Spatial skill's development and line-work improvement in learning the Design process in a Technology Subject at a Johannesburg University

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Abstract— spatial abilities and spatial tasks are an essential part for succeeding in Science, Technology, Engineering, and Mathematics (STEM) programs. It is often said that individuals without spatial skills fail to make it in the Technical field and concepts such as drawing. This paper was aimed at developing pre-service teachers' spatial skill and improves their line-work in order to perform the Design process in the Technology subject excellently. A total of 41 pre-service teachers were selected purposively to take part in the study. A qualitative approach was used in a form of a Spatial Ability Test as well as Purdue Spatial Visualization Test of Rotations (PSVT: R) by Newton & Bristoll and Dr. Roland Guay respectively. The findings of the study found that spatial skills can be developed through spatial skill's diagnosis where drawing should be practiced in order to improve line-work usage. With spatial skills being developed and line-work usage being applied properly, pre-service teachers can perform the Design process with ease.

Keyword- Design process, Engineering Graphics and Design, Spatial skill, Technology subject

Introduction

Spatial visualization skill has been recognized as a predictor of success in many technology-related fields, such as Engineering Graphics and Design (EGD) [24]. For engineering students, visualization skills can be very important for understanding fundamental concepts of technical drawing [1]. Findings by [22] stated that most of the EGD students encountered the problem of visualization in learning its concepts because current teaching and learning of EGD is via static drawing. The traditional teaching methods and approaches are not emphasizing the students' visualization skills [25].

Spatial abilities and spatial tasks are an essential part for succeeding in Science, Technology, Engineering, and Mathematics (STEM) programs. Spatial ability has been defined in many different ways by many different researchers over the years. [4] define it as, "individual differences used in the processing of non-linguistic information or individual differences in performance on spatial tests." According to [11], spatial ability can be broken down into three main factors: visualization, spatial orientation, and spatial relations. [14] defines visualization as "the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli". This means that for any attempt in a given drawing, one ought to have a skill to rotate objects, visualize shapes and figure out how a drawing looks like when rotated, both in two and or three dimensional (2D/3D).

On the other hand Technology is a subject that the Bachelor of Education pre-service teachers take in their First and Second years of their four year degree course. It is one of the major subjects that help in paying a way towards a third major subject choice when they do third year. In this case their third major subject could be Mechanical Technology, Information and Communication Technology and or any Science subjects. Therefore for pre-service teachers to successfully cope in their third major subject they need to have passed and understood Technology subject and its concepts in the first two years of their four year degree course. In Technology, pre-service teachers get engaged in some practical lessons where they apply skills in Woodwork/ Metalwork/ Fitting and Turning workshops. One of the rules that they need to apply when making a practical project is to provide a sketch of what they are making and this is known as the Design process. The Design process happens to be challenging to pre-service teachers especially when they enter into the degree course without EGD background from secondary schools. Not all of these pre-service teachers had EGD background from secondary schools; hence this paper was conducted to the first year Technology pre-service teachers in a Johannesburg University.

The importance of line-work in the Design process

According to [3], line-work plays a vital role in the 'making' of a drawing. This means that wrong application of line-work gives a drawing or a sketch a different image and description. This is so because in all the line-types that are used in EGD, each of them has its own function and their functions are interrelated because one drawing can have more than three types of lines. Various features of a drawing or a sketch are described through the use and interpretation of line-work. Some of the line-types can denote hidden features in a drawing and for one to easily identify these hidden features is through reading and understanding various line types that are used in EGD.

According to [15], there are ten different types of lines that are used in the entire EGD curriculum that also applies in schools. Out of these ten line types, seven of them are the main ones in EGD concepts with the other three mainly being the applications of some of the other types. If, for example, pre-service teachers are given a practical project of a car that is made of wires, the first step that is normally required of them is to provide a drawing. In the said drawing, there will be hidden features that could mainly be some of the interior parts of the car, or even a crank of a car. Therefore for such hidden features to be described there are certain line-types that need to reflect in the drawing of the car and failure to use a relevant line-types will result in the second person, to be unable to make sense of the drawing and the practical object that is to be made in the workshop. Table 1 provides some of the main line-types that are learnt in EGD and in Technology subject.

