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# Students Metacognitive Challenge in the Interpretation of Mechanical Drawings in Engineering Graphics and Design

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**Abstract**

There is great presence of misinterpretation of drawings, line types and application of drawing symbols among engineering graphics and design students. This is testament to the low pass rate in the sectional mechanical drawings where students are expected to apply different line types and drawing symbols to communicate a cast machine drawing. The purpose of this study was to understand how Engineering Graphics and Design (EGD) students interpret machine drawings from the scope of Engineering Graphics and Design. A case of first year preservice teachers in a university was used in this study to look at the extent to which students can interpret mechanical drawings which is the most complicated topic in machine drawings. Data was collected through classroom observations and students' daily exercises (sectional mechanical drawings). Two lessons were observed, and students' portfolio was used to collect data. Narrative analysis was used to analyse classroom observations and checklist were used to analyse students' activity portfolio to identify how they interpret Sectional Mechanical Drawing. The study found that most students lack relevant manipulative and spatial skills that are necessary for Sectional Mechanical Drawing. Moreover, they have a challenge to activate their cognitive capabilities that would help them to see how machine parts are to be drawn when subjected to sectioning. This was mostly attributed to the lecturer's way of teaching about machine drawings. Thus, a more student-centred approach coupled with guided discovery method is recommended to assist students in interpreting mechanical drawings.

**Keywords***:* Sectional Mechanical Drawing, Engineering drawings, Technology Education.

## 1. INTRODUCTION

Thinking about thinking, a metacognitive exercise that can surely be considered as one of the highest order of thinking in a student learning experience. This is because it helps students to map-out their logic and then questions why they think in a certain way. A metacognitive exercise is an essential skill needed to understand drawing concepts in Engineering Graphics and Design. For instance, most students during mechanical drawings draw a lot of machine parts without necessarily knowing them and their functions in mechanics. It seems there is not much rigorous mechanical thinking registered by students whenever they are drawing [1]. Also, whenever there are drawings with errors from printing, students rarely recognise such errors during their drawing process, this is an evidence of metacognitive suspension. I argue that students who are always in touch with their thinking and constantly examine their own thinking are able to see such design errors as they engage in the drawings. Mechanical drawings include a lot of assembling parts that are sectioned and knowing where auxiliary views are to be applied. This requires a great deal of cognitive thinking and understanding basic machinery operations. Hence, it is important to flag this metacognitive phenomenon as we continue to learn to teach drawing concepts and the thinking process involved in solving mechanical drawings. Engineering graphics and Design (EGD) is a subject coupled with a set of cognitive and manipulative skills used to design and communicate graphically (i.e., using a set of lines, symbols, and signs to render services and design processes [1,2]. It teaches internationally acknowledged principles that have both academic and technical applications [2]. Basically, the emphasis is on teaching specific basic knowledge and various drawing techniques and skills so that EGD students can be able to produce drawings within the contexts of mechanical technology, civil technology, and electrical technology [3].

As per drawing conditions, it is expected that all engineering drawings aligns with the Code of Practice for Engineering Drawing 0143 of the South African Bureau of Standards (SABS) and code 10111 of the South African National Standards (SANS) which gives students an idea of the draughtsmanship basics. This means that whatever interpretation a student has of EGD, should reflect understanding of the code of practice. In the same vein, students should possess some of the skills required for addressing mechanical drawing such as object rotational skills, in order to visualise parts, understand their combination and interpret different views of an object that is represented in the drawing [4]. This includes the ability to extract information from advanced mechanical drawing concepts like machining, symbols of texture and welding. According to Sorby and Baartmans [5], it is critical for students to understand how to interpret engineering drawings, particularly those presented in 3-D, in order to detect defects in machine parts and understand how they would appear if they needed to be redesigned. This means that students should consider interpretation to be a meta cognitive skill for solving mechanical drawings and manufacturing machine parts. Strong and Smith [6] considers it as a spatial skill that forecast the success of engineering drawings. Ofcourse, spatial abilities are not what one is born with, but they come as a result of a long learning process.

Despite mixed opinions from scholars such as Burnett and Lane [7] about whether spatial ability can be taught and developed, several research have suggested that with the right training materials, it can be enhanced. Thus, learning to interpret sectional mechanical drawing can be used to improve spatial ability. This is supported by Brazley [8] that these activities are the same as the ones that are used in teaching engineering drawings. It is important to emphasize that the purpose of this research is not to improve students' spatial abilities, but rather to improve their interpretation of sectional mechanical drawings as one of spatial skills component. This occurs after preservice teachers have been trained in analytical activities that aid in the comprehension of sectional mechanical drawings and when students' spatial abilities have been demonstrated. It is a premise of this study that there has been close to none of the scientific research that has specifically looked into metacognitive challenges involved in the interpretation of sectional views of a mechanical drawing. As a result, that gap can never be ignored.

## 2. PURSPOSE AND RESEARCH QUESTIONS

The purpose of this study is to understand how preservice teachers interpret Sectional Mechanical Drawings in Engineering Graphics and Design. Thus, the leading questions are:

- How do preservice teachers interpret Sectional Mechanical Drawing?
- Which knowledge do preservice teachers students lack that impact how they interpret SMD?

## 3. LEARNING SECTIONAL MECHANICAL DRAWING

Sectional mechanical drawings are learned to improve visualization and clarity of new designs, clarify multi-view drawings, reveal internal features of parts, and facilitate drawing dimensioning. They are also used for mechanical drawings to reveal internal features of an object when hidden lines cannot represent them properly (e.g., with multiple internal features and excessively superimposed hidden lines). Preservice teachers should interpret them in this way as they are sometimes compelled to teach mechanical drawings during teaching practice models.

