USE OF SPATIAL THINKING TO INCREASE STEM CAREER INTEREST IN STUDENTS

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Abstract

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Studies have been conducted over the years looking at the effects of integrating spatial thinking into math classes and some science disciplines in order to improve spatial visualization and mental rotation. Since there is such a significant need for people to fill STEM (Science, Technology, Engineering, and Math) positions, it is extremely important for instructors to find ways to increase interest in these fields. One suggestion is to implement spatial thinking into curricula. It has been shown that teachers that use this format of instruction in their lessons find an increase of students who enrolled in STEM post-secondary degrees, many of whom peruse STEM careers. If students feel uncomfortable and/or do not find success in these classes, they are less likely to pursue degrees and occupations in STEM fields. This review of literature and research studies suggest that implementation of spatial visualization techniques at early ages and continuing through to secondary education improves the chances that students will graduate in a STEM related field. According to an article in *Educational Psychology Review*, "…that the correlation between spatial ability and several measures of STEM achievement suggests that spatial training should focus on improving students' spatial ability" (Stieff, & Uttal, 2015).

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Chapter I Introduction

After attending an Anatomy & Physiology professional development conference, I became aware of how students attending postsecondary education institutions, especially those enrolled in a medical-biological based field, lack the ability to reason in a spatial manner and manipulate things in their minds in three-dimensions. This brought about a question to me, as an educator, regarding how we, as teachers in our classes, could improve spatial thinking in terms of spatial visualization and mental rotation. Spatial ability is an important cognitive function for all students, but is especially important for those students entering any STEM field of study in a postsecondary situation. According to an article on KQED.org

> The ability to mentally manipulate objects is key to success in many fields, including physics and engineering. Spatial skills are an early indicator of later achievement in mathematics, they "strongly predict" who will pursue STEM careers, and they are more predictive of future creativity and innovation than math scores. (Kris, 2016)

If students are lacking these spatial visualization skills, it can hinder them from pursuing an education in a STEM field and thus reduce the number of eligible employees for STEM careers. If this skill set is addressed in secondary science classes, will this then increase the interest in STEM overall?

Statement of the Problem

According to the Journal of Educational Psychology, achievement in STEM (science, technology, engineering, and mathematics) is related to how well a student views objects or manipulates things in the mind (Stieff, Dixon, Ryu, Kumi, & Hegarty, 2014). As the need for STEM related careers increases, educating people for these positions needs also to increase. If students in secondary education feel they do not have the skills to be successful in a STEM career, educators need to find ways to not only create excitement in STEM classes, but to develop teaching skills that will ultimately increase success for STEM-interested students willing to pursue majors in STEM-related education. Nora Newcombe reported in *American Educator*, “Spatial thinkers are likely to be more interested in science and math than less spatial thinkers, and are more likely to be good enough at STEM research to get advanced degrees” (Newcombe 2010, p. 30). To meet this need, educators in secondary education need to find ways to teach spatial thinking and help students improve spatial thinking and spatial visualization. How can educators improve spatial thinking in terms of spatial visualization and mental rotation in science class, to better prepare students for success in postsecondary STEM classes and careers?

Definition of Terms

- Spatial Ability – “ability in manipulating visual patterns, as indicated by level of pattern of difficulty and complexity in visual stimulus material that can be handled successfully, without regard to speed of task solution” (Carroll, 1993, p. 362). Can also be referred to as “spatial visualization, mental rotation, perspective talking, etc.” (Stieff, & Uttal, , 2015)

- Spatial Thinking/Reasoning – “the mental processes of representing, analyzing, and drawing inferences from spatial relations” (Uttal, Miller, & Newcombe, 2013).

- Spatial Training – tasks or strategies used to identify “spatial information and reasoning about dynamic spatial relations” (Stieff, Dixon, Ryu, Kumi, & Hegarty, 2014).

- Spatial Visualization – “…the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object” (McGee, 1979, p. 893).
- STEM - acronym for Science, Technology, Engineering and Math (Uttal, et. al. , 2013).

