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Practical Work Activities as a Method of Assessing Learning in Chemistry Teaching

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ABSTRACT
Practical work activities have been used for many purposes in science teaching. However, its use for assessment purposes has been limited. This study highlights the role of practical work activities in assessment. Practical work activities present various advantages as an assessment tool. Practical work activities allow the assessor access to a variety of knowledge types into a student's knowledge base. That is, with practical work activities the student's knowledge and skills may be assessed simultaneously. The study uses qualitative methods to ensure a broader and deeper understanding of the quality of knowledge structure and its functioning that individual students possess. The findings of the study demonstrate the extent with which knowledge and/or skills may be accessed using practical work activities. In addition, the findings illustrate through using practical work activities, the possibility of accessing and assessing different types of knowledge and their characteristics as possessed by each learner/student. With this capability in assessment, teachers are empowered to accurately and appropriately plan for future teaching and learning of concepts as they will be able to develop relevant teaching and learning materials for particular and different cohorts of students.
Keywords: practical work, concept possession, assessment for learning, knowledge structure

INTRODUCTION

Assessment plays a central role in the teaching and learning system (Biggs, 2003; Cowie, 2005; Duschl & Gitomer, 1997; Shute, Hansen & Almond, 2008; Watkins, Dahlin & Ekholm, 2005). Assessment is not only integral to a teaching and learning system but fundamental towards the achievement of the systems' objectives (Carless, 2007). The importance of assessment should not only be an accounting tool for learning. It must also assist in enhancing the quality of learning processes. Quality in learning and in assessment for learning processes may mean many and different things to different people. In the context of this study the quality of assessment of learning must be and reflect relevance, appropriateness, reliability and comprehensiveness (Saddler, 1998).

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State of the literature

- Practical work activities (PWacts) have been used differently and for different purposes in science education and in Chemistry learning in particular and with differing learning outcomes. Different purposes in which practical work have been used has provoked vigorous contestations among researchers.
- Practical work activities have been described as enhancing learning of science and developing scientific skills among students. In some quarters this notion has been rejected.
- No clear explanation of how practical work activities enhance knowledge has been forthcoming or which aspects of the student's knowledge practical work enhanced.

Contribution of this paper to the literature

- This study advances the argument of using practical work activities (PWacts) for assessment purposes. In addition, the study illustrates how PWacts as assessment method may assist in enhancing teaching and learning of science concepts.
- The methodological approaches employed here provide a different way of ensuring that information collected and used represents different ways of effectively accessing aspects of or about student extant knowledge that were previously not easily accessible.
- The theoretical framing of the study enhances a deeper understanding of the structure and functioning of concepts that students possess and/or use.

These quality characteristics are achievable only through the selection of tools of assessment that possess the capability of accessing most features of the unit or units of analysis. That is, assessment tools must fundamentally have the capacity to access the different ways students represent and apply knowledge. This paper sets out to highlight and to some extent illustrate the importance practical work activities may be used to access students' extant knowledge and/or its use in authentic situations.

The capacity of an assessment tool to assess knowledge or learning is reflected in its ability to access the structure and functioning of the concepts individuals use (Hickey, 2015; Smith, 1991). This happens when an individual represents and uses the knowledge they possess while engaging in learning. In practical work activity situations, the use of knowledge is demonstrated both mentally and physically and can therefore be accessed holistically and its quality assessed. Kaput, Blanton and Moreno's (2008) facility notion of symbol system of algebra explains clearly the individual student's structure and functioning of concepts. According to the facility notion of symbol system, students have the *looking at* and the *looking through* understanding. The looking 'at symbol' "involves working with symbols as objects in their own right without concern for their referents". This approach to learning is *typical* of what researchers (e.g. Ausubel, 1968; D'Mello, Lehman, Pekrun, & Graesser, 2014) refer to as memorization or rote learning of concepts. On the other hand, the notion of *looking through* symbol system involves "maintaining a connection between symbols and their referents" (Alibali, Stephens, Brown, Kao, & Nathan, 2014). The *looking through* notion is when students make connections between concepts or symbols they are learning and the context within which these concepts are used. That is, this is the situation when "meanings are activated and they can inform students' behaviour". This is especially applicable in practical work activities where apparatus, symbols and other special language systems are used (p.237).

If an assessment tool that considers the looking at and through of understanding is to be used in a science classroom or in practical work activities, most of the students' knowledge features and/or their use may be successfully assessed. In this way the assessment of specific features of students' knowledge would enhance a better and holistic understanding of their conceptions of the topic they will be learning at any given time. In using the lenses of symbol system especially in Chemistry topics, students' knowledge *structure* and *functioning* may be accessed optimally at least at the three levels at which matter is conceptualised. Thus the rationale for using PWacts is that multiple features of students' knowledge or its use may be assessed. This may in turn assist to enhance the teaching and learning of different areas of a science topic. Practical work tasks used must therefore engage students in multiple representations of applicable knowledge. In this study an attempt was therefore made to understand students' *look at, look through* concepts and their *actions* through the following questions:

- What are students' conceptual understandings of selected acid-base concepts and related processes in a titration activity?