According to the Department of Basic Education [2], every teacher who attempts to teach sectional mechanical drawings, must ensure that students know how to draw machine parts that display a detailed inside of an object, iron cast or machine. This is to expose students to the interior construction of a part that cannot be clearly described by hidden detail lines in exterior views [9].

Thus, sectional drawings are prepared as drawings that cut away a portion of the component to reveal internal details [11]. In fact, to create a sectional view, imagine a sectional plane that cuts through the mechanical component. Consequently, a sectional view is defined as a view used in a drawing to show an area or hidden part of an object by cutting away or removing part of that object [12]. Makgato and Khoza [13] define it as part of graphic communication in technical subjects to reveal the hidden details in a drawing. I therefore argue that preservice teachers need to display a similar understanding of mechanical drawings as the above authors.

The rule of thumb is that all sectional drawings must comply with the SANS 10111 guidelines since they serve as means of communication amongst engineers [13]. Consequently, in the engineering world, it is important to understand and comply with the SANS in drawings. This is supported by Simmons and Maguire [10] when they say that the reader of an engineering drawing should only be able to get a positive interpretation of the component, otherwise the drafter would have failed in his duty.

## 4. UNDERSTANDING SPATIAL VISUALISATION SKILLS

The consensus view about spatial skills is that it is mental skills concerned with understanding, manipulating, reorganising or interpreting relationships visually [14, 15]. Ofcourse there are different components of spatial skills which includes spatial visualization, spatial perception, mental rotation, spatial relations, and spatial orientation [15, 16].

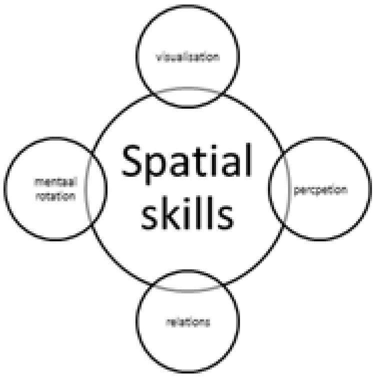


Figure 1: Spatial skills components

Mcgee [14] further states that spatial visualization is defined as the ability to mentally manipulate, rotate, rotate, or invert a stimulus object that is depicted. This suggests that when a student can mentally visualize an object and understand its spatial orientation, the student is considered to have achieved their spatial visualization skills. On the flip side, if a student does not have spatial visualization, he or she is unlikely to be able to interpret and draw a mechanical sectional drawing. Although this does not mean that there is no hope for a student who has not fully attained these skills, there is an opportunity for one to improve their skills for a better learning process as indicated by Ingale [17] using the spatial Visualization can be improved appropriate guidance and training.

## 5. COGNITIVE DEVELOPMENT THEORY

In this study, Piaget's theory of cognitive development was adopted. The theory is based on the belief that children's cognitive development goes through four stages of development. The four stages are: sensorimotor stage, pre-operational stage, concrete operational stage, and formal operational stage.

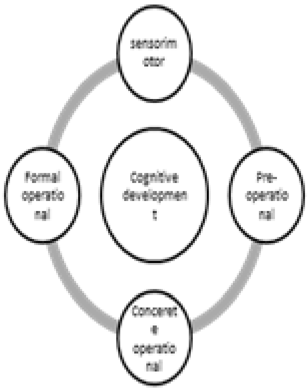


Figure 2: Cognitive stages

The sensorimotor stage starts from birth to language acquisition where infants are said to construct knowledge through motor activity without the use of symbols, and this knowledge is limited because it can only be accounted from physical experiences [18]. The pre-operational stage is where intelligence is "displayed using symbols, language use matures, and memory and imagination develop, but thinking is done in a non-logical, non-reversible manner" (p. 2). Concrete operational stage is where kids start to use a bit of logical thinking in how they interact with their surroundings and can integrate inductive reasoning [18]. When it comes to formal operational stage, "intelligence is demonstrated through the logical use of symbols related to abstract concepts." (p. 2). [18]. Meaning that children demonstrate a fair level of maturity and know that there are possible outcomes and consequences for actions.

Due to the nature of the arguments made in this study, formal operational stage was determined to be pertinent, as preservice teachers are typically 15 years old and have completed the first three stages of Piaget's theory of cognitive development. Although not all students might fit the assumption. It is considered that kids can work with abstract ideas when in the formal operational stage. Datta and Roy [19] sum up the link between abstraction and visualization best when they state that:

"Adolescents who are engaged in formal operational learning make predictions about the results of abstract reasoning tasks based on the conceptual knowledge and spatial knowledge they have acquired. Prediction accuracy increases as these knowledge structures mature and become more interconnected. When compared to early adolescents, late adolescents have a higher correlation between abstract and visuospatial reasoning, which suggests that their knowledge structures are more integrated." (p.5).

## 6. RESEARCH METHODOLOGY

A qualitative research approach was chosen for this study. Through a qualitative study, a researcher may be able to examine in detail the social or individual real-world processes [20]. The qualitative approach is an approach that is more concerned with exploring and understanding the meaning that individuals or groups attach to a social or human problem [20, p.4]. Therefore, a qualitative research approach was found to be relevant as this study aims to examine students' interpretation skills while learning how to draw mechanical sectional drawings. The case study design was adopted in the study. Creswell [20] explains that through a case study, the researcher examines in depth a program, event, activity, process, or person or people. More precisely, a case study is defined as an empirical inquiry that examines a contemporary phenomenon in its real-world context, when the boundaries between phenomenon and context are not clear, and that uses multiple sources. [21, p. 13]. Therefore, the case of EGD preparatory teachers was used in this study, with a focus on their interpretation skills of mechanical section drawing.

