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Engineering Graphics and Design Teachers' Understanding and Teaching of Assembly Drawing

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ABSTRACT

This study explored the relationship between teachers' content knowledge and their pedagogical skills, and reports on that relationship in the teaching of Assembly Drawing (AD) in a South African context. Given that Engineering Graphics Design (EGD) learners perform poorly in the AD section of the matriculation examination, we need to understand the extent to which this results from the quality of teaching. A case study approach was used to collect qualitative data from 25 purposively selected EGD teachers in the UThukela district of KwaZulu-Natal (KZN). Data was collected via an open-ended questionnaire, focus group interviews, lesson plans, observations, and post observation interviews. Our findings elucidate the relational interplay between teachers' understanding of AD and their teaching of AD. The majority of teachers failed to develop visual, spatial skills in learners. Our findings have implications for continuous teacher professional development.

Keywords: assembly drawing, engineering graphics design, teaching, teacher, understanding

INTRODUCTION

In *Engineering Graphics Design (EGD)* for the National Senior Certificate (NSC) examination, learners write two papers, paper one and paper two. In paper two, the section of mechanical assembly, which is weighted the highest, includes Assembly Drawing (AD).

Van Leeuwenn and du Plooy (2011) defined AD as the combination of any two or more individual components, with all those multiple-component devices making up the individually designed parts that fit together to form a functional unit. Narayana et al., (2006) elaborate that AD entails spatial visualisation ability, visualisation skills and drawing skills, because it entails mental manipulation of objects and their parts in 2D and 3D space. Agreeing with the above ideas, Kabouridis (2010) asserts that the fundamental skills required for all

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State of the literature

- Assembly drawing entails the use of spatial visualisation ability, visualisation skills and drawing skills to be able to combination of any two or more individual components, together to form a functional unit.
- Learner perform poorly in assembly drawing in tests and examinations.
- No clear link has been established between teachers' understanding of AD and their teaching of AD.

Contribution of this paper to the literature

- This study illuminates the impact of teachers' understanding of AD on their teaching of AD.
- Teachers understanding of AD contributes to new ways of defining AD.
- Female EDG teachers engage learners in hands on, project based learning and have learner centred classroom.

aspects of mechanical drawing are the ability to perceive and visualise parts, and to interpret different views of an object that is represented in the drawing. In an AD, learners are given representations of up to seven components, which must then be drawn correctly, assembled in third angle projection, reflecting the front, top and side views. In addition, when drawing the assembly, learners are also expected to apply the relevant Codes of Practice for Engineering Drawing as given in the South African of Bureau Standards (SABS) (1993) and the South African National Standards (SANS) (2011) (Sotsaka, 2015). These drawings are the means of communication in the engineering field, and must therefore be clear, complete and accurate, to prevent expensive or dangerous mistakes for manufacturers, producers or customers.

The National Senior Certificate EGD examiners and moderators report (DBE, 2012-2014) reflects that EGD learners encounter difficulties in attempting to answer questions pertaining to AD and highlights areas of learners' weakness and misconceptions related to AD. For example, the 2012 EGD NSC report notes: "Some candidates have difficulty interpreting, and or understanding the projection symbol for third angle and confusion between first and third angle orthographic projection understanding of machining symbols, learners should be exposed to the SANS code of practice 10111" (DBE, 2012, 4). Even though the examiners' and moderators' report are sent to all schools for the attention of the principal and EGD teacher/s, the identified areas of weakness and learner misconceptions persist.

It is widely recognized that the successful implementation of any curriculum is dependent on teachers having a solidly established personal construct (Tholo, Monobe, & Lumadi 2011). This means that EGD teachers need to be *au fait* with the EGD pedagogical content knowledge (PCK) and their context to engage effectively with the engineering sciences, design process and the mathematical and analytical reasoning associated with AD.