This question was specifically meant to establish the student's extant conceptual understanding of identified concepts through practical work activities. Drawing from Kaput et al's (2008) notion of the symbol system of algebra the student's scientific concepts and the relationship with her conceptual understanding were assessed. With the symbol system's approach, it was possible to distinguish expressions or representations of concepts and the relation to their use by the student. That is, links between representation of concepts and the student's activity or behaviour were inferred as reflecting conceptual understanding related to the practical work activities.

- How do students represent and/or express selected concepts in a titration practical work activity/ task?

The answer(s) to this question established different ways in which the student expressed and/or represented the selected concepts in the context of learning about acids and bases in a practical work activity. In the answer(s) to this question Kaput et al's (2008) assertion about the importance of facility with the symbol system in algebra were highlighted in a chemistry topic. This assertion emphasises the extent of understanding in their expression or representation of meanings of symbols. The system symbol is also applicable in chemistry considering the three levels (symbolic, macroscopic and microscopic) through which matter may be represented. Understanding these students' external representations has the potential to assist future teaching of the concepts under consideration.

Practical work activities as a form of assessment *of* and *for* learning

Practical work has been used for many different purposes in teaching. In science teaching it has been used for the development of scientific skills and conceptual understanding (Hofstein & Lunetta, 2004; Jagodzinski & Wolski, 2015; Lunetta, Hofstein & Clough 2007). However, the different purposes in which practical work activities have been used has provoked vigorous contestations among researchers (e.g. Hodson, 1992; Millar, 1998). In this study the aim was to use practical work activities (PWacts) as a form of assessment of students' representation of concepts or their conceptions of acids and bases. The use of PWacts as a tool for assessing students' conceptions is not common. The argument advanced for using PWacts in this study is supported by other researchers' (e.g. Clackson & Wright, 1992) contention that PWacts do not necessarily enhance learning unless they are first used to establish and understand specific problematic students' concepts or conceptions. Millar, Le Mare´chal, and Tiberghien, (1999) retort that the only way PWacts can be useful in enhancing conceptual understanding is when a link, or bridge is established between students' extant scientific conceptions and what can be observed through them. This link is highly probable through an integrated assessment of which practical work activities offer.

What does it mean to *assess science learning*? To answer this question, certain important phrases or concepts (of assessment, and science learning) and/or their relationships need explication. First, *science learning* refers to a dynamic process where students actively construct their own science knowledge and/or skills (Nicol, 1997; Nicol & MacFarlane-Dick, 2006; Yin, Tomita, & Shavelson, 2014). In learning science (Duschl & Gitomer, 1997) students develop the "thinking, reasoning, and problem-solving skills...to participate in the generation and evaluation of scientific knowledge claims, explanations, models and experimental designs" (p.38). These processes can be both cognitive and physical (i.e. manipulation of objects). What this implies therefore is that, if science learning is to be *accurately* and *sufficiently* assessed, it must be focused on points that are continually changing as knowledge is constructed and/or applied. For example, a stage of representing concepts symbolically and where concepts are used is dynamic and changes with the cognitive demand at that particular instant of knowledge construction. The dynamic representation and application of knowledge can therefore be effectively observed during practical work activities.

Assessment on the other hand (Doran, Lawrenz & Hegelson, 1994) is "the collection of quantitative and qualitative information about student learning using a variety of methods or techniques". Included in the methods of assessment are tests and observations (p.388) of conceptual activity. The collected information (Tamir, 1996) would describe knowledge "at, at least, two points of time...prior to the learning experience and upon completion of the learning task" (p.94). In the context of practical work activities, points at which information is drawn are maximised thus generating more and valuable information about the student's knowledge or its application. The number of instances and points at which assessment is conducted is mostly determined by the particular activity and purpose or purposes of the assessment. That is, assessment purpose must be specified at the outset of an assessment of an activity if an appropriate and accurate representation and interpretation of outcomes is to be realised.

It is not only points of assessment purpose that we need to specify. Levels of assessment purpose at which these points are assessed are also important. Newton (2007) identified three levels (i.e. judgment, decision and impact) of assessment purpose. The judgment purpose "concerns the technical aim of an assessment event" and is measured by allocating a grade or a mark. This judgment is a measure against a set standard or reference. The decision level reflects the assessment judgment. That is, it is an action derived from the judgment. It is the action we should take on the basis of the grade allocated. The impact level of the purpose, "concerns the intended impacts of the selected assessment system" or approach (p.152). That is, it gives meaning about or of the assessed variable on the assessed individual's activity. Each of these purposes may be used to address different aspects within a particular assessment process. That is, they can address what are normally referred to as *formative* and *summative* purposes. The so-called formative and summative approaches to assessment are distinguished by the *purpose*, *timing* and *generalisation* (Newton, 2007). The teacher's skill and level of knowledge of assessment is here paramount if assessment is to serve any purpose in teaching and learning. In this study PWacts may be used for both the teacher's and the student's purposes. That is, they may be used to:

- Highlight the teacher's shortcomings of the teaching methods used in the student's knowledge construction or learning;
- Highlight aspects in different knowledge areas that need attention at different instances of the learning and/or transfer processes and
- Assist in accessing and understanding many different small or large areas of different students' knowledge bases.

Using the formative approach as an assessment tool during PWacts, many different aspects of students' learning (e.g. transfer) are made accessible with greater possibility. This would in turn enhance a holistic teaching and learning of concepts. In this case assessment *for learning* (A*f*L) becomes the main beneficiary of PWacts as both a teaching and assessment method.

