their schools. All but five of those participants, who either taught in a K–12 setting or served as a K–12 administrator, reported that they had found a way to build a sustainable integrative STEM education program at the time of the alumni survey. See Table 5 for the descriptive statistics for alumni regarding implementation of integrative STEM education.

Table 5
Descriptive Statistics for Alumni: Implementation of Integrative STEM Education

Survey item	Number of responses (%) ($N = 42$)
Were able to work independently to implement integrative STEM education activities in their classrooms immediately following the institute.	31 (73.8%)
Were unable to work independently to implement integrative STEM education activities in their classrooms immediately following the institute.	11 (26.2%)
Worked with others to implement integrative STEM education at their schools immediately following the institute.	26 (61.9%)
Did not work with others to implement integrative STEM education at their schools immediately following the institute.	16 (38.1%)
Were still using integrative STEM education activities in their classroom or schools at the time of the survey.	32 (76.2%)
Were no longer or never did use integrative STEM education activities in their classroom or schools at the time of the survey.	10 (23.8%)
Were able to seek out additional resources or opportunities to help them learn about integrative STEM education activities.	26 (61.9%)

Additionally, alumni were surveyed regarding their opinion on the impact of the Institute and their long-term confidence in implementing integrative STEM education. See Table 6 for survey data.

Table 6
Perspectives of Alumni on Integrative STEM Education Institute

Survey item	Agreement level mean (*N* = 42)	*SD*
Alumni gained confidence in their abilities to implement integrative STEM education activities in their classrooms.	4.13 (*n* = 40)	.76
Alumni thought the Integrative STEM Education Institute was a worthwhile professional development experience.	4.23 (*n* = 40)	.83

Note. Agreement scale (1–5): 1 = *strongly disagree*, 2 = *Disagree*, 3 = *Undecided*, 4 = *Agree*, and 5 = *Strongly Agree.*

What the Findings Mean

Even though research on integrative STEM education is still relatively in its infancy, evidence does exist that these teaching techniques can make a positive difference in K–12 learning environments (Hurley, 2001; Lehrer & Schauble, 2006). There is a gap in the literature on how the field of education equips teaching professionals with the skills to teach integrative STEM education. This gap is evident when we consider how midcareer and seasoned educators learn integrative STEM education principles, especially when they were previously trained to understand and operate under a different teaching model. Our report helps to fill this gap in the literature by highlighting the successes in an integrative STEM education teacher PD program.

The results of our PD evaluation indicate that the Integrative STEM Education Institutes under investigation provided building blocks that teachers needed to build successful, sustainable, integrative STEM programs. The key objectives of the Institute were that participants would be equipped with a greater level of understanding of the principles and theoretical framework of integrative STEM education. With that knowledge, educators and administrators would have the self-efficacy, skills, and networks necessary to implement this pedagogy and continue to do so for many years. Those outcomes served as the foundational concepts for the evaluation questions.

Our pre–post surveys of the 2015–2016 cohorts provided evidence that Institute participants completed the program with greater knowledge of integrative STEM education concepts than they had when they began the Institute. This is evidence that facilitators and instructors of the program did, in fact, effectively teach the core principles associated with this integrative pedagogy. Tables 3 and 4 illustrate how participants oftentimes started the program with a relatively limited understanding of the Institute learning objectives, so the survey results suggest that Institute facilitators conveyed information in an effective manner to change participant confidence levels in a short period of time.

The survey of Institute alumni provided evidence to further support the immediate and long-term outcomes of the Integrative STEM Education Institute. This statement is evidenced by the significant percentage of alumni who implemented integrative STEM education pedagogy in their classrooms and had been able to sustain that for years after the Institute, as reported through the survey. Furthermore, a number of alumni were able to introduce other faculty and administrators to the integrative STEM education model.

Conclusion

Findings of this report provide evidence that there is a need to educate teachers of all experience levels about integrative STEM education. This scholarly conversation would also benefit from an expanded, replicated study with a larger sample size that either incorporates more years of a single program's cohort evaluations or examines multiple cohorts that teach the same integrative STEM education principles. By doing so, researchers may find different learning and concept implementation success rates across teachers with different discipline specializations and grade-levels. The results of these studies could have implications for PD planning teams as they seek to convey information to varied audiences.

Moreover, further study is needed to better understand how andragogy can be used to teach integrative STEM education concepts to educators and administrators. Better meeting the learning needs of education professionals could further support providing quality integrative STEM education PD, a statement which the National Academy of Engineering and the National Research Council have also echoed (Honey et al., 2014).

The results of this program evaluation study provide some preliminary evidence the 2-day Integrative STEM Education Institute can serve as a model PD program for integrative STEM education. We found that a key to success in implementing integrative STEM education is providing opportunities for stakeholders, including teachers and administrators, to develop a shared passion for preparing students in meaningful ways to solve real-world challenges (Chute, 2009; Daugherty, 2013; Havice, 2015; Sanders, 2012). With this type of PD, teachers are more confident and prepared to work with students in approaching problem-solving through a multidisciplinary method (i.e. integrative STEM education; Honey et al., 2014). Ultimately, through PD opportunities, teachers and administrators can model for students what it looks like to be engaged, lifelong learners who strive to impact children and the larger community.

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Effectiveness of Drafting Models for Engineering Technology Students and Impacts on Spatial Visualization Ability: An Analysis and Consideration of Critical Variables

Petros J. Katsioloudis & Jill E. Stefaniak

Abstract

Results from a number of studies indicate that the use of drafting models can positively influence the spatial visualization ability for engineering technology students. However, additional variables such as light, temperature, motion and color can play an important role but research provides inconsistent results. Considering this, a set of 5 quasi-experimental studies, was conducted to identify additional critical variables. According to the results, a dynamic, 3D-printed drafting model, presented with a blue background under lighting conditions between 500–750 lux had the highest impact on spatial visualization ability of engineering technology students.