Table 1 Seven-line types used in the EGD curriculum

LINE TYPE	DESCRIPTION	GENERAL APPLICATIONS
A ______________________	Continuous, thick and black, 0, 5 mm or 0, 7 mm	Used for outlines and page borders
B ______________________	Continuous, thin and black, 0, 3 mm	Used for dimension lines, sectional lines, screw threads etc.
C	Continuous, thin and black (freehand), 0, 3 mm	Used to indicate boundaries of part views
F -------------------------------	Dashed lines, thin and black, 0, 3 mm. Have an approximate 3 mm space in between and are each 2 mm long	Used to show the hidden detail (s) in an object
G _________ _ __________	Chain-like lines thin and black, 0, 3 mm. Have long dashes of 8 mm to 25 mm long and have an approximate length of 2 mm between them	Used for centre line/ lines of symmetry or pitch circle diameter in the construction of gears
H2	Where a cutting plane line is on a centre line, the centre line, outside the drawing, will change to a continuous thin line	Used to show cutting planes as well

Source: [15]

Therefore for the pre-service teachers to understand what is required of them during the Design process, they need to understand line-types that are the core-determiners to the understanding of EGD. This is because line-types help to make understand and visualize a drawing. According to [15], drawing is a graphic language used by engineers and draughtsman that comprise of symbols, dimensions, notes and different types of lines to convey the correct meaning of Engineer's idea. This translates into line-work being the key factor in students' understanding of any drawing concept as foundation for drawing activities. However, knowing only the application and definition of various line-types, cannot make an individual to be a good producer of a drawing if they do not have spatial skill. The two concepts ('line-work application and spatial skill') work hand in hand. [18] mention the following key concepts of line-work application:

To enhance visualization: this means that before an individual can make or machine an object, he must be able to visualize the object from the drawing placed in front of him. This visualization needs a good understanding of line-work because with that, one can be able to describe the underlying components in a drawing. This also means that for an individual to be able to visualize an object they need to be able to draw it first, hence the two concepts are interrelated.

To enhance perception: this enables one to discover the basic concepts of shape perception through self-investigation [18]. The above refers to the fact that when various line-types are reflected in a drawing, one needs to be able to visualize how the drawing looks like guided by the said various line-types. The visualization process will therefore be accompanied by perception also called spatial ability. The perception process will merely be applied for one to twist and turn the drawing in their mind when they imagine how the drawing looks like.

From the above assertion, it is apparent that spatial skill and line-work, work hand in hand. Even though Technology subject does not require a detailed EGD content, some basic concepts that include the application of line-work are beneficial, especially for learning the Design process and shaping their major subject choice to be a technical subject. Therefore for me to be able to know first year Technology pre-service teachers' level of spatial ability, I had to diagnose their level of spatial skill by using the Spatial Ability Practice Test by [20]. In a study that was conducted previously, it was found that spatial skill's diagnosis serves as a key indicator towards learning EGD because learning barriers are identified timeously [7]. The Spatial Ability Test that this paper used had three sections; the matching-type, the rotations as well as the similarity-identification sections as shown in Figures 1, 2 and 3 respectively.