The aim with PWacts is thus to establish both students' mental representation of the scientific concepts and their conceptual understanding. Liu, Hou, Chiu, and Treagust (2014) in their study found that mental representations are an important factor in "the effectiveness of learning as students undergo conceptual change" (p.135). Therefore, establishing the quality of mental representations may enhance a better understanding of students' learning difficulties of specific concepts. Nickerson (1985) links conceptual understanding to the parts that make up the concept and how these parts interact. That is, the structure of concepts as represented plays a major part in the meanings students generate and subsequently to the actions or functioning derived from such understandings. Through PWacts the possibility is therefore enhanced to "diagnose students' ideas and products" (Duschl & Gitomer, 1997, p.38). This diagnosis may be used to link the concepts' structures and their functioning. With this knowledge, teachers' judgements and decisions about their classroom learning activities may thus be effectively guided especially about concepts that are somehow *confusing* and *abstract* for students. Some of these concepts or their use is the focus in this study. The use of PWacts may promote access into students' multiple scientific representation of concepts and/or knowledge. How then do we do this in the face of a dynamic knowledge construction or learning process?

Gleaning through the activity lens

Accessing the concepts and the relationship of their parts in a dynamic process such as learning is a daunting and unpredictable task for assessors. This is more apparent in the complex interactive Chemistry practical work tasks. That is, one needs to observe and interpret events as they unfold from different and related activity interactions. This can only be possible if the teacher as assessor is clued about his/her *purposes* of practical work activity tasks. The teacher needs to be clear and specific about what it is that is assessed and how this assessment is to assist teaching and learning. In other words, a clear understanding of the practical work *system* and its constituent components and their relationships is imperative. Since practical work is a teaching method and a system (made up of the teacher, students and their practical work tools and related tasks), it is possible to understand the activities involved and/or their meanings. Therefore, teaching and learning through PWacts should be viewed as a system in which teachers and students share and use tools to communicate messages meant to enhance understanding of the purposes of the interactions.

In order to understand the activity or interactions where students work individually or in groups and the teacher's purposes, the activity theory (AT) becomes an appropriate *lens* to look at and through students' knowledge or its functioning. Activity theory as a framework (Sam, 2012) may assist in studying the "actions of people on both an individual and societal levels simultaneously" (p.84). In practical work activities teachers and students interact in a social environment as they engage among themselves and the tools they use. For assessment purposes, practical work activities assist in reflecting actions (Leont'ev, 1982) as functions of knowledge structures. Thus the functioning of knowledge structures would be the main foci of analysis in this study. The functioning in this case and to a large extent represents conceptual understanding whilst the nature of knowledge structures would be a reflection of how students represent their scientific conceptualisation from their knowledge bases. The activity here would refer to practical work activities of the student who is part of a social community of students studying the same course.

The use of AT as a theoretical framework in practical work activities serves as a mirror through which actions and reactions (i.e. the physical manipulation of objects and the teacher's reactions) in teaching and learning (i.e. object of knowledge interactions) may be interpreted. It is also used to explain associations and relationships that influence external activities that are informed by the student's knowledge structures. In fact, practical work as an activity mediates between knowledge and the dynamic *knowing process* (Radford, 2013). This assertion by Radford (2013) is based on his explanation of the link between knowledge and knowing - that is, the notion that "knowing is the instantiation or actualization of knowledge" (p.16). It is through the actualisation of the knowledge mediated by practical work *activity* that the interaction of different knowledge types may be identified, assessed and/or understood.

Constructivism (i.e. socio-constructivist) is an inherent aspect of the activity theory (Sam, 2012) and may add in explaining and reinforcing the importance of concepts (which are context-dependent) as building blocks of knowledge (Reif, 2008) and the social context/community in which the student and learning are situated. That is, highlighting the inherence of the constructivist theory within AT enhances a deeper understanding of the effect of concepts on knowledge actualisation in the process of knowing in practice and a better understanding of learning/teaching in different social contexts. These concepts are possessed by individuals as part of the network of knowledge structures (Lappi, 2012) in the context of practical work as a teaching method. It is this knowledge network that the individual uses to make decisions about the manipulation of objects or to construct new knowledge for future learning (Lappi, 2012). The constructivist theory is here complimentary to the assessment of the organisation or structure of knowledge and its effect on the functioning of concepts during knowledge construction.

As has already been indicated, the integrated *framework* of AT and constructivist theory may be used to interpret the assessment of the interaction between and amongst the different types of knowledge such that learning may be effectively enhanced. This may not necessarily be accurate because of the nature of both learning and knowledge. That is, knowledge construction is an on-going and dynamic process that is mainly influenced by the *quality* of the individual's knowledge structures. Determining the quality of knowledge, which is reflected through its organisation/structure, completeness and amount (Dochy, 1992) is to a larger extent, determining the functioning of knowledge structures and/or the outcomes of their interactions. Therefore, in assessing knowledge structures we are in fact assessing the knowledge that the student already possesses. This is the student's prior knowledge. Ackerson, Flick, and Lederman (2000) emphasise the importance of prior knowledge as the *organizing factor* of individuals' thought processes. The organizing process occurs when new information and experiences are integrated into the structures of prior knowledge for new learning.