### 6.1 Population and Sampling

The population for this study was 29 preservice teachers EGD students enrolled in a teacher training institution. This study purposefully sampled all students, and they engaged in the learning to interpret lesson. According to Etikan, Musa, and Alkassim [22] purposive sampling is widely used in qualitative research for the identification and selection of information-rich cases related to the phenomenon of interest, hence this study was concerned with gathering rich data on the phenomenon of interest.

6.2 Data collection and analyses techniques

Data was collected through narratives of classroom observations and students' drawing activities (sectional mechanical drawings).

6.3 Narratives of classroom observations

For each lesson the researcher wrote narratives of lessons. Sometimes notes of what happened in the classroom were noted down as the lesson continues. The narratives report on the teaching and learning processes in EGD classroom.

6.4 Students drawing activities.

Activities that students were expected to work on during the teaching of sectional mechanical drawing were used as a record of students' written samples. These samples served as data to investigate the processes they follow as they draw SMD.

6.5 Data analysis

6.5.1 Narratives of classroom observations

Students' drawing activities were examined to identify the processes students followed in interpreting SMD. The aim was to identify the mistakes they make due to their lack of spatial awareness. To the best of the researcher's knowledge, the researcher has not come across any journal article or book that prescribes the process that students should follow when interpreting and drawing SMD. However, various authors such as Makgato et al. [12], Olkos [23] and Singh-Pillay and Sotsaka [24] have specified the skills required to do this, which are:

- Application of the scale.
- Utilising the drawing equipment (pencil, compass and T-squares) with a neat pencil work.
- Orientation and the construction of the 3rd angle orthographic projection.
- Interpretation of 3rd angle orthographic projection to represent the views as pictorial representation (this can either be in a form of an isometric or perspective drawing).
- Interpretation of line work and line meanings on a drawing (hidden details).
- Interpreting section lines that indicate the position of the cutting plane arrows to indicate the direction in which section is viewed.
- Applying spatial visualisation skills of rotation and cutting (sectioned) models.
- Applying hatching techniques according to the SANS, which says the lines must be equally spaced and parallel to each other at an angle of .

Preservice teachers are expected to be able to learn, develop, and use these skills even while they do not understand Piaget's formal operational stage. The researcher therefore presupposes that preservice teachers who are at formal operational level should be able to demonstrate these competencies. In order to analyze the drawing activities of the pupils, the researcher employed these abilities as a framework.

## 7. FINDINGS AND DISCUSSION

The data were presented according to research question that guided the study.

RQ1: How do preservice teachers students interpret sectional mechanical drawings?

There are basic skills that students need in order to interpret and complete sectional mechanical drawings. The processes (skills) that students need to go through in order to complete a sectional mechanical drawing are as follows:

Application of the scale.

**Utilising the drawing equipment (pencil, compass and T-squares) with a neat pencil work.**

**Orientation and the construction of the 3rd angle**

| |
|---|
| **orthographic projection.** |
| **Interpretation of 3rd angle orthographic projection to represent the views as pictorial representation (this can either be in a form of an isometric or perspective drawing).** |
| **Interpretation of line work and line meanings on a drawing (hidden details).** |
| **Interpreting section lines that indicate the position of the cutting plane arrows to indicate the direction in which section is viewed.** |
| **Applying spatial visualisation skills of rotation and cutting (sectioned) models.** |
| **Applying hatching techniques according to the SANS, which says the lines must be equally spaced and parallel to each other at an angle of $45°$.** |

Figure 3: EGD skills

- Analysis of drawing activities.

The following task was given to students to complete. In the task students were asked to draw the front and a sectional right view of a pulley using the given cutting plane A-A. Students were required to use a scale of 1:1, and to show all the necessary constructions and centre lines. In answering the given figure below, students were supposed to apply all those necessary skills highlighted above in order to complete the drawing correctly.

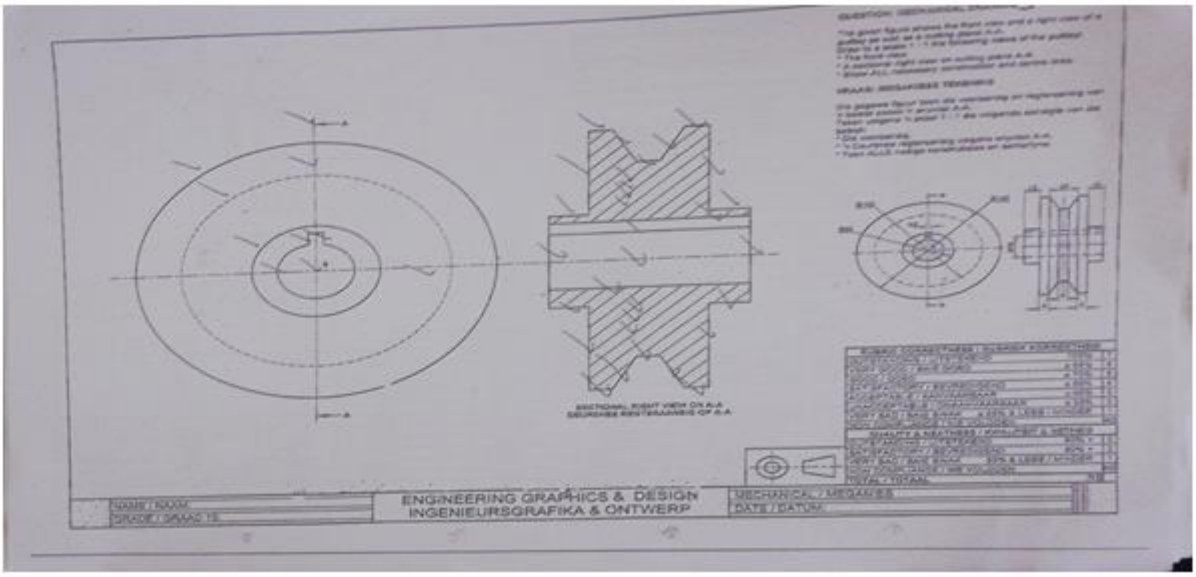


Figure 4: Task given to students with memorandum.