Shulman (1987) envisages PCK as the knowledge that teachers use in transforming content knowledge into forms that make or promote learning possibilities. It includes

knowledge about how learners learn, and the ability to predict common misconceptions or preconceptions. Simply put, this means that PCK is a fusion of both content knowledge (CK, knowing what to teach) and pedagogical knowledge (PK, how to teach). A teachers' CK can be highly specialised (SCK). According to Ball, Thames and Phelps (2008), specialised content knowledge (SCK) refers to the information that the teacher has that is specifically related to the subject being taught and it includes the teacher's ability to successfully organise this content into an appropriate teaching sequence. They assert that "teachers need to know the material they teach; they must recognize when their learners give wrong answers or when the textbook gives an inaccurate definition" (Ball et al., 2008: 399). SCK refers to the knowledge and skills that all EGD teachers must construct and have to be able to teach EGD effectively in their classrooms. SCK is a significant aspect of teaching since it affects planning, lesson preparation, task setting, explaining, giving feedback, and assessment. When teachers' SCK of the subject that they teach is rich, integrated and accessible, they tend to teach the subject more dynamically by using more varied ways while encouraging and responding more fully to learners' questions and comments (Brophy, 1991). Ma (1999) posits that a math teacher's capacity for selecting an appropriate way to convey ideas ultimately depends on the quality of their SCK.

From the preceding points, it stands to reason that for learners to engage with AD, they need to think and reason visually. In other words, learners must be able to study the given views of an object and form a mental image of it. Bearing in mind what AD entails, Van Leeuwenn and du Plooy (2011) assert that the teaching of AD should include and emphasise such skills, as many learners have difficulty in understanding or comprehending the graphic representation of three-dimensional objects. According to Perez and Serrano (2012) and Okolie (2014), the high failure rate of school learners in their exit examinations in EGD is associated with traditional teaching methods, which do not sufficiently develop learners' spatial ability. In particular, there are missing connections between the drawing and the design of the product itself, as well as the difficulty of understanding the mechanisms related to the representation of 3D objects in 2D (Kabouridis, 2010). For learners to develop the aforementioned skills, teachers of EGD must expose learners to hands-on experience of drafting techniques, drafting standards and conventions. The implication for teaching is that these skills cannot be developed "by rote learning or memorization" (Branoff, Hartman & Wiebe, 2003:9). In addition, learners should be exposed to emerging trends in technical graphics, developments in industrial technologies and advancements in computer technology. This means that EGD learners ought to have been trained in developing spatially related problem-solving abilities. From the above studies, it can be gathered that the SCK teachers acquire for AD, impacts how they engage with and enact it.

This article explores the relationship between teachers' understanding of AD and their teaching of AD. We argue that when EGD teachers do not understand or have a shallow understanding of AD, they are not likely to teach AD in ways that will help learners understand it.

CONCEPTUAL FRAMEWORK

Borko and Putnam, (1996), maintain that in order to be an effective teacher, a teacher needs both strong content knowledge and a thorough understanding of pedagogy. In agreement, Ball et al. (2008), assert that instructional quality depends heavily on the content knowledge the teacher holds. Resonating with the above scholars Sawchuk, (2012) hints of the interplay between of teachers' content knowledge and instructional strategies on learners learning. From the aforementioned points it can be gleaned that teacher SCK impacts instructional strategies they use.

In order to explore the relationship between teachers' understanding and teaching of AD, our conceptual framework is an amalgam of Bloom's revised taxonomy and certain components of Shulman's (1986) PCK model. The PCK components used were SCK, knowledge of the curriculum, knowledge of instructional strategies and knowledge of learners' understanding of AD. Teachers' understanding of AD is a part of their SCK. As a way to represent teachers' understanding of AD (their SCK) and to ascertain the level of understanding of AD used to facilitate learning, we draw on the cognitive dimension of the revised Bloom's taxonomy (Anderson & Krathwohl, 2001) as reflected in **Table 1**. The cognitive level of teachers' understanding of AD can be established by juxtaposing their understanding alongside Bloom's levels of cognitive dimension with their accompanying cognitive processes shown in **Table 1**. Teachers' understanding of AD (SCK) needs to be aligned with curriculum requirements, instructional strategies and learners' understanding (misconceptions).

Table 1. Levels of the cognitive dimension and examples of the cognitive processes involved

Dimension	Example of cognitive process
L1: Remember	define, duplicate, list, memorize, recall, copy, repeat, reproduce state
L2: Understand	classify, describe, discuss, explain, identify, locate, recognize, report, select, translate, differentiate, plan
L3: Apply	choose, demonstrate, dramatize, employ, illustrate, interpret, operate, schedule, sketch, solve, calculate
L4: Analyse	appraise, compare, contrast, criticize, discriminate, distinguish, examine, experiment, question, test
L5: Evaluate	appraise, argue, defend, judge, select, support, value, evaluate
L6: Create	assemble, construct, create, design, develop, formulate