If the interactions within knowledge structures are to be better understood, then the changes that prior knowledge undergoes need to be identified and known. Identifying these changes is possible when concepts possessed are in use or are in action during learning or in some activity. Hampton and Moss (2003) assert that "it is only through the study of usage of terms that we can have an independent way of fixing the contents of people's concepts" (p.507). Possessing a concept is characterised as one's ability to *recognize one, know what it is for, and how it works* (Peacocke, 1992). This ability plays an important part in one using his/her knowledge especially in making decisions in practical work activities. Therefore, our ability to identify and assess the interaction of different knowledge types would rely on our ability to *characterise* the individual student's possessed concepts. Our analysis must therefore focus on how students represent their scientific concepts and demonstrate their conceptual understanding both mentally and physically (i.e. by their manipulation of apparatus) during practical work activities. Thus the unit of analysis in practical work activities or in the tasks involved should generally be *concept possession.* What is important in analysing concept possession is the ability to identify aspects in their knowledge bases that confirm knowledge that make students to perform their tasks successfully.

RESEARCH METHODOLOGY

Context of the study

Practical work encompasses a broad range of activities that can have widely differing aims and objectives (Abrahams & Reiss, 2012; Lunetta & Tamir, 1979). As such, it is the effectiveness of specific practical tasks, rather than the effectiveness of practical work in general, that needs to be considered for assessment *of* or *for* learning. One should be considered to have learned if they can use their knowledge appropriately when it is required. In this study the focus is on a practical task at a particular instance of students' learning of a particular topic. The practical task was on a *titration* of a commercial vinegar solution meant to determine *percentage purity* of acetic acid. The study was conducted at a South African University of Technology (UoT) among first-year Chemistry students. The information collected represented a variety of events as the activity unfolded hence the use of different data collection methods.

Research Methods

The approach to the study was *qualitative* and descriptive. In this study the focus is on one case from a group of first year Chemistry students (due to lack of space). This case was selected from three purposively selected first-year Chemistry students. The original three students were selected on the basis of their responses and achievement in the *prior knowledge diagnostic test* (PKDT) on the topic of *acids* and *bases*. That is, the students were selected at three levels of the achievement continuum namely *bottom, middle* and *top*. In addition to using information from the PKDT, other sources; *unstructured interviews* (UI) and *observation of practical work* (OPW) activities were used to collect information. The initial data was a pen and paper PKD test (**Figure 1A**). The aim with the test was to benchmark students' extant knowledge before engaging in the practical work activity task and for use as a referent in the observation of practical work activities and follow up interviews.

The test focused on key and *problematic* acid-base concepts used in titration processes. These concepts were identified only after the test was written and students' responses marked. That is, the selection of the concepts (**Figure 1B**) that were used in the study was based on how students responded to questions that included these concepts irrespective of the form of such questions. Specifically, the titration concepts were those used in neutralization reactions and about the technical aspects of using apparatus and/or solutions in titration (**Figure 1C**).

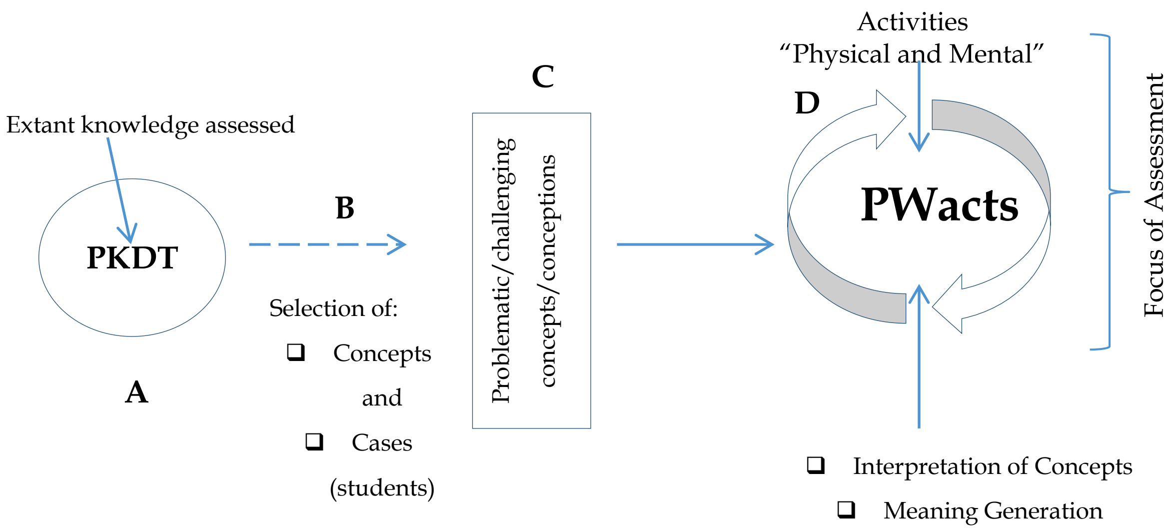

Figure 1. Stages of data collection and assessment of practical work activities

The second part of the data collection process was the observation of PWacts (**Figure 1D**). In this part both the manipulation of apparatus and the decisions students made about which apparatus and solutions were to be used were the foci of analysis. The judgments and the decisions that led to the actions that followed were the basis on which students' interpretation of concepts were inferred or established. Students' interpretation of concepts was here viewed as reflective of the meaning of their concrete concepts or their conceptual understanding. The assumption is that it is from their interpretation that their physical actions are drawn. The relationship between concepts or their understanding is two-fold according to Alibali et al (2014). That is, they may mislead their actions or lead them to act appropriately depending on the accuracy or lack thereof of their interpretation. To the teacher, they may be misleading if the students learned procedures by rote. This may therefore be viewed by the teacher as a *true* reflection of their conceptual understanding (p.238). What this means therefore is that assessment outcomes of knowledge structures or their functioning are not always *accurate* but an estimated reflection of students' knowledge or understanding of concepts.