The above figure is given with space on the side for students to answer in. However, some students answered the drawing by showing basic mistakes ranging from the incorrect use of scale, wrong orientation of 3rd angle orthographic views, wrong hatching techniques. The figure below is one of the solutions that the student has given:

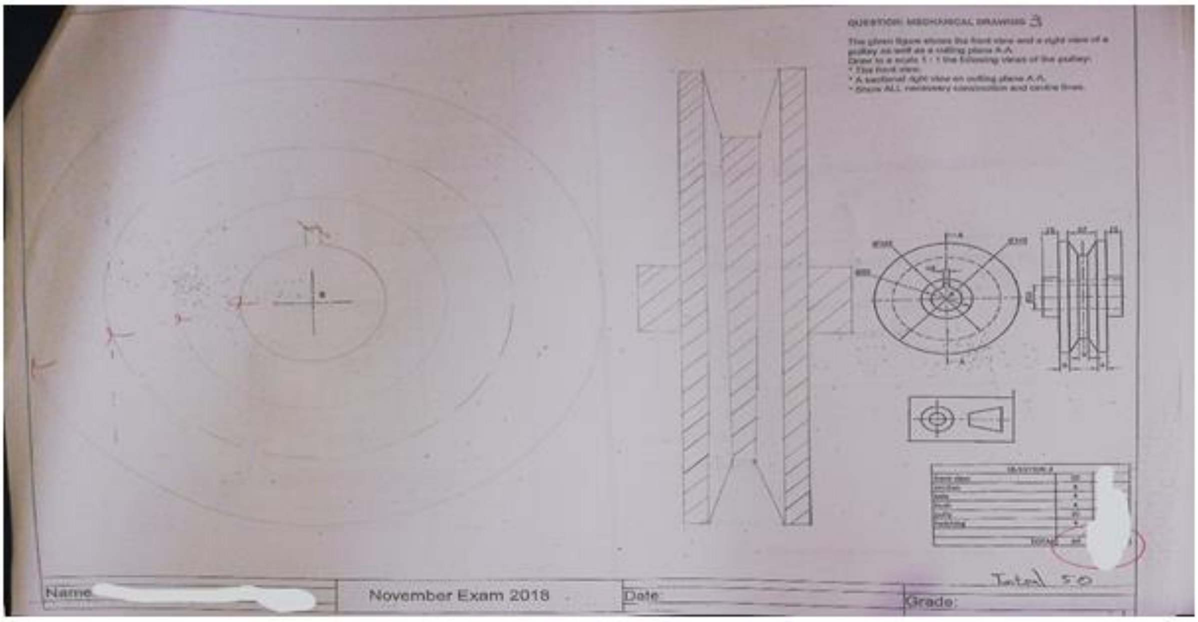


Figure 5: Student 1 written sample with scale error

In the above figure the student made a solution to the given sectional mechanical drawing task. In answering to the drawing, it is evident that the student used incorrect scale in making the drawing. This kind of error might have been caused by student's lack of knowledge about scale application, or the student might have not read the instructions to understand them, or he just ignored the instruction. This type of confusion might lead to the student not being able to interpret some of the EGD drawings that may consist of much bigger scale.

The figure below is another drawing stipulating other errors that were made by students as they interpret drawings.