(Source: Anderson & Krathwohl, 2001)

A teacher's teaching of AD is linked to knowledge of the EGD curriculum (knowledge of goals of EGD, curricula material, links between the purpose of teaching AD and teaching practice); instructional strategies (understanding and use of teaching strategies for AD,

knowledge of specific task based instructions) and knowledge of learners' understanding of AD (misconceptions / preconceptions that will talk back to instructional strategies deployed). Resonance/alignment amongst the above-mentioned three components of PCK, together with the teacher's SCK, is of pedagogical significance as it enables teachers to decide on effective instructional strategies for planning of lessons and assessments. To be able to illuminate the link between teachers' understanding of AD (SCK) and their teaching of AD in this study, we juxtaposed teachers' understanding (SCK) with the three components of our conceptual framework as reflected in **Figure 1**, reflected below. This will illustrate how teachers' understanding of AD impacts their lesson planning and their eventual teaching of AD.

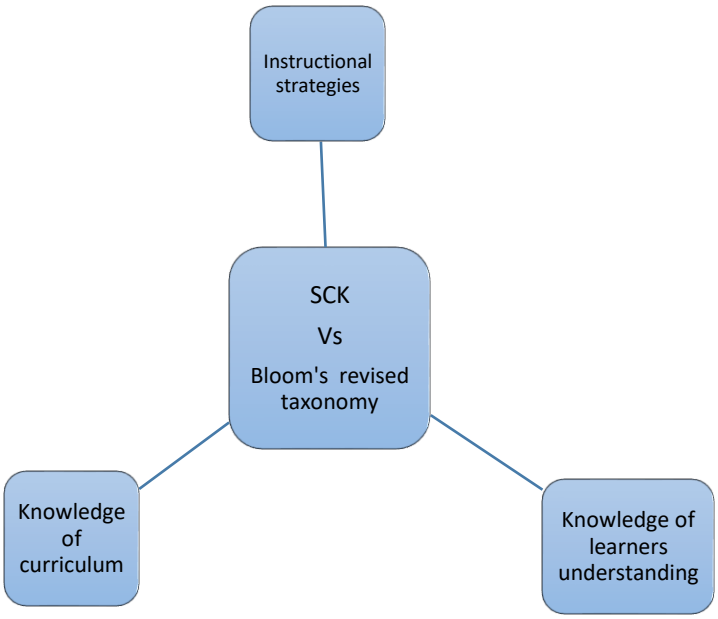

Figure 1. Elements of our conceptual framework

According to Van Driel, et al. (1998), when teachers' SCK is aligned with the three elements represented in **Figure 1**, teachers have several representations of a topic at their disposal and are better able to recognise learning difficulties.

METHODOLOGY

Design

This interpretative study used a qualitative research design to engage with 25 purposively selected EGD teachers from schools located in the UThukela district. The criteria for their selection was that they had to be teaching grade 11 and 12 EGD.

Data collection

Data was generated in four stages via the use of questionnaires, focus group interviews, lesson plans, classroom observations, and post observation interviews. Originally, the plan was to get teachers to engage in a pen and paper task-based activity as an entry point into the study, in order to establish their understanding of AD. Objections by participants and a teacher union to the use of a task-based activity resulted in an adjustment to our data production strategy to include questionnaires. The union explained that the task-based activity will be demeaning to teachers who do not excel in the task and this may impact their professional identity. Within the South African context, teachers who mark the matriculation examinations are required to answer the question paper they will be marking and their marks are available and displayed at the marking centre.

Stage one of data production involved an open-ended questionnaire that targeted teachers' biographical data and information on their SCK and PCK on AD. For SCK, we focused on their understanding of AD, what AD entails and aspects of the AD that were emphasised during teaching. For PCK, we asked questions pertaining to planning for teaching AD, strategies used to teach and assess AD, how they taught AD, what guided their choice of teaching strategy, knowledge of the goals of teaching EGD and AD, purpose of teaching AD, and awareness of learners' misconception/preconceptions about AD. An open-ended questionnaire was used as it allowed participants the opportunity to answer the questions privately, with information written down in their own words (Mcmillan & Schumacher, 2010).

Following the questionnaire completion, respondents were invited to participate in a focus group interview in order to probe and provide further information about the following: teachers' understanding of AD, methods used to teach AD, reasons for using the methods mentioned, and kinds of activities given to learners during AD. All 25 respondents proceeded to stage two of data collection. The focus group interviews were video recorded, transcribed and sent to EGD teachers for member checking.