Keywords: drafting models, engineering technology, spatial ability, spatial visualization

A plethora of scientific works reference the demand for good spatial abilities in engineering, architecture, and almost every science career (Martín-Gutiérrez, Gil, Contero, & Saorín, 2013). Research suggests that spatial abilities are fundamental, not only in engineering and technical fields but in an estimated 80% of jobs overall. This includes but is not limited to those in medical professions, pilots, mechanics, builders, and tradespeople (Bannatyne, 2003). Although studies exploring the effects of spatial visualization for engineering technology students have been conducted (Allam, 2009; Ben-Chaim, Lappan, & Houang, 1988; Katsioloudis, Jones, & Jovanovic, 2016; Rodriguez & Rodriguez, 2016), the focus of this review was to conduct further analysis on studies using the Mental Cutting Test (MCT; College Entrance Examination Board, 1939; see also Tsutsumi, 2004).

This systematic review yielded a total of five studies that were conducted to investigate the impacts of drafting models on the effects of spatial visualization ability for engineering technology students. The data were analyzed to identify additional critical variables among the five studies. The findings seem to suggest that additional variables played an important role. Recent advances in systematic review procedures make it an ideal tool for research synthesis (Creswell, 2015). Review procedures allow opportunities for direct interference from empirical studies.

Previous Studies

Study 1: Use of Static vs. Dynamic Visualization to Create a Sectional-View Sketch

The purpose of this study (Katsioloudis, Dickerson, Jovanovic, & Jones, 2015) was to determine significant positive effects among three different types of dynamic drafting models and to identify whether any individual type or combination contributed towards a positive increase of spatial visualization ability for students in engineering technology courses. "(Katsioloudis, Jovanovic, et al., 2015, pp. 4–5). In particular, the study compared the use of different visual models: a 3D printed solid dynamic visualization, a 3D computer generated dynamic visualization, and a 3D printed static visualization" (p. 23).

Research question and hypotheses. The following research question guided this study:

> Is there a difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object? (Katsioloudis et al., 2015, p. 14)
>
> The following hypotheses were explored during the study:
> H_0: There is no difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object.
>
> H_A: There is an identifiable difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view of the presented object. (Katsioloudis et al., 2015, p. 14)

Methodology. "A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the Fall of 2015. The study was conducted in an engineering graphics course, MET 120 (Computer Aided Drafting)" "All groups were asked to complete the Mental Cutting Test (MCT) instrument 2 days prior to the completion of the sectional view drawing in order to identify the level of visual ability and to show equality between the three groups" (Katsioloudis et al., 2015, p. 17).

Results. The study compared the difference between the type of visualization presented to engineering technology students (3D PC Ststic, 3D PC

Dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object. No significant positive evidence was identified in the study to justify the use of a specific visualization versus an other. The results of this study confirmed what other researchers (Catrambone & Seay, 2002; Hasler, Kersten, & Sweller, 2007, Hegarty, Kriz, & Cate, 2003) have found when attempting to investigate the superiority of animation as compared to static visualization.

Study 2: Exploration of the Impact of Visual Cues on Dynamic Visualizations

The purpose of this study (Katsioloudis, Jovanovic, & Jones, 2016) was to determine significant positive effects of visual cues (color blue) and to identify a positive increase of spatial visualization ability for students in engineering technology courses. In particular, the study compared the use of different visual models: a 3D printed solid dynamic visualization with the addition of blue glasses to add blue color background around the model, a 3D computer generated blue shaded dynamic visualization, and a 3D printed dynamic visualization with no additional visual cue treatment. It was found that the use of visual cue (color blue) provided no statistically significant higher scores versus the treatment that did not utilize any visual cues. (p. 11)

Research question and hypotheses. The following research question guided this study:

> Is there a difference in spatial visualization ability, as measured through technical drawings, among the impacts of visual cues (adding blue color) on dynamic visualizations for engineering technology students? (Katsioloudis, Jovanovic, et al., 2016, p. 1)
>
> The following hypotheses were explored during this study:
>
> H_0: There is no difference in spatial visualization ability, as measured through technical drawings, among the impacts of visual cues (adding blue color) on dynamic visualizations for engineering technology students.
>
> H_A: There is an identifiable difference in spatial visualization ability, as measured through technical drawings, among the impacts of visual cues (adding blue color) on dynamic visualizations for engineering technology students. (Katsioloudis, Jovanovic, et al., 2016, pp. 1–2)

Methodology. “A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the Fall of 2014. The study was conducted in an engineering graphics course, MET 120

(Computer Aided Drafting)" (Katsioloudis, Jovanovic, et al., 2016, pp. 4–5). Using a convenience sampling method,

> The students attending the course during the Fall Semester of 2014 were divided into three groups. The three groups (*n*1 = 24, *n*2 = 21 and *n*3 = 22, with an overall population of *N* = 67) were presented with a visual representation of an object (visualization) and were asked to create a sectional view. The first group (*n*1) received dynamic 3D printed dodecahedron visualization, self-rotated at 360 degrees on the top of a motorized base at about 4 rounds per minute (slow rotation was used to prevent optical illusion and distortion of the original shape) during the creation of the sectional view . . . . The second group (*n*2) received the same dynamic 3D printed dodecahedron visualization, also self-rotated at about 4 rounds per minute at 360 degrees on the top a motorized base at about 4 rounds per minute with students wearing blue glasses . . . ; thus, it created a blue background around the visualization during the creation of the sectional view. The third group (*n*3) received a blue, shaded PC developed, dynamic 3D dodecahedron visualization, also self-rotated at about 4 rounds per minute at 360 degrees at about 4 rounds per minute . . . . Since color was used as a part of the study treatment, and to prevent bias with color blind students, all participants were presented with a power point slide that had three color filled circles (red, blue and yellow) and were asked to report on a piece of paper the three colors. No students were identified as color blind since everyone stated the correct colors. (Katsioloudis, Jovanovic, & Jones, 2016, pp. 5–6)