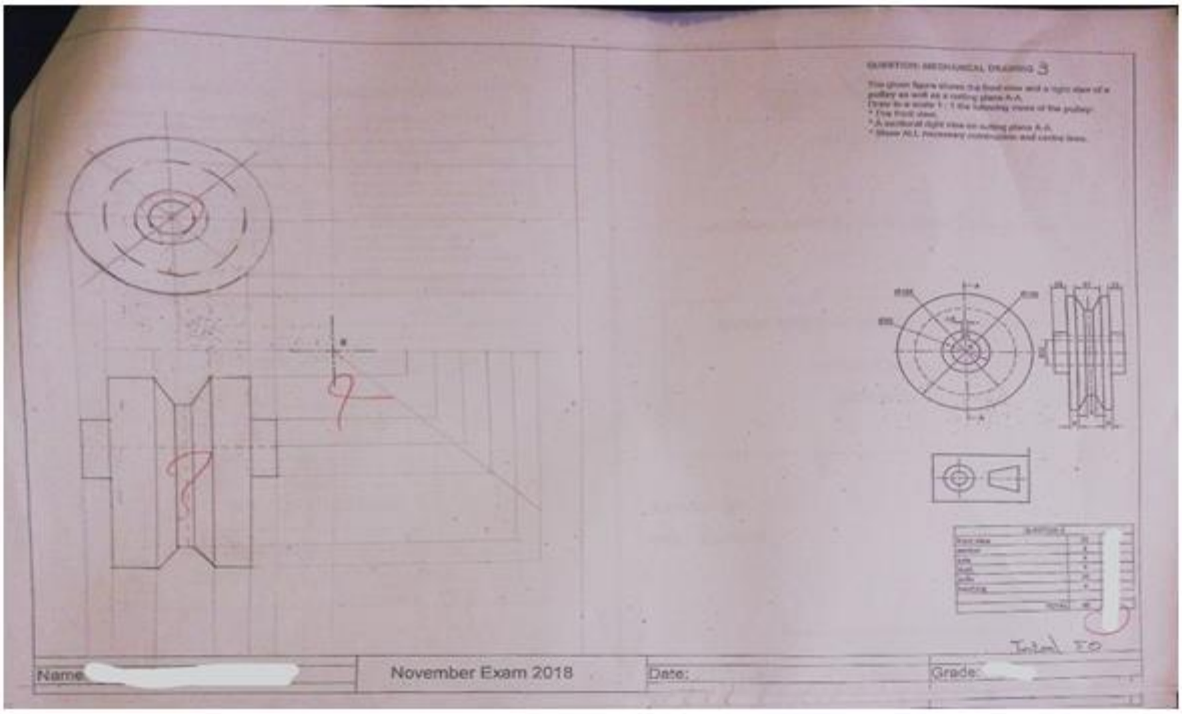


Figure 6: Student 2 written sample with incorrect orientation of views

In the figure above the student used an incorrect orientation of 3rd angle orthographic projection. The student's work also showed lack of skill in using the drawing equipment, which led to untidy pencil work. Interpretation of the used projection is very important as it is one of the carrier skills to able students to deal with other proceeding skill applications e.g. visualisation of the pictorial view. As evident it shows that the student could not finish the drawing. This might be due to lacking the skill of interpretation of 3rd angle orthographic projection, which affected the students' visualisation of the pictorial view which would have abled him to view the cutting plane.

The following figure shows other errors committed by leaners where they did not show hatching at all on their drawings:

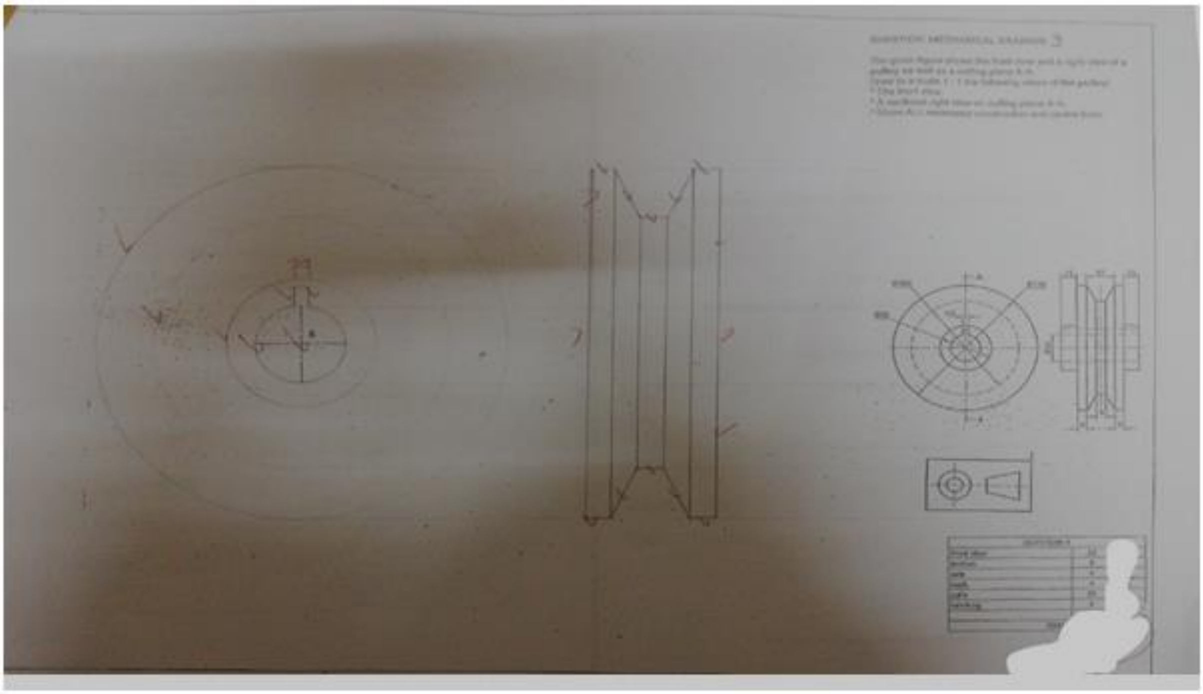

Figure 7: Student 3 written sample with missing hatching lines

According to the students' response it shows that the student could not interpret the section line that indicate the position of the cutting plane arrows to indicate the direction in which section is viewed. The other skills that is evident to be not understood is application of spatial visualisation skills. Lack of this skill will have students to be unable to draw their sectional mechanical drawing correctly.

The figure below is one of a drawing that the other student has made. In this drawing students hatched their drawings, but the hatching was still done incorrectly. There were several students who made this error.