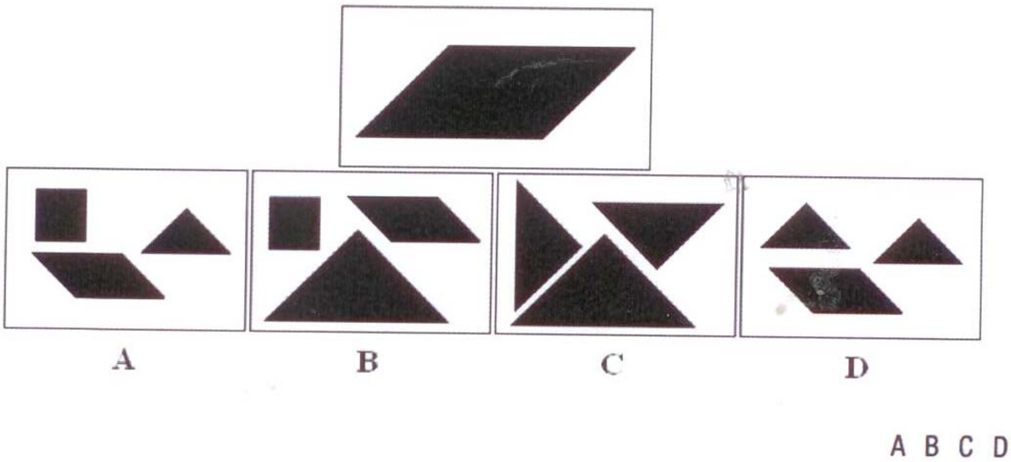


Figure 1 required from the pre-service teachers to start by viewing the block above the four given (A- D) and select from either A, B, C and D the possible pieces of blocks given that can complete the above given block. The other section that the pre-service teachers were tested on was the rotation section that was taken from Guay's Purdue Spatial Visualization Test of Rotations [6].

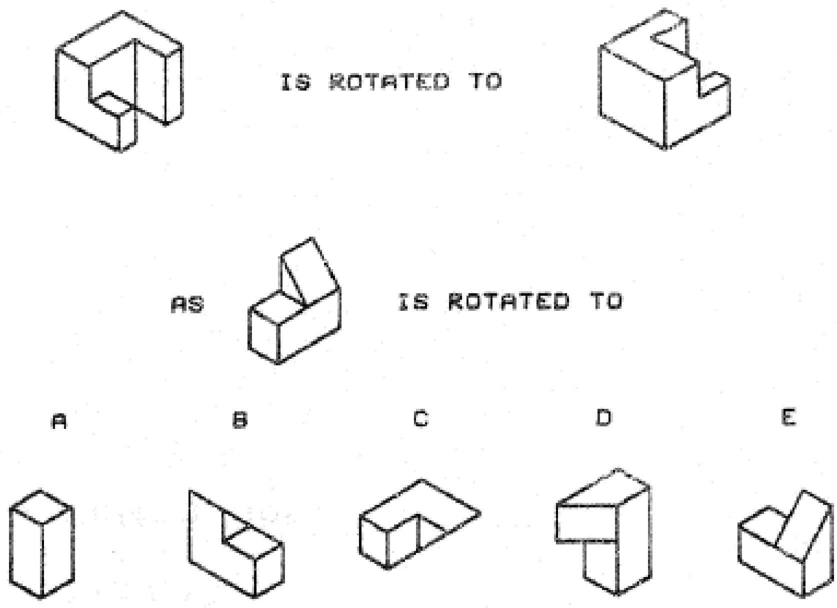
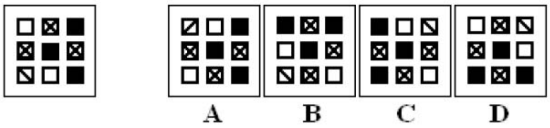


Figure 2: The rotations section test [6]

Figure 2 required from the pre-service teachers to rotate the object towards the given direction on the instruction and find a solution. This section happens to be one of the most difficult sections because if an individual does not have good visualization skill, they definitely will struggle to get it right. Figure 3 on the other hand presents typical examples of similarity-identification section.

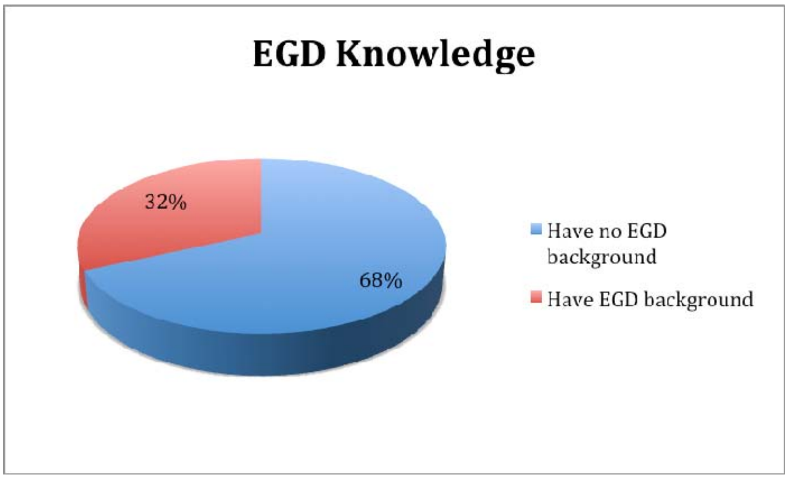


A B C D

Figure 3: Similarity-identification section [27]