In stage three of data production, lesson plans pertaining to AD were collected from 25 teachers. They were analysed as per our conceptual framework in order to establish the instructional strategy used, how curricula goals are aligned with the teaching strategy /content to be developed, how content is assessed, learners' conceptual development targeted, misconceptions/preconceptions identified, and knowledge of the curriculum goals.

During stage four of data collection, five teachers were purposively selected to have their lessons observed and to participate in a post-observation interview. The criteria used for their selection were their level of understanding of AD as per Bloom's revised taxonomy cognitive levels. Since most teachers' level of understanding of AD rested on level 1 (see **Table 3**), three teachers were selected from this level. One teacher whose level of understanding straddled levels 2 and 3 was selected and one teacher whose level of understanding was across levels 3 and 4 was selected. These lessons were video recorded to capture non-verbal data that audio recordings or the observer might miss. Using video recordings allows for repeated

viewing and checking, reinterpreting and analysis (Mcmillan & Schumacher, 2010). The video recordings were transcribed and sent to participants for member checking. The teachers' master portfolios of classroom work (lesson plans, and both formal and informal assessments) also constituted the data set giving insight into the planning logic of the teachers' intended pedagogy and assessment practices.

Data analysis

Data collected was inductively analysed. Content analysis was used for the questionnaires, lesson plans, transcripts from the lesson observations and interviews. The data was read several times before similar /meaningful words and phrases were noted and then grouped into categories. The verbs teachers used in their understanding of AD were used to establish their level of understanding, as per the revised Bloom's taxonomy. Once teachers' level of understanding of AD was established, the levels were juxtaposed with objectives from their lessons and their teaching/assessment activities for AD, as stated in the lesson plans. Lesson objectives of these plans were identified in two ways: as they were stated explicitly in the plans by the teachers themselves, or as they were inferred by us from the teaching/ assessment activities described in the plans. The teaching /assessment activities were examined as they illuminated insights about teacher knowledge of the curriculum and knowledge of learners' understanding of AD. Juxtaposing the teachers' understanding (SCK) against the three elements of our conceptual framework enabled us to make visible the interplay between teachers' understanding and teaching of AD. As part of the analysis process, data from stages 1-4 was (re)assembled and juxtaposed to trace the interplay between EGD teachers' understanding and teaching of AD.

Ethics

Permission to conduct this study was obtained from the relevant gatekeepers, the university's ethics committee, KwaZulu-Natal (KZN) provincial department of basic education, principals and EGD teachers. All respondents were assured of anonymity and confidentiality.

RESULTS AND DISCUSSION

In this section, we examine teachers' understanding and teaching of AD. **Table 2** below reflects data from the biographical section of the questionnaire. The biographical data serves as a context for EGD teachers' understanding and teaching of AD. The biographical data was used in our analysis to gain a deeper insight into teachers' understanding and enactment of AD.

Table 2. EGD teachers' qualification, professional activity and attendance of workshops

Category	Number of teachers
Qualification:	
Technology education qualification	**18**
EGD qualification	**7**
Professional activity:	
No engagement in professional activities	**15**
Marking of NSC EGD papers	**10**
Cluster monitor for Continuous Assessment (CASS)	**1**
Department of Education (DoE) training for curriculum implementation:	
Attended	**15**
Did not attend	**10**

Data from the questionnaire, focus group interview, lesson plans, classroom observations and post-observation interviews pertaining to teachers' understanding and teaching of AD are reflected in **Table 3** below.

Table 3 brings to the fore the intrinsically intertwined relationship between EGD teachers' understanding of AD, their ability to engage and access SCK pertaining to AD, and their teaching of AD. **Table 3** elucidates, first**,** that EGD teachers have level 3 understanding of AD, second, that their understanding and teaching of AD, as identified from the verbs in their lesson plan objectives, extend from level 1 to level 4 of the cognitive dimension of the revised Bloom's taxonomy and third, that they embraced three methods to teach AD (Chalk and talk, lecture/discussion and project based hands on learning). It is conspicuous from **Table 2** that there is a type of equivalence between teachers' understanding and their teaching of AD. In the section below we discus each understanding of AD and its related teaching of AD.