Results. Although "not statistically significant, the students who received treatment using the 3D printed Dynamic visualization, with the addition of the blue glasses visual cue, outperformed their peers who received treatment from the other two types of visualizations" (Katsioloudis, Jovanovic, et al., 2016, p. 11). These findings are supported by previous research (Khooshabeh & Hegarty, 2008) exploring how color affects the performance of students with low spatial ability.

Study 3: Impact of Effective Temperature on Sectional-View Drawing

The purpose of this study (Katsioloudis, 2017) was to determine significant positive effects related to sectional view drawing ability. In particular, the study compared the exposure of engineering technology and technology education students to three different kinds of treatments (different temperatures) and whether a significant difference exists towards sectional view drawing ability. (p. 20)

Research questions and hypotheses. The following research questions guided this study:

> Does the difference of effective temperature have an effect on students' spatial visualization ability as measured by the MCT?
>
> Does the difference of effective temperature have an effect on students' ability to sketch a sectional view drawing? (Katsioloudis, 2017, p. 17)
>
> The following hypotheses were explored during this study:
> H_0: There is no significant effect on students' sketching ability as measured by the MCT due to a difference of effective temperature.
>
> H_1: There is no significant effect on students' spatial visualization ability due to a difference of effective temperature.
>
> H_{01}: There is significant effect on students' sketching ability as measured by the MCT due to a difference of effective temperature.
>
> H_{02}: There is significant effect on students' spatial visualization ability due to a difference of effective temperature. (p. 17)

Methodology. A quasi-experimental study was used as a means to perform the comparative analysis of sectional view drawing ability during the Spring of 2016. Using convenience sampling instead of random assignment of the population, made the author believe that a quasi-experimental study was the appropriate methodology to be used. The study compared three groups comprising engineering and technology education students exposed to three different effective temperatures in order to determine whether there is a significant difference in sectional view drawing ability. (Katsioloudis, 2017, p. 18)

> Students attending the [engineering graphics] course during the Spring semester of 2016 were divided into three groups. The three groups (n*1* = 42, n*2* = 39 and n*3* = 44, with an overall population of *N* = 125) had the same academic background related to engineering graphics coursework (freshman engineering technology and technology education students had to complete the same intro to engineering graphics course the previous semester) were presented with a 3D printed visual representation of an octagonal pyramid . . . and were asked to create a sectional view drawing of it. To generate the three distinct temperature environments, the 3D printed model used for all groups was submerged in water . . . . The independent variable in this study was the temperature of the water: 84.2°F, 93.2°F and 102.2°F for the cold,

> warm, and hot treatments, respectively. Each group member received 60 seconds to "feel" the model in the water. Using only the sense of touch to receive mental data, each student had to create a sectional view of what they felt. (Katsioloudis, 2017, pp. 18–19)

Results. The null hypothesis that there is no significant effect on students' spatial visualization ability, as measured by the MCT was accepted. However, the second null hypothesis that there is no effect on students' ability to sketch a sectional view drawing due to the difference of effective temperature was rejected due to statistically significant evidence. Students that received treatment using warm water outperformed their peers who received treatment using cold and hot water temperatures, respectively. (Katsioloudis, 2017, p. 20)

Study 4: The Use of Dynamic Visualizations for Engineering Technology, Industrial Technology, and Science Education Students to Create a Sectional-View Sketch

The purpose of this study (Katsioloudis, Dickerson, Jovanovic, & Jones, 2016) was "to determine the existence of statistically significant differences between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object" (p. 29).

Research questions and hypotheses. The following research question guided this study:

> Is there a difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional view sketch of the presented object? (Katsioloudis, Dickerson, et al., 2016, p. 20)
>
> The following hypotheses were explored during this study:
>
> H0: There is no difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object.
>
> HA: There is an identifiable difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object. (Katsioloudis, Dickerson, et al., 2016, p. 20)

Methodology. A causal-comparative study was selected as a means to perform the comparative analysis of spatial visualization ability during the fall of 2014. The study was conducted in an engineering graphics course . . .

required for engineering technology and industrial technology students. Three independent groups participated in this study: group one consisted of engineering technology students, group two consisted of industrial technology students, and group three consisted of science education students . . . . Students from each discipline were placed into 3 individual groups. Using a convenience sample, there was a near equal distribution of the participants between the three groups. (Katsioloudis, Dickerson, et al., 2016, p. 24)

> The students attending the courses during the fall semester of 2014 were divided into three groups ($n_1 = 23$, $n_2 = 24$, and $n_3 = 27$, with an overall population of $N = 74$) and were presented with the same visual representation of an object (visualization) and were asked to create a sectional-view drawing. All groups received the same type of visualization (Dynamic 3D printed octahedron). (Katsioloudis, Dickerson, et al., 2016, p. 25)

All participants completed the MCT 2 days before “to identify the level of visual ability and show equality between the three groups” (Katsioloudis, Dickerson, et al., 2016, p. 25).

Results. “No differences were found between the sketching abilities of students who had engineering technology, industrial technology, or science education backgrounds” (Katsioloudis, Dickerson, et al., 2016, p. 29). Although this study did not yield significant results, it has furthered the research on factors impacting sketching and spatial visualization skills (e.g., Sorby, 1999).