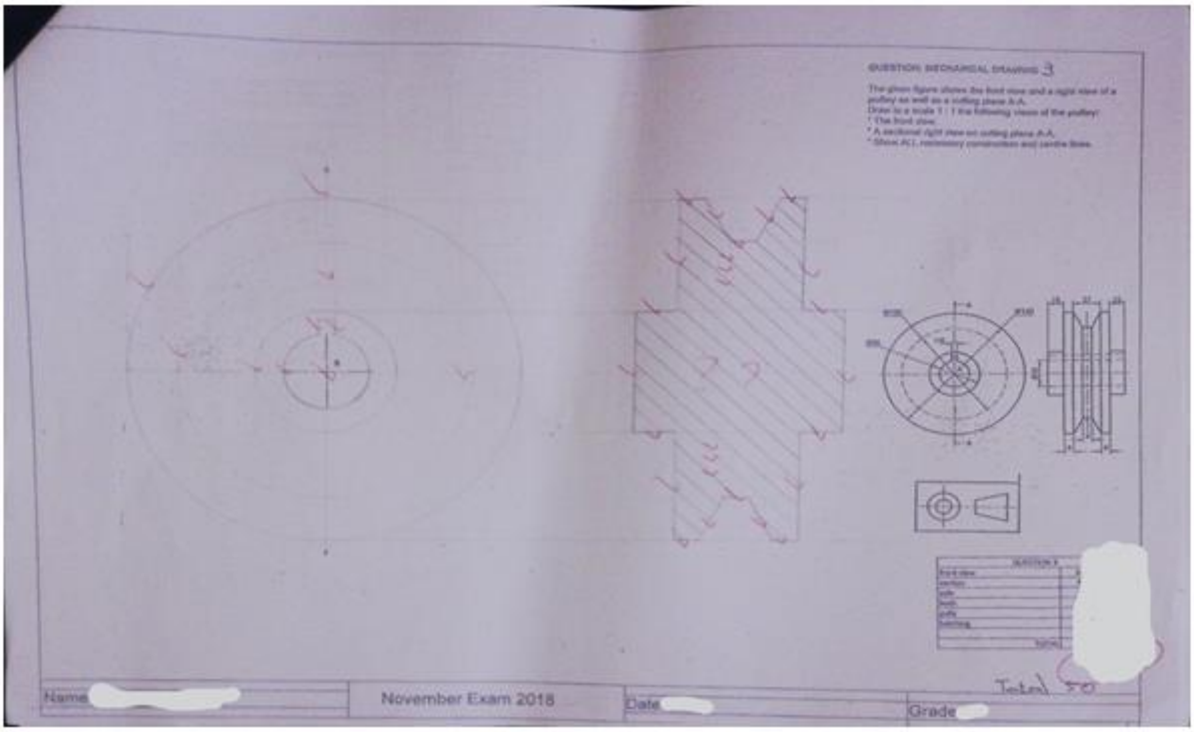


Figure 8: Student 4 daily exercise task with wrong hatching

Students' inability to comprehend a third-angle orthographic projection, visualize a three-dimensional model, and mentally imagine the location of the cutting plane and arrows designating the direction in which a section is being viewed is clearly demonstrated by this type of inaccuracy. Because hatching details are intended to help students, draughtsmen, and engineers show internal intricacies, their improper use alters the sketch's genuine appearance [24, 25]. Sectional views are described as drawings that depict a region or concealed portion of an object by removing or cutting away a portion of that object [11,12].

RQ 2: Which knowledge do preservice teachers students lack that impact how they interpret SMD?

The analysis and discussions in this section was an attempt to respond to the question above. The discussions at face value seem to be focussing on the way the teacher is facilitating her lessons. However, as the discussions draw towards the end, the researcher draws the reader to the knowledge that students struggle with, and ultimately how these struggles impact their visualisation skills for SMD.

Analysis of Narratives of classroom observations

Raising arguments on teaching orthographic projections from lesson 1

The teaching did not engage students in a manner that would make it easy for students to make sense of 3rd angle orthographic projection, sectional view, cutting plane, hatching, and dimensioning. Students should fully understand these concepts if they were to be able to draw sectional mechanical drawing. Looking closely at the narrative for lesson 1, students are struggling to make sense of the above-mentioned concepts. At this stage, it is not necessarily their fault but it how they were taught that hinder their understanding.

The teacher made assumptions about students' understanding. For example, the extract below shows how she rushed through 3rd angle orthographic projection. In explaining it, this is what she said:

She highlighted that the same procedure used when drawing 3rd angle orthographic projection for non-sectional views will be used in this section. Immediately she reminded students by drawing a rough sketch on the chalkboard showing the orientation of views drawn in 3rd angle orthographic projection.

The excerpt shows that the teacher did not ask the students what the orthographic projection of the 3rd angle is. Instead, she made a drawing herself instead of asking the students to do it. By allowing the students to do this, she would have been able to see the challenges the students had in drawing the 3rd angle orthographic projection. Since knowledge of the 3rd angle orthographic projection is required when students need to draw an SMD, it is highly unlikely that students will be able to draw an SMD. Nordin [26] points out that understanding one concept in EGD depends on understanding the other related concept. Yasin, Halim, and Ishar [26] refer to this type of development as an essential hierarchical design in EGD. Therefore, it becomes more difficult for students to learn at the next level if they do not understand the basic concepts [26]. In this case, the lesson already suggests that the students do not fully understand and know how to draw orthographic projections of the 3rd angle, since the teacher did not follow this up in lesson two.

The extract below is another example of teaching that hindered students' understanding of another EGD concept – an SMD. The teacher resorted to showing students how to draw an SMD instead of allowing students to follow instructions that will ultimately result in to an SMD. The extract goes as follows:

The teacher went on to completing the drawing that was projected on the board. The question asked the student to complete a full sectional right view, given the other two views (front and top). The teacher finished quickly and asked the students if they could see and understand what happen. Students kept quiet for some time, until one of them laughed (giggled), and said "ey sorry mam but this is just too confusing.

The extract shows that the teaching on its own compromised students' development and understanding of SMD. This way of teaching- the traditional way- is against what was suggested by Widad, Rio, and Lee [28] when they said that traditional method of teaching and approaches are not emphasising the students' visualisation skills.

Raising arguments on sectional views from lesson 2

At the end of lesson 1 students were given a task wherein they were expected to use their knowledge of 3rd angle orthographic projections to draw an SMD. From the lesson 2 narrative of classroom observation, it shows that not a single student attempted the question. Although the teacher acknowledged that this was because lesson 1 was not concluded well, she did not go back to address the problem on 3rd angle orthographic projections at the beginning of lesson 2. Meaning that the problem that students have on this concept will persist.

When asked if they at least have an idea of what is meant by sectional views, Student C responded by saying

Sectional views are the right views with hatching lines.

The teacher asked if other students have something to say and instead of answering they laughed looking at Student C. However, the teacher went on to explain what sectional view is and gave out examples. There is nothing from the narrative of classroom observation that suggest that she tried to engage students' understanding of sectional views. This suggest that students might still be having a challenge on what sectional view is.