Table 3. Teachers' levels of understanding of AD and their related teaching of AD

Conceptual understanding of AD as per questionnaire & focus group discussion	**Number of teachers**	**Level of understanding as per revised Bloom's taxonomy**	**Objectives of lesson plan**	**Method of teaching of AD as per focus group interview & lesson plan**
Putting components together:	20	L1: Remember: rote learning, recognition	**Copy** the assembled drawing from the board/chart, **Trace** the different view of the assembled drawings from the diagrams provided, **Labe**l the drawing	Chalk and talk: Teachers centred- "information dump" approach that involves presenting specific information, allowing little opportunity for student interaction. The expectation is that students would have mastered the information by the time of the exam
Putting mechanical parts, to facilitate an understanding of how they all function	3	L2 & 3: Understand & apply	**Interpret** given drawing and assemble different parts of the given drawing, **Differentiate** between the different views of the assembled machine **Plan** and assemble all different machine components in correct scale**,** **Interpret** the exploded views of all parts and inter link them to form one operating machine, **Calculate** all dimensions where required.	Lecture discussion/ demonstrations: the students are able to see first-hand how the construct or phenomena presents itself in the real world

Table 3. Teachers' levels of understanding of AD and their related teaching of AD *(continued)*

Conceptual understanding of AD as per questionnaire & focus group discussion	Number of teachers	Level of understanding as per revised Bloom's taxonomy	Objectives of lesson plan	Method of teaching of AD as per focus group interview & lesson plan
Involves visual reasoning, thinking of graphical images of mechanical components manipulating them and then putting it onto a diagram according to specifications	2	L3&4: Apply & analyse	**Analyse** the assemble drawing and answer all questions based on it, **Organise** assemblies and draw detailed multi-view drawings Include title, notes and symbols of projection **Determine** the line of intersection when two simple objects, are joined as per given scale. **Produce** a sectioned isometric drawing from given information relative to machine components. **Illustrate** the parts that should not be sectioned	Project based hands on learning

Putting components together: chalk and talk

Table 3 reflects that the majority of the EGD teachers (20) have a very basic or rudimentary understanding of AD that corresponds with level one (remember) of the revised Bloom's taxonomy. These teachers envisage AD as the putting together of components as reflected below:

> *"It is just the putting together of components –you mustn't complicate this or you have to find a way to teach it – this is not a section I like"* T1 (Focus group interview)

> *"AD is putting things together to make a structure and you have to draw it"* (T2-focus group interview)

> *"There are no models, so I have to draw on the board and learners copy and practice drawing, haibo, ….this is not the only subject, I'm teaching two other subjects, I'm*

trying to teach it, the training for CAPS is so bad, manje (now) the trainer needs training too, .. I don't get time to teach or explain, I only draw, there is no thinking, abafundi (learners) they just follow, only coping drawings, hey you saw they don't keep quiet when I'm drawing, they are so rude" (T4, post observation interview)

The excerpts above confirm that these teachers have a very basic conceptual understanding of AD (*putting things together*) and are unable to access deep SCK about AD. They do not envisage AD as involving mental manipulation of objects and their parts in 2D and 3D space (Narayana et al., 2006) and they see it as involving "*no thinking*". Their rudimentary understanding of AD formed the foundation for their methods of teaching AD (*practice drawing, copy*). Our results indicate that teachers' understanding of AD is not isolated or confined to themselves but it penetrates and proliferates their teaching of AD and thereby impacts learners' learning as is visible in the lesson objectives below:

"Learners should be able to copy the assembled drawing from the board" (T6 objective of lesson plan)

"Learners should be able to list and draw all parts as per given diagram" (T4, objective lesson plan)

The action verbs used in the lesson objectives (*draw, copy, list*) confirm these teachers' lack of depth of SCK pertaining to AD required to scaffold learners' thinking needed for the matric examination. Additionally, these verbs reveal how these teachers' understanding of AD (*putting together things*) influences their decisions about content-specific instruction (*trace, draw, label, copy, list)*. The above finding resonates with that of Ma (1999) who asserts that SCK influences a teacher's capacity for selecting ways to convey ideas to learners.