Study 5: Effects of Light Intensity

The purpose of this study (Katsioloudis, Jones, & Jovanovic, in press) was to determine whether the different levels of light intensity, 250–500 lux, 500–750 lux, and 750–1,000 lux, significantly change the level of spatial visualization ability, as measured by the Mental Cutting Test, (MCT) and sectional drawings for engineering technology students.

Research questions and hypotheses. The following research question guided this study:

> Will different levels of light intensity, significantly change the level of spatial visualization ability as measured by the Mental Cutting Test and sectional drawings for engineering technology students?
>
> The following hypotheses were explored during this study:
>
> H_0: There is no effect on engineering technology students’: (a) Spatial

> visualization ability as measured by the Mental Cutting Test and (b) ability to sketch a sectional view drawing, due to the different levels of light intensity: 250–500 lux, 500–750 lux, and 750–1,000 lux.
>
> H_A: There is an identifiable amount effect on engineering technology students': (a) Spatial visualization ability as measured by the Mental Cutting Test and (b) ability to sketch a sectional view drawing, due to the different levels of light intensity: 250–500 lux, 500–750 lux, and 750–1,000 lux.

Methodology. The three groups ($n_1 = 38$, $n_2 = 40$, and $n_3 = 41$, with an overall population of $N = 119$) were presented with a visual drafting model. All three groups (n_1, n_2, n_3) received a 3D printed pentadecagon model, and were asked to create a sectional view sketch while the model was exposed into three different light intensities for each group (250–500 lux, 500–750 lux, and 750–1,000 lux), respectively. Since light was used as a part of the study treatment, and to prevent bias for students using glasses or contact lenses, all participants were exposed into several light intensities (varying from 250–1,000 lux) and were asked to report whether they could clearly see or not. All students were identified as having no difficulty seeing within the spectrum of the lighting conditions used in this experiment (Katsioloudis, Jones, & Jovanovic, in press).

Results. It was found that the different levels of light intensity provided statistically significant higher scores; therefore, the hypothesis that there is an identifiable amount of effect on engineering technology students': (a) Spatial visualization ability as measured by the MCT and (b) ability to sketch a sectional view drawing, due to the different levels of light intensity: 250–500 lux, 500–750 lux, and 750–1,000 lux, was accepted. Specifically, students whose model was exposed between 500–750 lux outperformed the other two groups (Katsioloudis, Jones, & Jovanovic, in press).

Systematic Review

Methodology

A causal-comparative methodology was selected as a means to perform a systematic review of the data previously collected for each independent study. Specifically, all five studies described above used the MCT and scores received on sectional-view drawing to identify spatial visualization ability differences between pre- and post-treatment for each group respectively. The purpose of the current study was to identify whether the combination of treatments used for the five studies independently have any additional critical variables (see Figure 1).

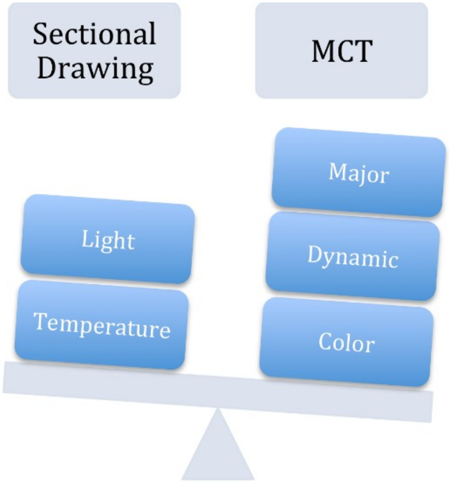

Figure 1. Meta-analysis diagram.

Results

Data analysis involved the comparative analysis of the pre- and post-Mental Cutting Test (MCT), which was used to show equality and improvement of spatial ability between the five different study groups. The pretest results can be seen in Table 1: 23.432, 22.532, 23.450, 22.932, and 23.743, respectively. As far as the posttest, overall means were higher: 23.822, 23.532, 23.670, 24.014, and 23.839, respectively. No noticeable difference was seen for any of the groups that completed the treatment.

The second method of data collection in five studies involved the creation of a sectional-view drawing. As shown in Table 3, the average means for the five groups were 5.753, 4.932, 4.432, 4.213, 4.424, and 4.750, respectively. It was interesting to see that the average mean for the Study 1 group was 5.753, which was statistically significantly higher than the other four groups.

A one-way ANOVA was run to compare the mean scores of the graded sketches for significant differences among the five groups. The results of the ANOVA test, as shown in Table 3, were significant: $F(0.530) = 0.039$, $p < 0.05$. The data were dissected further through the use of a post hoc Tukey's honest significant difference (HSD) test. As shown in Table 4, the post hoc analysis showed a statistically significant difference in two cases: the blue vs. temperature groups ($p < 0.046$, $d = .456$) and the 3D printed vs. temperature groups ($p = .043$, $d = .342$).

Table 1
MCT Pre- and Post-Test Descriptive Results

						95% confidence interval for mean	
Studies	*N*	Mean pretest	Mean posttest	*SD*	Std. error	Lower bound	Upper bound
Study 1	54	23.432	23.822	2.422	0.424	23.452	23.804
Study 2	67	22.532	23.532	3.042	0.593	22.453	23.422
Study 3	125	23.450	23.670	3.524	0.522	23.529	23.602
Study 4	74	22.932	24.014	3.023	0.532	22.495	24.002
Study 5	119	23.743	23.839	2.927	0.345	23.485	23.726
Total	439	23.217	23.775	2.987	0.483	23.088	23.711

Table 2
Sectional-View Drawing Descriptive Results

					95% confidence interval for mean	
Studies	*N*	Mean	*SD*	Std. error	Lower bound	Upper bound
Study 1	54	5.753*	1.542	.345	4.643	5.642
Study 2	67	4.932	1.422	.534	4.345	5.532
Study 3	125	4.432	1.432	.654	4.532	5.578
Study 4	74	4.213	1.568	.643	4.356	5.753
Study 5	119	4.424	1.534	.682	4.532	5.298
Total	439	4.750	2.691	.571	4.481	5.560

* Denotes statistical significance.