The figure below was given to students in order to practice drawing sectional mechanical drawings. However, when lesson 2 ended not all students were done with their drawing as others still claimed that they did not understand.

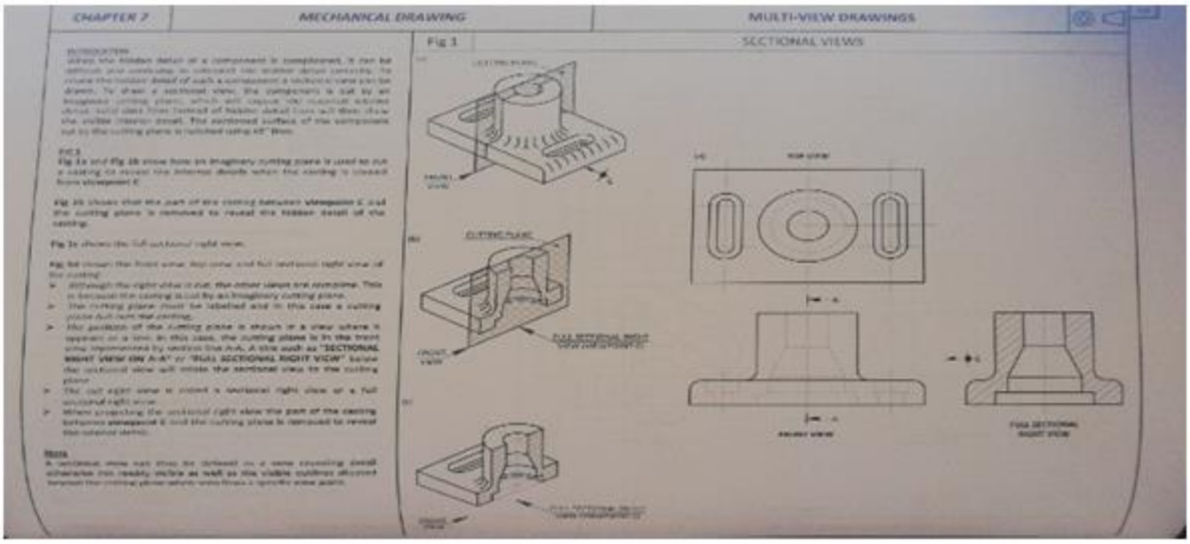


Figure 9: Lesson 2 task

This is not surprising at all given the struggles that students had on sectional views as a result of the teaching they received. Although she did mention in lesson 3 that she was satisfied with students' submissions of the previous task, nothing was mentioned on students' understanding of sectional views.

Raising arguments from lesson 3

In lesson 3 students were given a task to draw a full sectional mechanical drawing. The task was taken from the previous year question paper. In the task students were asked to draw the figure given below as front and right view, and then show a sectional view on cutting plane A-A.

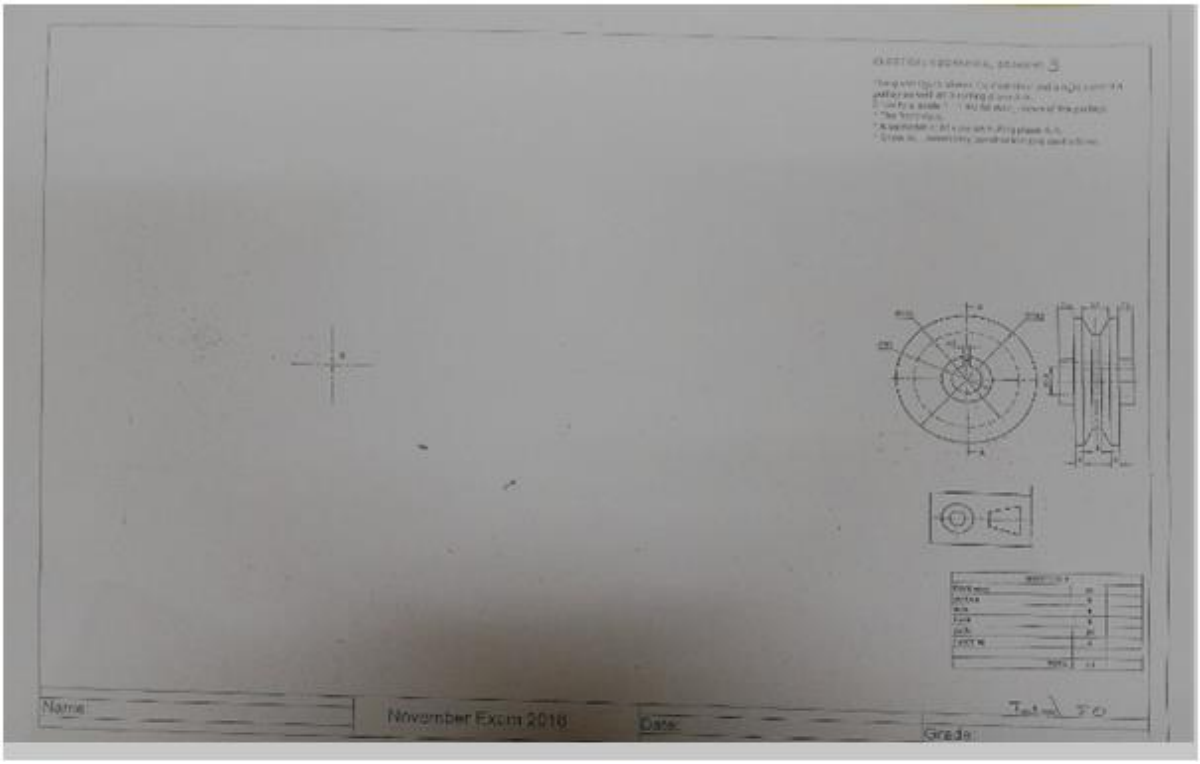


Figure 10: Lesson 3 task

As students were working on the task, she moved around to help those who were struggling. In the process she made the following observations:

• Students did not know how they should go about viewing the cutting plane as shown.