In figure 3 pre-service teachers were required to check a block between A-D which is similar to the first one. This section is related to the first two sections and they are fairly easier than the rotations section. The above sections were used to diagnose the pre-service teachers' level of spatial skill and it cut across by bringing both pre-service teachers, with or without EGD background from school. Table 2 presents the EGD background of pre-service teachers when they entered the BEd programme.

Table 2: Pre-service teachers EGD knowledge (N=41)



According table 2, sixty eight percent (68%) of the pre-service teachers entered into the degree course without the schools' EGD background with only 32 % of the pre-service teachers having done EGD at school level. Even though the study was not investigating pre-service teachers' spatial skill knowledge by gender, it would be a worrying factor if it was found that most of the pre-service teachers without EGD background from secondary level were female. According to [8] males score higher than females on tests that require rotating objects in mental images in psychology courses. Although it may vary by socioeconomic background [8] and sexual orientation [19], this effect occurs consistently across cultures [19] and age ranges [9]; [13], and it is a critical empirical pillar of theories of human sex differences in spatial abilities, including evolutionary theories [19].

The table figures triggered the strong argument for spatial skills diagnosis in order to come up with a tailor made programme that would introduce pre-service teachers to the relevant design skills in the subject Technology. The spatial skill diagnosis was conducted using Newton and Bristoll's Spatial Ability Practice test [27] as well as Purdue Spatial Visualization Test of Rotations (PSVT:R) by [6]**.** Dr. Roland Guay developed the first familiar spatial skills test in 1976 with students in the Chemistry Department at Purdue University to assess a person's ability to visualize rotated solids [6]. Paul Newton and Helen Bristoll further developed this test and named it a Spatial Ability Practice test, which was the one used in this paper. The reason why the [27]'s test was preferred over that of [6] is that it contains the sections that I wanted to assess which are matching block-type section as well as the similarity-identification sections which match the curriculum offered to the pre-service teachers that took part in this study. However, the rotations section used was taken from [6]'s PSVT: R test of rotations.

The above sections were used in order to assess first year pre-service teachers' levels of spatial skills before the commencement of the academic year which would also assist the Technology subject facilitators in planning and arranging content in the subject Technology especially the Design process. Pre-service teachers who took part in the study had different EGD backgrounds from secondary schools as shown in Table 2.

Purpose of the paper and Research Questions

The purpose of the paper was to develop pre-service teachers' spatial skill and improve their line-work use in the Design process of their Technology subject. This was triggered by the pre-service teachers' constant poor performance in the design process and line-work usage when producing sketches before the practical component is made in the workshop. The following research questions guided the study:

a. What is the pre-service teachers' level of spatial skills when entering into the BEd programme?
b. What are pre-service teachers' challenges in the Design process in the Technology subject?

According to [12] the Design process is the decision making process which involves any design whether it is architecture/ graphic/ something abstract which results in a drawing. Often in the Technology drawing component, pre-service teachers fail to perform drawing/design tasks successfully because of incompetent abilities in spatial skills, which is said to be a good predictor of success in engineering and any drawing concepts [23]. In order to address spatial skill challenges, [25] suggest that individuals' spatial skills be diagnosed at an early stage before they engage in drawing courses because the traditional teaching methods and approaches, which are currently used as a teaching tool, are not emphasizing the students' visualization and spatial skills.

Spatial skill is a fundamental skill for those working and studying in the field of engineering, as well as those individuals in technology professions who work with a diversity of vector graphic tools designing in three-dimensional space and virtual environments [26]; [2]; & [23]**.** For this reason, spatial skill has long been considered an essential component towards careers using and interpreting graphics technologies [26]. According to [17], students who score poorly on tests of spatial perception are at risk of failing Engineering Drawing and Design courses. [16], [17] have also found that students experiencing difficulties in spatial skills can be trained in perception and the use of mental imagery in drawing tasks. After receiving training, it has been found that their performance on tests of spatial perceptions improves. More importantly, the students also pass their Engineering Drawing and other technical subjects, which have drawing and/or design components.