The above excerpts illustrate that teachers understanding of AD (their SCK) is perpetuated into their teaching of AD (PCK). Hence they foreground and favour rote learning and simple recall during their teaching of AD in their classroom. Data from classroom observation of three purposively selected teachers who display the chalk and talk practice reveals that these teachers painstakingly draw diagrams on the board or make charts to teach AD to their learners. A rigid teacher dominated approach to teaching prevails leaving no room for learner engagement or creativity. Data from the post observation interview illuminates that:

"I need auto cad to help, I'm not trained in EGD... siza mina (help me) I do what I think is right the training for CAPS is so bad, hey its bad, it, they don't show us how to teach AD, bakuluma, (they talk a lot) … we need hands-on training not talk-talk-talk .. on what we must do in class, I draw and learner copy or they trace from my drawings on worksheets, how can I explain? I don't know, I'm not a specialist? I can't do what they want for AD" (T8, post observation interview)

What comes to the fore via these teachers' understanding and teaching of AD is that there is very little room for learner engagement with the "content" during their teaching of AD (*They copy, I can't explain*). The planned lesson does not occupy the learner all the time hence classroom management is poor (*they don't keep quiet … learners are so rude)*. The pace of the lesson and learning is hindered by the teachers' practice of drawing on the chalkboard (*no time to explain*).

An examination of the teacher's master portfolio shows that the EGD CAPS curriculum is not used to plan their teaching and learning, hence the limited transfer of curriculum content to their lessons. The aims of the lessons are not aligned to the goals of the curriculum in terms of orthographic projection, sectioning, use of drafting conventions, dimensioning, pictorial views and sketching in their lessons. Furthermore, there were no rubrics to guide their assessment of learners' work or to provide feedback to learners on their replications of drawings**,** neither were there diagnostic analyses of learners' errors or misconceptions (*how can ..I'm not a specialist.. can't do what they want for AD*). These teachers**'** level of understanding of AD restricts them to the level of recall.

The interplay between these respondents' understanding of AD (their SCK) (*put parts together, put components together*), knowledge of the curriculum, knowledge of how learners come to know (*there is no thinking here, just copying*), teaching practice (PCK) and contextual conditions (*no models, teaching other subjects, poor training, not trained)* get elucidated via the above excerpts. These teachers' teaching of AD is not sequenced or graded into tasks for learners (*they just copy… trace from my worksheets*), learning and assessment. For example, they do not use their drawings to instruct the sequence, orientation and positions of components in the assembly task. They are not specific about the graphical style they used, in other words, are they orthographic or isometric drawings. Their "teaching strategy" is teacher centered (*learners follow … copy the diagram*) and they do not espouse the learner-centered philosophy of the NCS CAPS curriculum. These teachers' practice begs the question: How cognitively stimulating is copying without deep understanding and exposure to the discourse of AD?

Putting mechanical parts to facilitate understanding: Lecture method and teacher demonstrations

Table 3 reveals that three EGD teachers recognise AD as a process of putting together mechanical components in order to understand how they function together, as is visible in the excerpt below:

> *"It's putting together mechanical component, moving them about seeing that they function optimally and then drawing it"* (T13, focus group interview)

The notion of specific mechanical components and manipulation of parts to ensure optimal functioning embraces critical thinking (*seeing that it functions optimally*) and alludes to these three teachers having a deeper understanding of AD (SCK). The action verbs represented in the Objective column in **Table 2** (*interpret, differentiate, plan, calculate*) clarify that

these three teachers' understanding of AD, which straddles Levels 2 and 3 of the revised Bloom's taxonomy, is transmitted to their teaching of AD.

Data from an examination of the teacher's master portfolio, during the classroom observation, demonstrated that this particular EGD teacher used the EGD CAPS curriculum to plan his teaching and learning, hence a transfer of curriculum content to context. The aims of the lessons were aligned to the goals of the curriculum and the pace of the lesson and learning were on par with the KZN Department of Basic Education (DBE) work schedule provided to teachers. Furthermore, an examination of the learners' assessment tasks reveals that they were provided with multiple opportunities to engage with NSC exam type questions. The atmosphere in the classroom was relaxed and learners asked questions.

Data from the post observation interview exposes the rationale for this teacher's preferred enactment in terms of AD.

> *"I use teacher demonstration due to time constrains and the scarcity of models to let learners engage in hands-on activities, but in this way learners can see how to put these machine parts and understand how they work, why they work like that and then they draw, I expose them to exam type questions, it is expected of us, I try my best, with all the challenges we encounter in our schools, discipline issues, poor attendance, I enjoy teaching EGD, In an ideal context my teaching will be different – more hands on."* (T15 - interview)

The above excerpts indicate the interaction between these teachers' understanding of AD (*how to put these machine parts and understand how they work, then they draw),* knowledge of the curriculum (*I expose them …is expected of us*), teaching practice (*teacher demonstration, lecture method*) and contextual conditions (*discipline issues, poor attendance*) that drive and sculpt these teachers' teaching practice of AD.