DATA PRESENTATION AND ANALYSIS

The results reported in this section are a product of analysis of data from three sources and will be indicated as such in the report. However, only data that serve as evidence for establishing facts about practical work activities as a *tool* for assessing how students express and represent their conceptual understand are reported. The reporting reflects the individual student's interpretation of concepts and/or conceptual understandings as idiosyncratic. However, there may have been co-construction of meanings in the activities shared. Co-construction of meanings was not the focus of this study. The manner in which concepts are represented or presented and reflected in individual actions are according to Peacocke (1992) the student's concepts or knowledge possession.

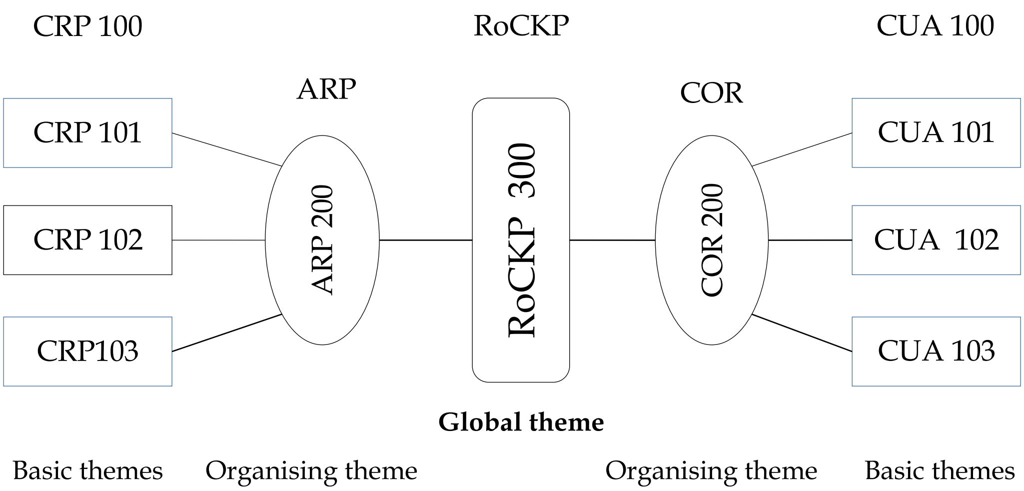

Figure 2. Thematic networks for data analysis

Data analysis

In this activity system a student manipulates and observes real objects and/or materials. The teacher's purpose is mainly to identify aspects of the *concept or knowledge possessed* by the student. That is, the teacher has to establish if the student can *recognise a concept, know what it is for, and how it works* and be able to apply it in practical situations (Peacocke, 1992). The characteristics of possessed knowledge are integrated and may only be analysed in a dynamic situation of an activity; hence the need for multiple sources of data collection. For a meaningful construction of understanding, an analysis of the overlap between structure and functioning of knowledge is fundamental. Thus based on the research questions, thematic networks are used to analyse data. Thematic analysis organizes themes from textual data at different levels of complexity to answer research questions (Braun & Clark, 2006). In this analysis three levels of themes were used namely *basic themes, organizing themes and global themes* (Attride-Stirling, 2001). The thematic networks (**Figure 2**) were here derived from both the *research questions* and related theory especially the concept of *knowledge possession, knowledge construction and the knowing process*.

The data in the themes (basic and organising themes) represent the information collected towards the understanding of the representation of *knowledge and/or concepts possessed by* the students (RoCKP) during their situational behaviour or action when engaging in practical work activities. It is from these actions or behaviour by students that the teacher may gather information for use in his/her teaching to enhance the learning of concepts students may have used inappropriately or failed to use appropriately. A concept cluster (Appendix A) is formed from different data sources for the student under consideration. It is from the concept cluster that the student's representation of knowledge and/or the concept possessed is synthesised. From the thematic networks for data analysis two basic themes and two organising themes emerged (**Figure 2**). The two basic themes were *concept recognition and purpose* (CRP) and *concept usage/application* (CUA). The organising themes were *activity representation in practice* (ARP) and *conceptual representation* (COR).

Results of the analysis

This section of the study presents data collected during a practical work activity when students were engaged with a titration task. The data is from one student although many other students were part of the activity (see **Appendix B, Table 1**).

Discussion

The results are drawn according to the two themes from the analysis (**Appendix B, Table 1**). The results in this study clearly reflect the two research sub-questions and will be discussed as such.