Table 3
Sectional-View Drawing ANOVA Results

Quiz	*SS*	*df*	*MS*	*F*	*p*
Between groups	1.642	2	0.603	0.530	0.039*
Within groups	243.428	98	2.501		
Total	252.521	100			

* Denotes statistical significance.

Table 4
Sectional-View Drawing Tukey HSD Results

Studies	Treatments	Mean Diff. (1-2)	Std. error	*p*
1 vs. 2	3D printed vs. blue	.264	.234	.125
1 vs. 3	3D printed vs. temperature	.342	.642	.043*
1 vs. 4	3D printed vs. major	.934	.753	.452
1 vs. 5	3D printed vs. light	.431	.425	.320
2 vs. 1	Blue vs. 3D printed	-.385	.643	.457
2 vs. 3	Blue vs. temperature	.0456	.643	.046*
2 vs. 4	Blue vs. major	-.643	.754	.346
2 vs. 5	Blue vs. light	.532	.345	.284
3 vs. 4	Temperature vs. major	.531	.942	.653
3 vs. 5	Temperature vs. light	.334	.233	.221
4 vs. 5	Major vs. light	.545	.234	.223

* Denotes statistical significance.

Discussion

This study was done to determine significant positive effects related to sectional-view drawing ability. In particular, this review compared the results from five previously conducted studies in order to identify additional critical variables. All studies shared the same assessment tools: the MCT instrument and a sectional-view drawing.

> Sectional views are very useful engineering graphics tools, especially for parts that have complex interior geometry, as the sections are used to clarify the interior construction of a part that cannot be clearly described by hidden lines in exterior views (Plantenberg, 2013). By taking an imaginary cut through the object and removing a portion, the inside features could be seen more clearly. Students had to mentally discard the unwanted portion of the part and draw the remaining part. The rubric used included the following parts: 1) use of section view labels; 2) use of correct hatching style for cut materials; 3) accurate indication of cutting plane; 4) appropriate use of cutting plane lines; and 5) appropriate drawing of omitted hidden features. The maximum score for the drawing was 6 points (Katsioloudis, Jovanovic, & Jones, 2016, pp. 8–9).

The major results of the studies suggest that a dynamic 3D-printed drafting model presented with a blue background under lighting conditions between 500–750 lux positively impacted the spatial visualization ability of engineering technology students (see Figure 2). As shown in Table 2, the students that participated in the temperature study were able to achieve a higher score in the sectional-view drawing, and when compared to the other five study groups, a *p*-value of .039, $p < 0.05$ showed significant difference among the other means (see Table 3). Additional analysis, using the post hoc Tuckey test, showed that Studies 2 and 3 (blue vs. temperature), with a *p*-value of .046 ($p < 0.05$), and Studies 1 and 3 (3D printed vs. blue), with a *p*-value of .043 ($p < 0.05$), had the most significant differences among their respective means (see Table 4).

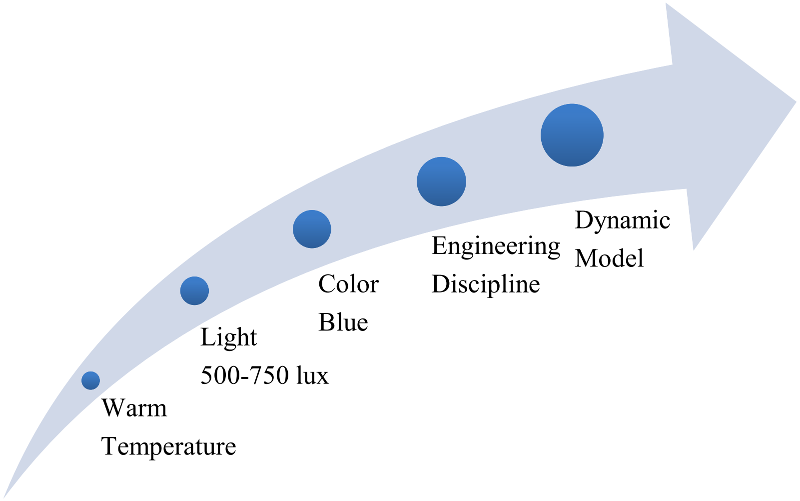

Figure 2. Diagram of effective spatial visualization drafting model based on a series of experimental studies.

The present results provide support for the hypothesis that when a dynamic 3D-printed drafting model is presented with a blue background under lighting conditions between 500–750 lux for Engineering Technology students, it positively impacts the spatial visualization ability of engineering technology students. This finding is consistent with previous research findings.

Focused on temperature, Filingeri, Redortier, Hodder, and Havenith (2015) “tried to identify whether the absence of humidity receptors in human skin (the sensitivity of skin wetness) is considered an output resulting from the integration of temperature (warm, hot cold) and mechanical inputs” (Katsioloudis, 2017, p. 20). Filingeri et al. found that “warm temperature stimuli have been shown to suppress the perception of skin wetness during initial contact with a wet surface” (p. 13).