Data from the biographical section of our questionnaire reveals that teachers who have a foundational background in EGD (qualification in EGD) have a cognitive platform for their understanding, engagement and teaching of EGD. Additionally, these teachers were engaged in professional activities pertaining to EGD and they teach at schools where they receive support from within the school structure for their professional development and practice.

Visual reasoning, mental manipulation, putting components onto a diagram according to specifications: Demonstrations, hands-on activities, project based learning

Table 3 reflects that two respondents' understanding of AD straddles Levels 3 and 4 of the revised Bloom's taxonomy, as is confirmed by the excerpt below:

> *"It is not as easy or straightforward as they make it, it's a complex process, it does involve assembling or sectioning of mechanical components, visualizing 3D parts from 2D drawings, visually manipulating them as per specification and*

> *construction the diagram, you must also know your lines and codes"* (T16, focus group interview)

These teachers' understanding of AD exemplifies the skills required to engage in AD, namely, visual reasoning, spatial perception, mentally manipulating objects into different projections, drawing**,** and critical thinking. It is evident that these EGD teachers' understanding of AD is shaped by their learning style (*it's a complex process)* and their SCK (*sectioning of components, visualizing 3D parts from 2D drawings, visually manipulating them as per specification and construction the diagram*) and affects how s/he engages with the subject material during the enactment of AD (PCK).

An examination of this teacher's master portfolio showed that this EGD teacher's teaching and learning outcomes were aligned with those of the CAPS EGD curriculum. The aims of the lessons were aligned to the goals of the curriculum – the teacher foregrounded orthographic projection, sectioning, use of drafting conventions, dimensioning, pictorial views, and sketching in her lessons. Also ample evidence of rigour was visible in the assessment tasks given to learners. Learners were provided with multiple chances to acquaint themselves with the different skills required to excel in AD via informal assessments. These assessment tasks comprised low, intermediate and higher order questions to cater for the diverse cognitive levels of learners. Learners were also given two formal tests comprising past year NSC exam questions on AD. Detailed memos were also provided to learners to help them identify their areas of weakness and scaffold their learning. The atmosphere in the classroom was relaxed and learners worked in groups and asked freely for feedback on their projects. The teacher actively encouraged learners to ask questions while they engaged in hands-on activities. This EGD teacher facilitated learning.

Data from the post observation interview reveals that this particular EGD teacher embraces a learner-centered approach in her teaching of AD.

> *"Learners have great difficulty in visualizing objects in 3D. In the absence of this skill it is hard to draw different views of an object. Learners are expected to do this in the exams, I demonstrate these views by sectioning models, get learner to assemble parts in group, then draw the various views, I give them the past year exams questions, they know what is required in AD, they must be able to get all the taken for granted marks in the section, I give detailed feedback on their drawings so they know what they did wrong."* (T7, post observation interview)

The synchronicity between this particular EGD teacher's understanding of AD, knowledge of the curriculum, personal knowledge, ontological commitment, assessment practice, awareness of difficulties learners encounter, and her teaching of AD is elucidated via the above excerpt.

This particular EGD teacher studied EGD at school and pursued a qualification in EGD. Additionally, she is actively involved in professional activities such as marking NSC-EGD

examination scripts and monitoring EGD teachers' CASS portfolios, which all affect her awareness of the EGD curriculum content (SCK), its philosophy, teaching and learning requirements, and assessment criteria (PCK).

CONCLUSION

Our findings exemplify the intertwined relationship between EGD teachers' understanding and teaching of AD. EGD teachers (20 respondents) who have a rudimentary understanding of AD that lies on **L**evel 1 (remember) of the revised Bloom's taxonomy, embraced rote learning and a chalk and talk strategy during their teaching. These teachers' superficial understanding of AD affected their capacity to make content accessible to learners to promote understanding and to plan their lessons and their assessment strategies. EGD teachers (3 respondents) who display a deep understanding of AD that lies across Levels 2 and 3 of the revised Bloom's taxonomy, embrace learning by reasoning, a lecture method and demonstrations in their teaching of AD. EGD teachers (2 respondents) who have the deepest or advanced understanding of AD that lies across Levels 3 and 4 of the revised Bloom's taxonomy, embrace critical thinking, demonstrations, hands-on activities and project based learning in their teaching of AD.