The student's conceptual understanding of selected concepts

Kaput, Blanton and Moreno's (2008) facility notion of symbol system of algebra aptly explains this student's *structure* and *functioning* of concepts. The results of the first research question reflect the fact that students have the *looking at* understanding. That is, the looking at symbol involves working with symbols as objects in their own right without concern for their referents. In many situations (*see* CRP 100) of this student's answering of questions she relied more on their definitions rather than understanding the concepts especially in relation to other concepts applicable to the topic and the activities involved. The student therefore relied on what Ausubel (1968) generally termed memorisation or rote learning. This approach does not enhance the individual's ability to construct meanings and/or understanding during the knowing process (see COR 200). Practical work activities are an opportunity for individual students to engage in knowledge construction and meaning making. This is only possible provided students' possess prior knowledge which Ackerson, Flick, and Lederman (2000) describe as having a high organizing factor of the individuals' thought processes. That is students need to be able to integrate new information and experiences into the structures of prior knowledge for new learning.

Representing and/or expressing concepts in practical work activity/task

Assessment is about determining the quality of knowledge, which is reflected through its organisation/structure, completeness and amount (Dochy, 1992). The quality of knowledge can also be determined by its amount or the individual's ability to use or apply it in different situations. Students use knowledge optimally if they can make connections between concepts and generate understanding from these connections. The other side of Kaput et. al's (2008) facility notion of symbol system of algebra is the notion of *looking through* symbol system. This notion involves "maintaining a connection between symbols and their referents" (Alibali, Stephens, Brown, Kao, & Nathan, 2014). Clearly the student's *looking through* was limited as far as understanding and applying concepts within and across meanings. As has been alluded to, the student was only limited to defining the concepts without the ability to use individual concepts and/or in constructing understanding of their relationships. That is, the student was limited in making connections of her concepts and/or their meanings. The element of application in this student's knowledge possession seems to be an area of concern for teaching and may be highlighting or reflective of the teaching approaches or the student's learning style.

CONCLUSIONS

This study was an attempt to assess knowledge holistically for purposes of future teaching and learning. Assessment of or for learning assists both the teacher and the student to reflect on the teaching approaches and the knowledge and skills they possess. This is important as it assists in improving both their teaching and learning respectively. With practical work being used for assessment purposes the reflection is enhanced as assessment is conducted in the dynamic process of knowing. Assessment during knowing has the potential of judging the situation of the activity appropriately because it is accurately reflected as it is done in the context of the activity. That is, interpretation is context specific and in this way aspects of ambiguity are minimised. In this case concepts or their use are assessed according to the meanings that reflect the context. That is, assessment identifies and characterises knowledge in terms of its components (concepts) and structure (how they relate and completeness and what is missing) in the context in which knowledge is used. The immediacy of assessment in context enhances and remedies misconceptions through an accurate and relevant action.

Hampton and Moss' (2003) assertion that "it is only through the study of usage of terms that we can have an independent way of fixing the contents of people's concepts" (p.507) holds true if practical work is used as an assessment tool of knowledge and knowing. Thus using practical work activities enables assessment to correctly and accurately reflect the concepts possessed by the student. That is, with practical work activities we are able and to some extent correctly characterise knowledge or concepts possessed by students and in doing so we will be in a better position to align objectives, assessment and the materials used in teaching and learning of concepts and/or their use.

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APPENDICES

Appendix A

Concept Cluster: Codes → Themes: Case 1

A concept clustering process is a process of data reduction and consists of selected information from different sources used in the study. That is, it consists of selected questions (Q) posed during the study. Such questions could have emanated from the test (PKDT), the interview (UI) and observation of practical work (OPW) and their responses (R). Other information was sourced from the student's practical work report (PWR). In the cluster the student's responses and sources of information are also indicated.

Q.1: [Differentiate] between an Arrhenius and a Bronsted-Lowry [acid concepts] [PKDT].
R.1: Arrhenius' acids [increase the concentration of H^+ ions] when dissolved in water while Bronsted-Lowry acids are [proton donors].

Q.2: You are told that an *aqueous [solution is acidic]*. What does [this mean]? [PKDT]
R.1: It means the solution [has a high concentration of H+ ions].

Q.3: As the [hydrogen-ion concentration] of an aqueous solution [increases], the [hydroxide-ion concentration] of this solution will; (i) increase (ii) or (iii) remain the same. Explain. [PKDT]
R.3: [Decrease] {No explanation from the student}

Q.4: When HCl (*aq*) is [exactly neutralised] by NaOH (*aq*), the [hydrogen-ion concentration] in the resulting solution is … [PKDT]
R.4: [Always equal] to the concentration of the OH^- ions.

Q.5: Why is ethanoic acid (CH_3COOH) considered a [weak acid]? [OPW]
R.5: It is a weak acid…CH_3COOH is [not ionised completely] because [there are still H^+ ions] [within the CH_3COO^-].

Q.6: What is the [difference] between a strong and a weak acid? [OPW]
R.6: Acid that [dissociate or ionise completely] in an aqueous solution

Q.7: Presume that you are titrating a weak acid (e.g. CH_3COOH) and a strong base (e.g. NaOH). What would the expression [“equivalence point” mean in the titration process]? [PKDT]
R.7: The amount of a titrant is [chemically equal] to the [amount of the analyte].