Purpose of the Study

The purpose of this research study is to decide if educators can improve spatial thinking and mental rotation in science classes by exploring different spatial learning techniques, also known as training tasks. Training tasks include: writing with descriptive spatial words, drawing maps and using models, utilizing visualization, and using analogies (Newcombe, 2010). By inserting training tasks into science lessons, and then measuring the difference in spatial test scores, spatial ability for the involved students should improve. This study reviewed multiple research articles that investigated areas of spatial visualization, spatial training, spatial ability and spatial thinking in an effort to see if these explorations were implemented in classrooms and then, if this focus influenced preparation of students for postsecondary academic success. The hypothesis created to help answer the research question is as follows; If extra emphasis is placed on spatial visualization and mental rotation in science classes, will all students in the class improve in spatial ability skills by the end of the school year, potentially preparing them for future STEM classes and perhaps ultimately STEM careers.

Significance of the Study

In recent years the importance of spatial thinking has become a more apparent need for students entering post-secondary institutions, especially those enrolled in STEM fields of study. According to the *Journal of Women and Minorities in Science and Engineering*, “There is also a growing recognition of the importance of spatial thinking for educational and occupational success in STEM" (Sorby, & Veurink, 2019). The same article further quotes a study conducted by Wai, et al. (2009) that "analyzed eleven years of longitudinal data from over 400,000 talented high school students. Spatial ability emerged as a consistent and statistically independent predictor of STEM-related career selection and attainment of an advanced STEM degree." (Sorby, & Veurink, 2019).

Knowing what curricular inclusions need to be provided in the classroom to enhance spatial thinking remains an unknown. As quoted in *American Educator*,

> The National Academies' report *Learning to Think Spatially* pointed out that we still lack specific knowledge of what kinds of experiences lead to improvement, how to infuse spatial thinking across the curriculum …(and) what kinds of teaching best support spatial learning? (Newcombe, 2010)

Even though training for spatial ability is not a new idea, integrating spatial thinking into a science curriculum is a new concept for the Shullsburg science program, (and probably for many rural schools' science curricula?) The relevance of implementing this type of learning into an existing curriculum should not be considered an unattainable task for the teacher. A recent study shows that students can improve on spatial skills by participating in such investigations in a biology class (Castro & Uttal, 2019). Spatial ability is an important cognitive function for everyday actions, such as driving a car or rearranging items in a fixed space. "Findings from experimental studies thereof have established evidence that this ability is trainable when trainings are designed with specific focus on this ability" (Rafi, 2008).

Methodology

Research for this paper was organized online using Google Scholar search engines along with the Educational Resources Information Center (ERIC) and the UW-Platteville Karrmann Library search engine. Key words used to obtain research articles included: spatial visualization, spatial ability, spatial reasoning, spatial training, and training for STEM. The majority of information found was in the form of literary research articles, research papers, and academic journal articles. A few books on spatial ability and reasoning were also included in the results.

Chapter II Review of Literature

Spatial ability testing in some format has occurred for quite some time. According to Harrison J. Kell's research, "assessment of mental competence via tasks now recognized as spatial reasoning measures dates back to the 19th century" (Itard, 1962, p.181,1962, in Kell, & Lubinski, 2013). Spatial ability studies have been conducted on multiple ages, from young children to students attending universities. Although some strides have been made in training for spatial abilities, much more research needs to be conducted to determine what "methods of training will lead to the greatest STEM-related improvements" (Uttal, et. al., 2013). For these reasons finding learning tools that will improve spatial thinking and reasoning ability is an important research topic to investigate.

What is spatial ability?

I became aware of the term, spatial ability, during the fall of 2019, when a professor from a California university used this term several times while teaching a professional development training I attended. She explained that many of her own students were challenged with "seeing" things in their mind and manipulating three-dimensional objects mentally. She also explained how a lack of spatial ability influenced students' decisions on continuing in a STEM focused degree or career. So, this made me think of my own classroom and what influence I can have on students by using different tools in my classroom to improve spatial ability. Today more than ever, careers have increased technology needs. Research shows a demand for STEM-minded students has become crucial. Yet, unfortunately students are not going into these fields. Additionally, students in these fields often drop out or change from STEM programs. Some of this, it appears, can be attributed to the lack of spatial ability. According to an article in the *Educational Psychology Review*:

> Recently, several researchers have shown an increased interest in the role of individual and group difference in cognitive abilities on STEM achievement and degree attainment. In particular, spatial abilities (e.g., spatial visualization, mental rotation, perspective taking, etc.) have received significant attention, and there are many ongoing studies that are investigating whether low spatial skills explain why some students struggle to succeeded in specific STEM course or drop out of STEM career pathways. (Stieff, & Uttal, 2015)

With these things in mind, more STEM instructors in primary and secondary education should be made aware of the importance of these skills and how they can therefore create opportunities for inclusion of spatial skills in their instruction. However, how many teachers are unaware of this discrepancy? How many educators have even heard the words spatial ability? Spatial ability requires the use of mind, eyes, and a level of understanding of how these two things interact with each other. This understanding depends on “the cognitive processing of visual projections arriving at the retina and the creation of a mental understanding of how objects relate to each other in time and space” (Birchall, 2015). Perceiving objects in this manner is especially important in the medical field, engineering design, geology, and many other STEM fields. In some fields, spatial ability is so important, that individuals must pass a specific spatial ability exam before entering specialized programs (Birchall, 2015). Over the years, several studies have been performed to show the correlation between spatial ability, education, and career preference. In those studies, students that displayed elevated scores in spatial abilities were more attracted to STEM fields. For example, “students scoring in top 20% on math-space (not math-verbal) were more attracted to undergraduate majors in engineering, mathematics, and computer science.”

Whereas those in the math-verbal were more inclined to major in humanities (Kell, & Lubinski, 2013). In addition to comparing student's spatial abilities, these studies also looked at how teachers implemented opportunities for spatial ability enhancement, but found many instructors are either unaware of these practices or do not have them included in their curricular investigations to enhance spatial abilities during the school year (Kell, & Lubinski, 2013). These instructional shortcomings create missed opportunities for STEM instructors.

How Spatial Visualization Improves Spatial Ability Reasoning

When looking at spatial ability and improving opportunities in learning, one area that must be addressed is spatial visualization, or being able to manipulate objects mentally (McGhee, 1979, p. 893). Spatial visualization can be a genetically inherited trait, but it can also be developed through training (Ben-Cham, Lappan, & Houang, 1988). However, for spatial training to be effective, it must be designed with specificity and focus on spatial ability using a variety of options of spatial visualization (Rafi, Samsudin, & Said, 2008). Several studies have shown that with proper instruction, spatial visualization can be learned. This learning can be accomplished with hands-on learning, verbal instruction, and even with digital programing. Unfortunately, spatial visualization requires many facets of the brain to be working at the same time, which can tend to be difficult for many people. Some spatial ability tests that are created that involve spatial visualization do not always represent the real-world problems and do not always show a true representation of the abilities of the taking those tests (Kozhevnikov, Motes, & Hegarty. 2007). In one particular study, researchers used spatial ability problems, along with physics motion problems, to see what the effects were on overall brain memory capacity. They compared high-spatial ability students to low-spatial ability students. For some tasks, students worked at the same level, but for other tasks, students with lower spatial ability were not able to use descriptive details in their work as easily as the higher ability students. Overall, the study showed that visualization is important, but requires much more mental memory. The lower-ability students had difficulty with these complex actions (Kozhevnikov, Motes, & Hegarty, 2007). Another study looked at the relationship between spatial visualization and spatial structuring to assist in understanding how to measure in volume. Cubes were used to enhance the spatial visualization learning and apply concepts of volume measurement. Several strategies used blocks, along with students block drawings and varied instruction from the teacher. With practice, students eventually were able to predict volume and build models of the volume asked. (Revina, Zulkardi., Darmawijoyo, & van Galen, 2011). Although spatial visualization is an important part of spatial reasoning, it may prove to be a challenge for some students, especially if they do not have the mental fortitude to comprehend those tasks. However, proper training and practice can increase spatial visualization mental function to create a more efficient spatial reasoning pathway.