From the foregoing, it stands to reason that deep understanding of AD affects the teaching of AD, including the formulation and design of assessment and teaching strategies used to teach AD. Our findings support our argument that a teacher's SCK affects the quality of his/her teaching. Our findings resonate with those of Alonzo (2002) who demonstrates that in mathematics, teachers who understood multiple representations of mathematics concepts were able to use those representations in their teaching practice to promote learner engagement. This means that teachers with deeper SCK were more likely than those with weaker knowledge to engage learners in meaningful learning through their classroom activities and teaching strategies (Alonzo 2002). Additionally, our findings illustrate the impact that the school ecology (contextual factors) and the professional activities that teachers engage in, have on their PCK. The findings of this study have implications for: EGD subject advisors, the continuous professional development of EGD teachers, the current models used to workshop EGD teachers during curriculum reform**,** and the training of pre-service EGD teachers.

REFERENCES

Alonzo, A. C. (2002). Evaluation of a model for supporting the development of elementary school teachers' science content knowledge. *Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science*.

Anderson, L., & Krathwohl, D. A. (2001). *Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Longman.

Ball, D.L., Thames, M.H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5): 1-55.

Borko, H., & Putnam, R. (1996). Learning to teach. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 673-708). New York: Simon & Schuster Macmillan.

Branoff, T. J., Hartman, N. W., & Wiebe, E. N. (2003). Constraint-based, three dimensional solid modeling in an introductory engineering graphics course: Reexamining the curriculum. *Engineering Design Graphics Journal*, *66*(1): 5-10.

Brophy, J. (1991). *Advances in research on teaching: Teachers' knowledge of subject matter as it relates to their teaching practice* (Vol. 2). Greenwich, CT: JAI Press.

Department of Basic Education. (2011). *Engineering graphics and design. Curriculum and assessment policy grade 10 – 12*. Pretoria: Government printers.

Department of Basic Education. (2012). National Senior Certificate Engineering Graphics and Design Examiners report. Pretoria: Department of Education

Kabouridis, G. (2010). *An innovation approach to face the first-year mechanical engineering students' conceptual difficulties in engineering design*. Proceedings of 1st WIETE Annual Conference on Engineering and Technology Education Pattaya, Thailand, 22-25 February 2010

Ma, L. (1999). *Knowing and Teaching Elementary Mathematics – Teachers' Understanding of Fundamental Mathematics in China and the United States*, New Jersey, US: Lawrence Erlbaum Associates, Inc.

Narayana, K. L., Kannarah, P., Reddy, K. & Venkata. (2006). *Assembly drawing*. New Age International: Pretoria.

Okolie, U. C. (2014). Management of woodwork workshop in Nigerian tertiary institutions. *Malaysian Online Journal of Educational Management 2*(1): 20-36.

Perez Carrion, T. & Serrano, M. (2012). Ejercicios para el desarrolo de la perception especial. Editorial Club Universitario: Espania.

Sawchuk, S. (2012). Duncan has harsh words for teacher colleges. Retrieved on 20 July 2015 from: http://blogs.edweek.org/edweek/teacherbeat/10/duncan_has_harsh_words_for _tea.html.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1): 1-22.

South African Bureau of Standards. (1993). South African Standard Code of Practice. Engineering Drawing SABS 0111-1.

South African National Standards. (2011). South African National Standards Code of practice for engineering drawing SANS 10111.

Sotsaka, D.S (2015). An exploration of the interface between Grade 11 Engineering Graphics and Design Teachers' understanding of Assembly Drawing and their practice: A case study of the uThukela District, KwaZulu-Natal. Unpublished master's thesis. University of Kwa Zulu Natal.

Tholo, J. A. T., Monobe, R. J., & Lumadi, M. W. (2011). What do boys and girls think about Technology? *US-China Education Review*, USA. 8(12): 5-11

Van Driel, J.H., Verloop, N., Vos, W. de. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, *35*(6): 673–695.

Van Leeuwen, J. & du Plooy, D. (2011). Engineering Graphics and Design Grade 10-12 Textbook. All Copy Publishers, Sanlamhof.