Q.8: Why is there a [temporary colour change] in a solution whenever the NaOH solution [drops land in the centre] of the solution (in the analyte) during a titration? [OPW; UI]
R.8: Because it has [reached the equivalence point].

Q.9: What is [meant by equivalence point]? [OPW; UI]
R.9: Amount of vinegar is [equivalent] to NaOH in the solution.

Q.10: What is [meant by endpoint]? [OPW; UI]
R.10: When we [observe colour change].

Q.11: What is the [purpose of an indicator] in a titration? [OPW; UI]
R. 11: To [find the colour change] and [observe the pH] of the solution.

Snippets from the practical work report: the purpose of the task was to determine the percentage of ethanoic acid (estimated at 4-6%) in a commercial vinegar solution.

Method

- Pipette [10 ml of vinegar] solution into a [100 ml volumetric flask].
- [Add deionised water] to the [graduation mark].
- Pipette [25 ml of the vinegar] solution into a conical flask and dissolve in 75 ml of water.
- Titrate with a [standard NaOH solution] until an end point is reached.

Observation: *At the beginning of the titration there is a [colour change at the centre] of the conical flask. As the process continues, the [colour turned dark pink] (endpoint). The colour change is [due to the indicator added]….*

Calculated percentage: [461% (too high)]

Q.12: [Differentiate] between [a dilute solution] of [a weak acid] and a [concentrated solution] of a [weak acid]. Illustrate your response with appropriate examples [PKDT]
R.12: [Dilute weak acid] does [not produce gas] while concentrated acid [produces substances].

$H_2CO_3 \rightarrow CO_2^- + H^+$

$H_2CO_3 \rightarrow H_2O^+ + HCO_3^+$

Q. 13: Calculate the molarity of HCl with a density of 1.057 g/ml and a purity of 12% by mass [PKDT]
R.13: [D = m/v]; 1.057= 12/100/v
V = 0.12351

C = m/mv
= 0.03 mol /dm^3

Q.14: Illustrate/Show how 500 ml of a 6 M solution is [diluted by a factor of 25] [PKDT]
R.14: *[6 x 500/25]*

Q.15 What do you understand by the term: "concentration"? [OPW; UI]
R.15: Concentration is the [ratio of moles per volume (n/v)]

Q.16: What do you [mean by the term "dilute"]? [OPW; UI]
R.16: To [reduce the concentration] of vinegar.

Q.17: What is the concentration of ethanoic acid in a vinegar solution after dilution? High or low? [OPW; UI]
R.17: [It is not yet known].

Q.18: What happens to the concentration of the solution if the [volume is increased] by adding water? [OPW; UI]
R.18: It [reduces the concentration] [language]

Appendix B

Table 1. Representation of knowledge and/or concepts possessed by an individual student

Key: Basic themes (COR & ATR) → Organising themes (CRP & CUA) → Global theme (RoCKP)		
CASE		
Basic theme/s (CRP & CUA)	***Organizing theme/s (ARP & COR)***	***Global theme/s (RoCKP)***
At this level although much of the data has been sifted into meaningful groups, the data is still isolated into bits of terms, concepts and statements that need to be linked together to make sense of different aspects in the study.	*Organizing themes group data meaningfully to make sense although not necessarily conclusive. They individually give direction towards reaching findings about aspects of questions of the study.*	*Under this theme a synthesis of organising themes is presented to arrive at the result/outcome of the analysis of the research process as per research **sub-questions** or the **main question** of the study.*
CRP 100	**ARP200**	**RoCKP 300**
[CRP101*:* Differentiate…acid concepts Arrhenius …Bronsted-Lowry…: *…increase the concentration of H^+ ions; proton donors*] [CRP102*:* Meaning of acidity: *high concentration of H^+ ions*] [CRP103*:* Meaning of equivalence point*: …vinegar "equivalent" to NaOH*] [CRP104*:* Meaning of endpoint*: …observation of colour change*] [CRP105: Differentiate concepts… dilute and concentrate solutions of weak acid: *….dilute…does not produce gas-* CO_2^- + H^+ *concentrated… produces substance-* H_2O^+ +HCO_3^+] [CRP106: Calculate molarity given density, % purity…of an acid solution ….see R in Q.13] [CRP107: Predict from practical experience concentration change (High/low) when a solution is diluted… *concentration is not yet known*]	*Under this theme the main concepts under consideration are the two acid-base concepts (**Arrhenius and Bronsted-Lowry**). Other concepts or associated concepts considered for analysis were **concentration**, **dilution, equivalence point, endpoint and acidity**. The aim with this analysis was to establish aspects of the student's concept possession. Specifically, and as a response to the first research sub-question aspects answered here are:* • ***Concept recognition** i.e. what the concept is and is for. The student managed to recognise the two acid-base concepts through **definition**. It is however clear that the student could not go beyond defining the concept to demonstrate their **distinguishing features even from their definitions**.* *The concepts **endpoint** and **equivalence point** are here recognised for their purpose. That is **endpoint** is seen as indication of colour change. The chemistry of colour change is clearly not understood. Equivalence point on the other hand is seen as meaning or demonstrating equality of reactants.*	*In both the **ARP** and **COR** sub-themes two distinct ways the student possesses her knowledge are revealed. That is the quality characteristics of her knowledge can therefore be described. It is possible to describe the **structure** of her concepts and/or her knowledge. It is also possible to describe and explain her **use** of her knowledge in the context of engaging in the practical task described.* *In reporting the outcomes of this analysis, the elements of quality of knowledge are used to simplify what the assessment revealed. That is terms such as **organisation/structure, completeness and amount** are used to describe the state of knowledge possessed. The following describe the quality of this student on the task performed during the practical activity:* *CONCEPTUAL UNDERSTANDING OF SELECTED CONCEPTS* *In describing the quality of knowledge one cannot do so by focusing on individual concepts without their associate concepts. That is a concept cannot be a concept without context or in relation to other concepts. For this student:*