> This finding suggested that the temperature of warm water, versus hot and cold, allows the absence of skin wetness perception that could lead to a

> more direct focus. Based on these findings, it can be assumed that the absence of the skin wetness perception could increase the amount of sensitivity data transferred to the brain that can then be translated into spatial visualization data. (Katsioloudis, 2017, p. 20)

In a study conducted by Sanger and Greenbowe (1997), the use of dynamic animations in a college chemistry class was investigated. The researchers first assessed students' conceptual understanding of salt bridges and electrochemical cells and found that many students held alternative conceptions of these topics. Computer-generated dynamic visualizations were then used as a part of the lecture to provide college general chemistry students with dynamic views of the chemical processes occurring in the salt bridge and electrolytes of an electro-chemical cell system. The dynamic computer generated visualizations depicted current flow in the electro-chemical cell. According to Sanger and Greenbowe (1997), the percentage of students who held alternative conceptions after receiving the lecture using the dynamic computer generated visualizations versus those who received a no animation lecture were compared. It was observed that a significantly lower percentage of students who received the visualization-enhanced lecture showed alternative conceptions than did students who had not viewed the animations. In addition, Sanger and Greenbowe (1997) supported the theory that a detailed dynamic visualization presentation provided by computer animations helped most students overcome their alternative conceptions. The researchers indicated that the dynamic visualizations helped students visualize complicated chemical reaction processes and led them to change their alternative conceptions to scientifically more acceptable conceptions (Sanger & Greenbowe, 1997). (Katsioloudis, Dickerson, Jovanovic, & Jones, 2016. pp. 30–31)

In a study exploring the addition of blue color (Katsioloudis, Jovanovic, et al., 2016),

> Students who received treatment using the 3D printed Dynamic visualization, with the addition of the blue glasses visual cue, outperformed their peers who received treatment from the other two types of visualizations. Previous research supports that the effect of color on those with high spatial ability may result in little benefit, as high spatial ability learners develop mental models on shape alone. According to Khooshabeh and Hegarty (2008) it is suggested that color affects the performance of learners with low spatial ability more so than those with high spatial ability. (p. 11)

Related to the light intensity paper, it is suggested that a specific spectrum of light (500 lux up to 750 lux) could aid learning. Several studies suggested positive correlation between lighting levels and oral reading fluency performance among middle schools students and learning in general (Mott, Robinson, Walden, Burnette, & Rutherford, 2012). The literature also supports that color and light intensity have positive effects on cognitive performance and that the level varies across different groups such as female or male students (Knez, 1995). According to Sanger and Greenbowe's (1997) study about the use of dynamic animations in a college chemistry class,

> the percentage of students who held alternative conceptions after receiving the lecture using the dynamic computer-generated visualizations versus those who received a no animation lecture were compared. It was observed that a significantly lower percentage of students who received the visualization-enhanced lecture showed alternative conceptions than did students who had not viewed the animations. (Katsioloudis, Dickerson, et al., 2016, p. 30)

Future Plans

In order to have a more thorough understanding of spatial visualization ability and its implications for different professional disciplines and student learning, it is imperative to consider further research. Research in the area of spatial visualization could benefit from repeating the abovementioned studies included in this review by using additional types of drafting models. Although these studies focused on engineering technology students participating in engineering graphics coursework, additional studies exploring different student populations in the areas of mathematics and engineering education may offer additional insights into variables impacting spatial visualization.

Although the majority of participants were male students, additional research could be conducted exploring whether there are differences between male and female students. Further analysis exploring additional visual cues during the display of 3D objects, including shadows, construction lines, and size, could also provide additional feedback into the cause and effect of these spatial variables.

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From the Field

Graphic Design and Instructional Methods: An Action Research Study

David E. Gorski

Technology and engineering education is filled with so many varied topics that it is almost impossible to break them into grade-level courses. As a result, courses are often mixed with all grade levels and all types of learners. On rare occasions, one course section pops into the schedule that is all one level. When this occurs, it may become necessary to reevaluate the practices that have been implemented in the classroom related to instruction, discipline, and policy. For this study, the population of graphic design students consisted of primarily freshman students.

In this case, the researcher was faced with an entire section of graphic design with primarily freshman students. In the past, there had been freshmen mixed into other sections without any problems. However, this class posed an interesting problem: traditional instructional methods were not working. This section of mostly freshman students was falling behind the usual curricular pace for the class. They were struggling to work with the independence that they are granted as high school students. They were also struggling with following the directions given to them in the manner traditional for this course, which was backed by past practices. With this new demographic, it became necessary to evaluate alternative instructional practices in relation to freshman students.

The typical collegiate style in which instruction has been given in my classroom has been successful in the past. However, this approach, in which all expectation is put on the learner, was not proving successful in a classroom filled primarily with freshmen students who have not fully made their transitions out of middle school mentality. Therefore, I decided to look into scaffolded instructional models as a means to increasing student understanding and mastery.

Literature Review

The concept of scaffolded instruction (Bruner, 1975) stems from Lev Vygotsky's concept of the "Zone of Proximal Development" (ZPD), which is the area within the students' intellectual ability between where they can act independently and where they need instruction or help to achieve the goal (Shabani, Khatib, & Ebadi. 2010). Scaffolded instruction allows the educator to create a support system for the student in order to move them through contend within their ZPD. Scaffolded instruction can be thought of exactly as scaffolding while building. You will always need support if you are trying to work over your head our beyond your reach. In 1997, Hogan and Pressley summarized the preexisting literature into eight essential scaffolding guidelines:

- “Pre-engagement” (i.e., selecting tasks appropriate for students and curricular goals);
- “Establishing a shared goal”;
- “Actively diagnosing the understandings and needs of the learner” (p. 82);
- “Providing tailored assistance”;
- “Maintaining pursuit of the goal”;
- “Giving feedback”;
- “Controlling for frustration and risk”; and
- “Assisting internalization, independence, and generalization to other contexts” (p. 83).