• Students did not know how to apply the given scale.

• Students did not know the views orientation (according to 3rd angle orthographic projection).

• Some did not know what the cutting plane meant, according to the way it was placed (the arrows which indicated direction).

• Leaners did not know how the cut model would appear as a pictorial view

• Students did not interpret lines correctly (more especially the hidden details).

This shows that students' struggles are piling up. But looking closely at these struggles, they emanate from their lack of understanding and interpretation of 3rd angle orthographic projections as they would be from a pictorial view, and sectional views. Consequently, their spatial visualisation would not be developed up to the level enough to be able to interpret and draw SMD.

According to Piaget's formal operational stage, students' cognition has developed enough to be able to visualise and deal with abstract concepts. Although the teaching, as evident from the narratives of classroom observation, contributed to students' struggles with visualising 3rd angle orthographic projections and sectional views, one would expect them to make sense of some of these concepts on their own given their cognitive level.

However, follow up lesson were given using videos to aid their development of spatial visualisation. These lessons were given at a time when the researcher had started analysing data through narratives of classroom observations. Instead, students' written samples of an assessment task given at the end of this lessons were collected and the analysis of those is presented in the next section.

## 8. DISCUSSION

This study discovered that preservice teachers had a challenge to activate their cognitive capabilities that would help them to see how machine parts are to be drawn when subjected to sectioning. This was mostly attributed to the lecturer's way of teaching about machine drawings. The analysis of narratives of classroom observations allowed the researcher to identify the knowledge that students lacked as they were engaged in drawing SMD. The knowledge identified are as follows:

Lacking knowledge on 3rd angle orthographic projections

Third angle orthographic projection is a required skill in drawing SMD. The analysis of narratives shows that preservice teachers students in this school lack this skill. The lack of knowledge on 3rd angle orthographic projections suggests that these students are unable to:

• Identify the top, front and side views of the object,

• Align the views in terms of their height and width, and

• Visualise 3rd angle orthographic projections in terms of isometric views.

However, a closer look at the narratives shows that this lack of knowledge might have been as a result of how the teacher facilitated her lessons. A few extracts were used in the analysis of data to show that the teacher did not actively engage students during the teaching and learning process. She resorted to demonstrations on the board instead of allowing students to following instructions and do the drawings themselves. This way of teaching is said to not emphasise students' visualisation skills [28].

Inability to draw Sectional Mechanical Drawing

The analysis of narratives of classroom observations shows that students were struggling to complete SMDs. This was further demonstrated by their written samples of the tasks they were given. The analysis of students' written samples shows that students either failed to complete the task or there were mistakes that led to an incorrect drawing of SMD. Failure to draw SMD suggest that these students might be lacking knowledge on:

- 3rd angle orthographic projections,
- Visualisation of how 3D views appear when given 2D views,
- Visualisation of how the cut model would appear through the given cutting plane.

Again, the narratives suggest that these struggles and lack of knowledge by the students might have been influenced by how they were taught. It is clear from the narratives that the teacher did not, even when she was aware of students' struggles, revisit the concepts that students were struggling with. Instead, she continued to teach and add more skills over and above the one's students were struggling with. As Nordin [25] suggested, understanding of one concept in EGD depends on the understanding of the other concept. It would then make sense to see students struggling with drawing SMD. It is, however, worrying to note from the narratives that this teacher did not fulfil one of her roles of being a reflective practitioner as she continued to teach the same way.

Students' processes of drawing Sectional Mechanical Drawing

One of the research questions was around the processes that preservice teachers students go through as they draw SMD. However, the analysis of narratives and students' written samples suggests that students lacked knowledge and skills that are necessary for drawing of SMD. This lack of knowledge and skills, regardless of how they manifest themselves, hindered the processes that would have allowed them to successfully complete SMD. This was evident when students could not finish their drawings, made wrong hatching of the views, and presented wrong views orientations. As such, the researcher could not identify clear processes that preservice teachers students followed as they completed SMD tasks.

## 9. CONCLUSION OF THE STUDY

The main question of the study was around how students interpret sectional mechanical drawings. In addressing these questions, the researcher came up with two questions that were used to guide the study. Narratives of classroom observations and students' written samples were used to collect data that assisted in responding to these questions. The analysis of the collected data shows that preservice teachers students lacked the following skills and knowledge:

- Identify the top, front and side views of the object,
- Align the views in terms of their height and width,
- Visualise 3rd angle orthographic projections in terms of isometric views,
- 3rd angle orthographic projections,
- Visualisation of how 3D views appear when given 2D views,
- Visualisation of how the cut model would appear through the given cutting plane.

The lack of knowledge and skills that preservice teachers students exhibited shows that they are unable to interpret sectional mechanical drawing. Although preservice teachers students, according to Piaget's formal operational stage, are expected to be able to visualise and work with abstracts concepts, the study shows that this is not always the case. However, the analysis also shows that the teaching hindered these students to construction of knowledge and skills necessary for sectional mechanical drawing.

## 10. RECOMMENDATIONS

Given the results of this study, the researcher recommends that more studies be done on the teaching methods that will improve high school students' skills of SMD. Most importantly, they should focus on designing materials that will improve South African high school students' spatial abilities. More studies should be done on EGD teachers' level of pedagogical content knowledge and how guided discovery method can be used to aid students with metacognitive skills.

Acknowledgement

I would like to acknowledge Isabel Sathekge for starting such a rare insight into mechanical drawings. I appreciate your school of thought which has given birth to this scholarly contribution.

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