Table 1. Representation of knowledge and/or concepts possessed by an individual student *(continued)*

Basic theme/s (CRP & CUA)	*Organizing theme/s (ARP & COR)*	*Global theme/s (RoCKP)*
CUA100 [CUA101*:* How does increase in [H^+] affect [OH^-] in an aqueous solution*?*] *decrease...* no explanation provided for the answer]. [CUA102: HCl is *exactly* neutralised by NaOH… [OH^-] *is always equal* to [H^+]] [CUA103: Weak acid explained: *not ionised completely… there are still H^+ ions within the CH_3COO^-*]. [CUA104: Differentiate weak acid from strong acid: *Acid that dissociate or ionise completely*] [CUA105: What does "equivalence point" mean in the titration process? *Titrant… chemically equal to analyte*]. [CUA106: What is the meaning of temporary colour change when drops of titrant land in the centre of analyte solution? *it has reached the equivalence point*]. [CUA107: What is meant by endpoint? *Colour change*] [CUA108: Purpose of indicator: *to find the colour change and observe the pH*] [CUA109: Demonstrate how 6M solution may be diluted 25 times]… *[6 x 500/25]* [CUA110: "Concentration"? *Is [ratio of moles per volume (n/v)]* [CUA111*:* What happens to concentration if volume is increased? It *reduces the concentration.*	• *What **the concept is for or can be used for**.* *The student is aware that acidity is the measure of **H^+** ions. This understanding is limited since the student does not relate it to any other constituent ions of the solution. For example, in [CRP107] the student could not instantiate this understanding to construct meaning and/or the appropriate answer to the question. This can be inferred as a limited understanding of the concepts of concentrated and dilute solutions. It can also be concluded using response [CRP105] that the two concepts, **concentration** and **dilute** are not clearly understood. In CRP105 the student appears to distinguish a concentrated solution from a dilute one through the amount of fumes one produces and what they produce. The **representation** (in CRP105) seems to suggest that the **composition** (not amount) of same solution is different when in different concentration.* **COR 200** *Under this theme the focus is on the same concepts discussed in **ARP 200 with the addition of acid strength and pH** except that they are discussed under different aspects of **knowledge possession**. In this theme the responses are discussed under:* • ***What the concept is for** i.e. the student must understand the concept i.e. what it is and be able to assign it an appropriate meaning and where it is used or what its purpose is.*	✓ *The understanding of most of the concepts is limited to definitions.* ✓ *That is the student managed to define concepts but was lacking in using them appropriately in other situations of the practical work task.* ✓ *The student's knowledge was apparently **incomplete** and in some instances lacking in **organisation.*** ***REPRESENTING AND/OR EXPRESSING CONCEPTS IN PRACTICAL WORK ACTIVITY/TASK*** *One of the important attributes in understanding and using science concepts is the ability to represent it at all its levels of conceptualisation. In the case of this student this was her area of concern.* ✓ *That is, her knowledge of concepts at application level was limited by lack of integration of knowledge possessed/prior knowledge.* ✓ *That is, the student could not relate her knowledge even if it was appropriate and 'available' when needed.* ✓ *The student could not construct meaning or understanding from some of the concepts she managed to define.*

Table 1. Representation of knowledge and/or concepts possessed by an individual student *(continued)*

Basic theme/s (CRP & CUA)	*Organizing theme/s (ARP & COR)*	*Global theme/s (RoCKP)*
	In her response to ***CUA101*** *the student manages to give a valid answer. However, she was unable to justify it. This lack of justification can be traced back to her answer in* ***CRP102****. Both the answers (in* ***CUA 101 and CRP102****) show that the student's conceptualisation of reactions in solution has limitations. That is, the visual imagination is somehow limited to* ***definitions****. These responses are also not consistent to her answer to* ***CUA 102****. In* ***CUA 102*** *the response is valid although the justification was not required in the question.* • ***How the concept works*** *i.e. the individual student needs to be able to* ***use*** *the concept appropriately.* *In her attempt to explain the concept of 'weak acid' the student misrepresents the concept of ionisation. That is, ionisation in her explanation is represented as disintegration of a molecule into its atoms (see* ***CUA 103****). The student's knowledge is more on defining concepts than on understanding how they work.* *The concept of dilution is about reducing original concentration. In her response in* ***CUA 109*** *there is a suggestion of increasing concentration based on the calculation. It is apparent that her answer in* ***CUA 110*** *although valid did not assist her in answering* ***CUA 109.*** *However, her answer in* ***CUA 111*** *is valid but contradicts or does not assist in answering* ***CUA 109****.* *The student's knowledge possession is not integrated…her concepts or knowledge structure is not well organised*	