Following these guidelines, not necessarily in a set sequence, will allow an educator to reach students at all levels and help facilitate growth in both high and low achieving students. Some potential “challenges and cautions for scaffolding instruction” (Larkin, 2002, p. 4) are as follows.

- Use scaffolding as needed. Not all students will need it in every lesson.
- Know your curriculum and your students. This will allow you to identify problem areas ahead of time.
- Prepare prompts ahead of time.
- Have patience.

Scaffolded instruction is a powerful tool that can allow an instructor to make accommodations and modifications to pre-established curriculum in order to maximize student achievement.

Action Research Questions

The purpose of this study was to answer the following two questions.

- Does scaffolding instruction in a graphic design class improve achievement?
- Does scaffolding instruction in a graphic design class help keep students on the curricular timeline?

The intent was to take current practices and investigate a new instructional method to help a class of mostly freshman succeed. Students’ completion dates and grades were compared to previous years’ records in order to show the need for this study. Then, after new instructional methods were integrated and a new batch of assessments were completed, they were compared with the grades of freshmen in the mixed-level classes from the previous semester to establish the effectiveness of the modifications.

Methodology

This class consisted of 15 students, six of whom were freshmen. This may not seem like a high concentration; however, given the usual demand for classes, it is unlikely that students will get into these classes until they have more free slots in their schedule. At the beginning of the semester, there were eight freshmen in the class, but two were removed for scheduling reasons. The previous semester, there were only six freshman in total across all three sections of the course.

Data were generated by modifying an introductory lesson in Adobe Illustrator® about perspective (Appendix A). This tool is a very powerful way of adding visual interest to artwork. Unfortunately, mastery of this tool is very difficult because small mistakes or additions could ruin the entire project. Students were given an instructional booklet, a modified tutorial that was prepared to increase student understanding. This packet replaced our traditional demonstration and lecture method for this lesson. With the introduction of the packet as well as direct instruction, guided practice, and teacher demonstrations, we built a true scaffold of support.

The lesson was delivered with supports to all students in the class, and after a few days, the students submitted their projects for grading. The resulting projects, although simple, demonstrate mastery of the various tools and components in Adobe Illustrator to create a 3D cityscape. The project grades were compared with those of freshman students in the Semester 1 class who did not receive the same scaffolded instruction that the Semester 2 students did. Fortunately, the sample sizes where the same for each group: Semester 1 had a total of six freshmen from the three course sections, and Semester 2 had six freshman in the course.

Data Analysis

After all the data were collected and compiled, conclusions could be drawn. The data were compared across four dimensions: passing grade on the assignment, correct components of the buildings, correct coloring of the buildings, and assignments submitted in the correct format.

The data for the Semester 1 students, who received traditional non-scaffolded instruction, are as follows. Of the six freshmen spread across three sections of the graphic design course, 83% completed the task with a passing grade. Only 33% of the students had all of the components of the buildings correct. This means that all buildings and windows were aligned perfectly in perspective as per the directions given. Only 16% of the students correctly colored the buildings as per the directions. Finally, only 50% of the students submitted their assignments in the correct format to our Google Classroom.

The data for the Semester 2 students, who received scaffolded instruction, are as follows. Of the six freshmen in the Semester 2 section, 100% completed the assignment with a passing grade. Of these students, 100% had all of the components of the buildings correct. However, only 83% of the students had the buildings colored correctly. Finally, 100% of the students submitted their assignments in the correct format to our Google Classroom.

The first data point (Figure 1), passing grades, marks a 17% increase from Semester 1 to Semester 2 students. This shows that scaffolding was beneficial for the freshmen students. Although a marginal increase, it still lends support for the use of scaffolding to improve student learning.

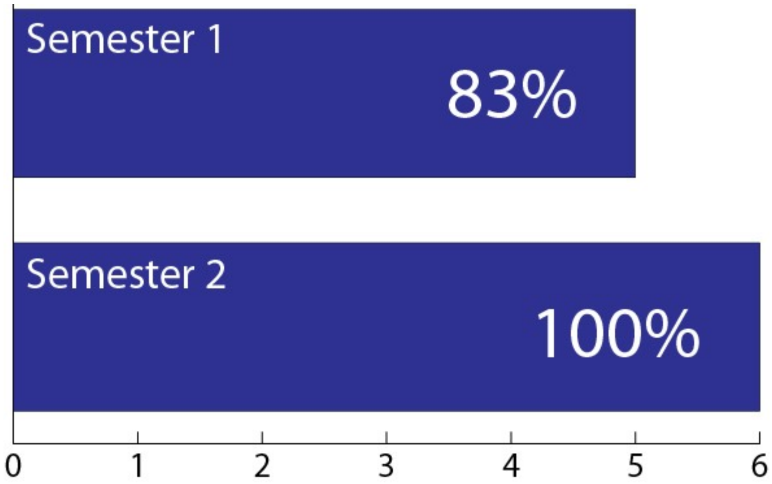

Figure 1. Number and percentage of students who completed the assignment with a passing grade.

The second data point (Figure 2), correct components of the buildings, marks a 67% increase in the students' ability to demonstrate mastery of the various tools and concepts in Illustrator required to create a cityscape in perspective. This point is the most critical to me. A student may or may not submit a finished assignment; however, if they can demonstrate mastery of the individual tools and techniques, then I know that they have developed an understanding of the program and what it is capable of.