In the meantime, a lot of pre-service teachers in the Technology education field do not perform well when confronted with spatial-visual relations tasks**.** With this continued and expanding interest in spatial research, many formats and instruments have been developed for testing spatial visualization from the perspective of cognition and perception.

Methodology

The study made use of a qualitative approach in a form of a Spatial Ability Practice Test by [27] as well as the PSVT: R test of rotations [6]. According to [10] qualitative research strives to discover meaning and investigate processes in order to gain in-depth understanding of an event or situation.The data include interview transcripts, personal documents and other official records. A total of forty one (41) pre-service teachers were purposefully and conveniently selected to take part in the study. All the pre-service teachers were registered for Technology level one subject in the BEd degree course. The analysis of the data was done quantitatively where figures in terms of performance differences were shown.

Results and discussions

Pre-service teachers were given Spatial Ability Practice Test by [27] where two sections; matching block type and similarity-identification sections were selected as well as the PSVT: R test [6] for the rotations section. The main purpose of the test was to assess the pre-service teachers' level of spatial skill because not all of them had EGD background from secondary level. The test also aimed at assessing the level of spatial skill of the pre-service teachers who had EGD background from secondary school level. This test was to ensure that pre-service teachers would be able to cope in the Design process during Technology subject which has been a challenge for most pre-service teachers over the years. Table 3 shows pre-service performance on the matching block section.

Table 3: Pre-test results of the matching block section

EGD background	**Matching block section**				
	20%	**40%**	**60%**	**80%**	**Total**
No EGD	7	13	6	2	**28**
Have EGD	1	2	8	2	**13**
Total	**8**	**15**	**14**	**4**	**41**

After the Spatial Ability test was administered, it was found that 49% of the pre-service teachers who were without EGD background scored less than 50% on the matching block type test. This performance proved that pre-service teachers' spatial skills without the school EGD background was poor when they entered into the BEd programme as discussed earlier on in this paper by [24] that poor spatial skills lead to poor performance in EGD. On the other hand 7% of the pre-service teachers who have done EGD at school level performed below

50% in the matching block test with 24% of them having scored above 60% in the same section. In the meantime, 20% of those with no EGD school background scored above 60%. None of the pre-service teachers scored a 100%.

Table 4: Pre-test results of the rotations section

EGD background	Rotations section						
	0-10%	**11-20%**	**31-40%**	**51-60%**	**71-80%**	**81-100%**	**Total**
No EGD	5	1	0	1	3	18	**28**
Have EGD	0	0	1	0	0	12	**13**
Total	**5**	**1**	**1**	**1**	**3**	**30**	**41**

Table 5: Pre test results of similarity-identification section

EGD background	Similarity-identification section					
	20%	**40%**	**60%**	**80%**	**100%**	**Total**
No EGD	1	7	2	10	8	**28**
Have EGD	0	1	1	4	7	**13**
Total	**1**	**8**	**3**	**14**	**15**	**41**

Table 5 shows that 20% of the pre-service teachers with no EGD background from school scored below 60% in the similarity-identification section with 20 pre-service teachers (49% of the population) having scored between 60% and 100%. Only one pre-service teacher with EGD background from school scored below 60% with 29% of their counterparts having scored between 60% and 100%. Even though the overall performance of the pre-service teachers in the three sections was not that poor with the exception of the matching block section, it was important to come up with an intervention in a form of a bridging course so as to bring the poor performing pre-service teachers on par with the rest. An intervention in a form of a four-week programme was put in place, adapted from [22]. The intervention is tabled in table 6.