How Spatial Training is Used to Increase Spatial Ability Reasoning

Spatial thinking is a major piece of the puzzle when looking at spatial reasoning and then implementation into a curriculum piece. Many challenges create hurdles for implementation: age, gender, and socio-economic status. These obstacles are all factors that can play a role in performance in any school subject, but especially in spatial thinking. A recent study conducted by Sorby & Veurink, looked at the relationship between spatial training, female performance vs. males, and the number of those that enter the engineering field. They researched several factors that influence spatial thinking: academics, gender, socioeconomic status, and brain malleability.

All these factors played a role in student spatial skills and in how they performed in spatial instruction. Middle school students were placed into a spatial training-based curriculum with half of the students receiving the special curricula and the other not during a two-year period. Many different spatial training methods were used in this study to assist students in spatial reasoning. Examples of these tools included working with 2-D objects, constructing objects, creating 3-D objects from 2-D patterns, object rotation, and several more. Much of the work completed by the students was either done using a workbook or computer software. Results of this particular study were very promising in showing gains for females in their mental spatial reasoning along with improved math scores especially when compared to those students not in the spatial instruction (Sorby, & Veurink, 2019). Thinking spatially and application of spatial thinking in the classroom is not a common piece in all curricula, though it is included in some math curricula. Spatial thinking is not very commonly taught in the primary and secondary school instruction. Time is also a challenge for effective implementation. However, if spatial training, were to be effectively included, a greater confidence level in math and science scores could lead to more students enrolled in STEM based majors.

How Application of Spatial Thinking Affects STEM

Spatial thinking, utilizing spatial ability skills, has an impact on learning STEM classes. This could influence the number of students perusing STEM careers. The first step in this style of learning is to define spatial thinking and the tasks needed to implement spatial training. Once this is determined, convincing the teaching community, especially STEM teachers, of the importance and perceived benefits of implementing this facet of curriculum into their already filled and taxing lesson plans. Another consideration is differences in those students who possess the traits to easily learn spatially, versus those who do not have the same opportunities to learn due to race, gender, or socioeconomic means. All of these could create issues in STEM learning and in closing the STEM gap. Spatial training does not have to just be confined to the classroom. There are several video games, recreational activities, and good old-fashioned play that improve spatial abilities, especially in younger students. Creation of spatial training specific to STEM classes, or even modifications to current curriculum by implementing small changes, could lead to boosts in spatial reasoning (Newcombe, 2017). Spatial training relies heavily on implementation and execution in the classroom in order to improve spatial reasoning and spatial abilities. Spatial ability success has a high correlation to STEM ability and success (Stieff, Dixon, Ryu, M., Kumi, & Hegarty,2014). The education system, especially the STEM courses, need to be vigilant in finding ways to implement spatial training strategies to help close the gap in STEM and, thus in turn, facilitate enrollment of more students in a STEM major with a STEM career focus.

Summary

Although studies on the influence of spatial abilities have been around for decades, implementation of spatial training is not widely used in the primary/secondary education community. This lack of knowledge and understanding leads to a disservice to students. It also does not allow teachers to create more interest in STEM, so confidence can be improved in these classes, and then interest created in majoring in these fields. Nora Newcombe sums this dilemma very well in the last paragraph of her paper on the subject of spatial visualization supporting STEM learning.

> There is emerging evidence that interventions that increase spatial skills have downstream effects on STEM learning, although more studies are needed, especially

> work that takes a more analytical look at various spatial skills and their mechanisms linking each skill to a particular aspect of STEM learning. (Newcombe, 2017).

If instructors have the proper tools, training, and "the why" spatial training is important, then more teachers would find reasons to implement these strategies. In turn, theses implementations, hopefully, will spur more students to pursue STEM majors and thus fill the needs of STEM jobs.

Chapter III Conclusions and Recommendations

How can educators improve spatial thinking in terms of spatial visualization and mental rotation in science class, to better prepare students for success in postsecondary STEM classes and careers? This is the questions I posed at the beginning of my paper. As my research has found time and again, studies specifying on those areas that improve spatial reasoning skills and how they best fit into a curriculum without removing content but enhancing what is already taught suggests the topic definitely needs to be included. As Newcombe states, "there is extensive research on each of these tools, but less than is needed on how to combine them and how to use them collectively to mold curriculum" (2017). If industry demands more STEM workers, then perhaps part of the solutions would be for corporations to fund studies so that proper curricula can be developed and implemented.

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