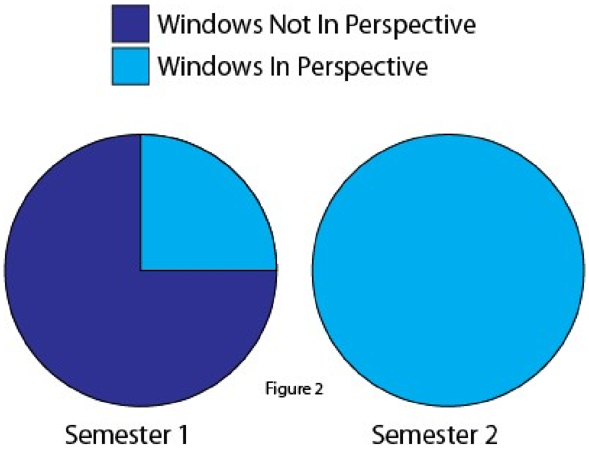

Figure 2. Correct components of the buildings: windows in perspective.

The third data point (Figure 3), correct coloring, marks a 66% improvement in the students' ability to use the various color tools and create complex gradients to enhance their designs. The ability to complete such a complex task and create these gradients shows that the students can follow a complex set of directions perfectly to achieve their goal.

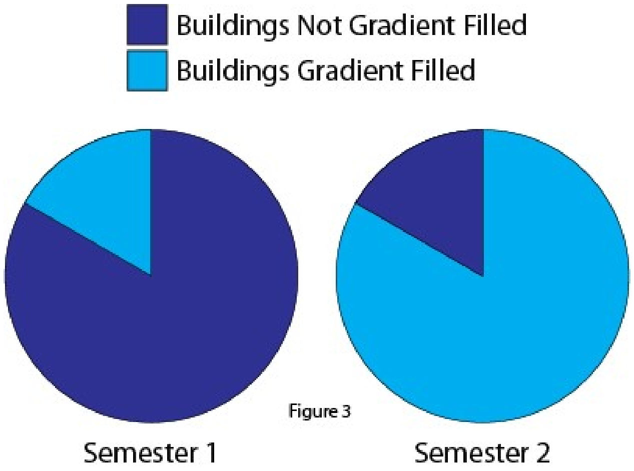

Figure 3. Correct coloring: building are gradient filled.

The fourth and final data point (Figure 4), correct submission, marks a 50% improvement. Having students submit the assignments correctly is important for any teacher. Having file format and naming convention correct is vital when dealing with many files that all look the same. This data point also takes into consideration the timeline of this project.

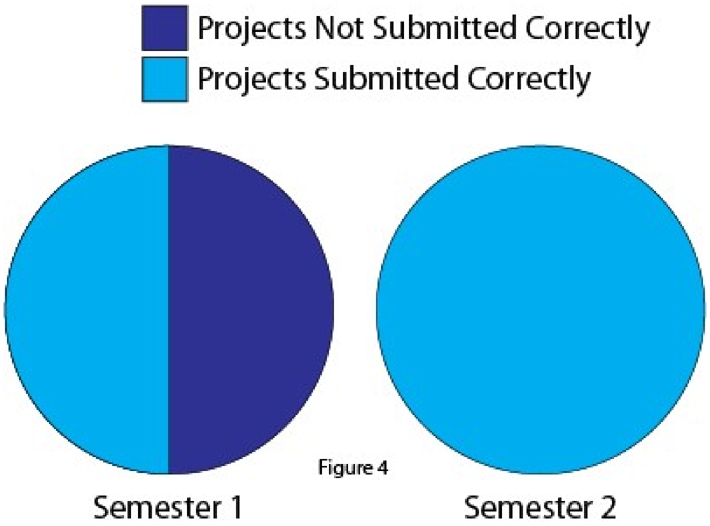

Figure 4. Correct submission of projects.

In addition to the above data points, the assignments submitted were of a higher quality than the previous sections of the course. Although this observation was more subjective in nature, it showed that students were referencing prior content and putting more effort into their assignments.

Summary and Conclusions

In summary, the freshmen students in this graphic design class reacted positively across all measurable indicators. The students were able to use the scaffolded lesson to complete the assignment to expectations. The data show that for freshmen, the inclusion of scaffolding has drastically improved the results at the end of the lesson. Students have produced work in the same timeframe as Semester 1 while improving in all measurable areas.

Student success has shown that although the traditional methods of instruction have worked with other grade levels in years past, scaffolded instruction had a positive effect on freshmen of all achievement levels. Because 100% of Semester 2 students submitted assignments correctly, set up buildings correctly, and received passing grades, it is clear that the level of instructional support that was provided was appropriate for the lesson.

Future Actions and Directions

Looking towards the future, there are a few changes that I would like to make based on the data collected. I would like to collect data from a larger sample of freshmen students to ensure that the supports are what increased success and that this was not an abnormality. I would also like to modify a more base-level introductory lesson to see if getting students on a scaffolded structure earlier in the course will build upon success as the semester progresses.

Next steps for researching will involve restructuring content and lessons in order to provide supports at a lower level. Along with the restructure, I will need to create a new series of rubrics and grading materials in order to create more data points to monitor student progress. Finally, I need to develop some sort of mode for student feedback. Whether that means direct responses on each assignment or anonymous surveys, I need student feedback in order to help them succeed.

An interesting side effect of this research has been increased interest in direct tutorial based instruction from students. Some students have asked for both simple and in-depth tutorials for all aspects of the graphic design class. I anticipate that delving deeper into these requests will increase student interest and hopefully help students gain a deeper interest in the topic.

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About the Author

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A link to David's instructional unit is linked under the actual article at http://scholar.lib.vt.edu/ejournals/JTE/.

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