Table 6: Drawing fundamental bridging course

No.	Topic	Weight values	Week ending
1.	**Introduction to Drawing Fundamentals** *Students were introduced to drawing fundamentals in the form of line-work, sketching and dimensioning*	10%	1 & 2
2.	**Visualization and Spatial Representation** *Students were given exercises of drawn sketches so that they could produce hidden views and three-dimensional sketches*	25%	2
3.	**Drawing Projections: Orthographic, Isometric** *Students worked on their three-dimensional drawings to produce front, left and top views and also worked backwards to three-dimensional views in freehand*	30%	3
4.	**Working with Drawing Instruments** *Drawing to scale and with instruments was then effected to produce the three-dimensional drawings*	10%	4
5.	**Design Project** *Students then made the final products that they drew with wood/boards in the workshop for concrete understanding*	25%	4
	Total	**100%**	

Table 6 shows the four-week programme that the pre-service teachers were taken through in order to bring them to speed to the expectations of the Design process and drawing fundamentals. Some of the concepts that were part of the four week course were not necessarily what were in [22]'s Course Outline, but I have included mine so that they respond to the needs to the pre-service teachers' curriculum. For the first two weeks pre-service teachers were exposed to drawing fundamentals. Basic drawing skills like line-work and sketching were done and few sketching exercises were also given. Towards the end of the second week and the third week visualization as well as orthographic projections was facilitated. Orthographic projections deal with 3D drawings where a drawing or an object is drawn so that its three sides can be able to be seen. The first three weeks were facilitated through freehand drawings and in week four, drawing with instruments was then encouraged. It was during the fourth week that pre-service teachers were asked to provide a simple sketch drawn with instruments of any model of their choice. This would be a model that they would work on during their practical lesson upon mastering drawing fundamentals. At the end of the fourth week, the same spatial Ability Practice test was administered to them as a post-test. The results are shown in table 7.

Table 7: Post-test results of pre-service teachers in three sections

EGD background	**Section**					
	$\leq 60\%$	$\geq 60\%$	$\leq 60\%$	$\geq 60\%$	$\leq 60\%$	$\geq 60\%$
	Matching block		**Rotations**		**Similarity**	
No EGD	5	23	1	27	3	25
Have EGD	1	12	0	13	1	12
Total	**41**		**41**		**41**	

Table 7 shows the improvement in all the three sections in the pre-test that was administered to pre-service teachers. The table shows that 56% of the pre-service teachers with no EGD background from school scored above 60% in the matching-block section. This performance is far much better compared to 20% of the same pre-service teachers who scored above 60% in the same section before the bridging course. The pre-service teachers with EGD background showed an improvement also as they 29% of them scored above 60% in the matching-block section as compared to 24% of them having scored above 60% in the pre-test. Sixty six percent of the pre-service teachers with no EGD background scored above 60% in the rotations sections with 32% of their counterparts with EGD background having scored at the same margin. This performs is better than what they scored in the pre-test at a percentage of 54% and 29% respectively. The similarity-identification section saw 61% of pre-service teachers with no EGD background scoring above 60% with 29% of their counterparts with EGD background having scored above 60%. This performance is better than what the two types of pre-service teachers scored in the pre-test of 49% and 29% respectively.

The pre-service performance after the intervention attest to what was discussed earlier by [7] that diagnosing spatial skills before the commencement of the academic year does improve develop spatial skills. Also what was observed in week three under topic 4 of the intervention programme was that pre-service teachers drawings made sense in a way that their line-work were correctly used and the visualization section which was done in week 2 was exceptionally done and with the given tasks submitted on time. The tasks given to pre-service teachers were quite a few but they managed to do them with a good display of line-work and this showed a good interpretation of line-work and visualization skills. This also attests to what was discussed earlier on that line-work makes a drawing to be clearly understood [3].

Conclusions

The performance of the pre-service teachers in both the pre and the post-test shows an improvement that might not seem significant, but the pre-service teachers' level of spatial skills showed to have improved after the intervention. It was also noted that during the fourth week of the intervention or the bridging course, played a significant role in developing pre-service teachers' spatial skills because the post-test results improved than in the pre-test. The paper also found out that lack of constant practice caused challenges to pre-service teachers in line-work improvement. However the structure of the intervention programme ensured that both the pre-service teachers' spatial skills and line-work development rest squarely in first (a) diagnosing spatial skills at an earlier stage and coming up with an intervention and (b) with the intervention, more tasks should be included which will ensure that line-work is developed.

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Acknowledgment

This project was kindly funded by the FRCs 2015 Ad Hoc Grant of the University of the Witwatersrand.

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