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Teachers' Transformed Subject Matter Knowledge Structures of the Doppler Effect

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ABSTRACT

The pupils' poor performance in science in South African secondary schools is well documented. Therefore, it is deemed necessary to conduct a study that would portray knowledge structures for teaching a science topic. This is an empirical qualitative interpretive multiple case study looking at four physical science teachers teaching Doppler Effect to Grade 12 pupils. The data was collected through classroom observations and teacher interviews. Data analysis was done using concept maps. The results show that teachers' knowledge as portrayed during the teaching lack coherence and to some extent the correctness that is expected of teachers. The weaknesses are considered likely to compromise their pupils' conceptual understanding of the topic.

Keywords: concept maps, connectedness, correctness, pedagogical content knowledge, subject matter knowledge

INTRODUCTION

It is a standard practice to measure teachers' professional proficiency in order to comprehend, appreciate and determine the quality of their teaching. This practice is centred partially on the notion that teachers are key intermediaries of any educational activities and that; they have major influence on the quality of teaching and learning (Juttner, Boone, Park, & Neuhaus, 2013). Since teacher thinking plays an important role in influencing teaching process, teachers' professional knowledge especially its structure and quality has taken a centre stage in research. Among others the focus has been on pedagogical content knowledge (PCK) and subject matter knowledge (SMK) of teachers. The assumption is that the way teachers conceptualise the subject matter they teach has influence on how they transform it (Bartos & Lederman, 2014). The transformation is made possible not only by the amount of teacher's subject matter but also how such knowledge is structured (Koponen & Pehkonen, 2010).

This study draws on the theoretical idea of Pedagogical Content Knowledge (PCK) that gives distinction to Subject Matter Knowledge (SMK) transformation (Shulman, 2015; Kind, 2009; Wood, 2003). The transformative PCK framework indicates SMK as one of the teacher knowledge domains from which teachers draw the knowledge they use in teaching. During the teaching process the teachers transform their raw SMK into forms that will be easily understood by their pupils (Geddis & Wood, 1997; Mavhunga & Rollnick, 2013). The SMK that is observed during the teaching has therefore been transformed taking into consideration the curriculum, the pupils and their prior knowledge, what is difficult to teach and conceptual teaching strategies (Pitjeng, 2014). This study focuses on such teachers' transformed SMK which emanates during teaching.

The research has shown that structuring of subject matter differs according to the level of teacher's expertise. The expert teachers have subject matter structure that is more complex with more cross-links, interconnections and chunks (Kinchin, Hay & Adams, 2010). These structural differences have been found to have manifold influence on classroom practice. Teachers with sophisticated complex structure tend to teach in ways that portray such coherence and integration of concepts which is important for conceptual understanding of pupils (Bartos & Lederman, 2014). Pupils' knowledge structures have also been found to resemble those of their teachers, an indication of the influence teacher knowledge has on pupils' understanding (Rutledge & Mitchell, 2002).

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Contribution of this paper to the literature

- This study contributes to the limited literature on creating concept maps from subjects' observations and interview responses.
- This study also suggests the alternative way of portraying knowledge gaps of subjects who cannot construct concept maps themselves.
- The study also highlights the teachers' knowledge structure for teaching Doppler Effect which has not been done before.

The poor performance in physical science in South Africa is well documented. In the past few years the physical science average pass rate at matric has been around 60%. These were pupils who got 30% and above while only around 37% scored above 40% (Department of Basic Education, 2015). This low pass rate has been attributed to various factors among which are teaching strategies (Brodie, Lelliott & Davis, 2002), pupils' interest and motivation (Makgato and Mji, 2006), teachers' subject matter knowledge (Pitjeng, 2014), lack of resources (Legotlo, Maaga, Sebego, van der Westhuizen, Mosoge, Nieuwoudt & Steyn, 2002) and media of instruction (Probyn, 2008). This poor performance has been persistent even though teachers are often taken for workshops by Department of Education. Even though science teachers' subject matter knowledge has been studied in South African context only how much of such knowledge teachers have was researched. The way such knowledge is structured is one area that is still under researched.

The purpose of this study was to find out the structure of teachers' transformed SMK about the Doppler Effect. The topic was chosen because it was one of the few new topics included in the revised South African curriculum. One way of portraying teachers' knowledge structure is through the use of concepts maps. Concept maps are graphical representation of the relationships among concepts indicated with linking lines and phrases which define such relationships (Nakiboglu & Ertem, 2010). The concept maps can be constructed by the subjects or the researcher from subjects' responses, the latter being the case in this study.

The use of subjects' responses to construct the concept maps is not a new idea. Some researchers (Daley, 2004; Iuli & Hellden, 2004; Kinchin, Hay & Adams, 2010; Novak & Canas, 2006; Novak & Musonda, 1991; Rye & Rubba, 2002) have constructed concept maps from either the verbal expressions (interviews) or texts that the subjects have written or even observation transcripts (Daley, 2004). Novak and Canas (2006) constructed concept maps from interview transcripts and the text from a book to represent the author's knowledge. They further suggest that while there is high expectation that methods like interviews, critical incident analysis, case study analysis and others are likely to extract and represent individual knowledge, the use of concept maps is more likely to be the best way to represent knowledge gathered through any of those (Novak & Canas, 2006). Daley (2004; p1) argues, "the maps allow the researcher to see participants' meaning, as well as, the connections that participants discuss across concepts or bodies of knowledge".

The concept maps are normally scored to indicate the level of understanding of an individual. The rubric used have constructs; Complexity, connectedness and correctness (Rollnick, 2014). Complexity is used to describe the teacher's knowledge structures. It is a product of width, depth and cross links (Hough, O'Rode, Terman & Weissglass, 2007). The depth and width of the concept map are used to depict the complexity of teachers' understanding. This is an evaluation of the knowledge structure portrayed. It takes into account the number of concepts on the same level, the number of links in the longest chain and the cross-links. Cross-links are connections between two nodes that are on either same or different levels.

Connectedness on the other hand indicates the number of chunks and the cross-links the map contains. In this case only the correct chunks and cross-links are counted. A chunk is a group of linked concepts for which the leading concept has at least two correct successors (**Appendix A**). A successor is a linked word one level down from a node. On the other hand correctness assists in assessing the teachers' level of accuracy of their content. It looks at the number of correct links between the concepts.

METHODOLOGY OF RESEARCH

General Research Background

This was an empirical and interpretive qualitative case study focusing on four teachers teaching Doppler Effect to Grade 12 pupils. The focus was on the in-depth analysis of teachers' knowledge about Doppler Effect.

Research Sampling

Purposive sampling was used to select the participants for this study to maximise the richness of information collected (Guba & Lincoln, 2005). The study was carried out in schools situated in Gauteng Province, South Africa. The four teachers were selected from four schools that have been performing well (75% and above) in physical sciences in the last seven years. The selected teachers held post graduate degrees from the universities in Gauteng Province as it was anticipated that they were likely to provide rich data due to their research experience. These were teachers with more than ten years of science teaching experience who were also willing to participate in the study. These teachers were also given pseudonyms (Mr Libele, Mr Liephe, Mr Tseki and Mr Skeby) in this study.

Data Collection and Instruments

Doppler Effect is taught during the second school term in the curriculum, which runs from April to June. The three participants (teachers) taught the topic within the stipulated time. However, one of the participants informed the researcher in advance that the school cluster decided that the topic (Doppler Effect) would be covered during the third school term (in August). Therefore the data collection process took place over a period of five months.

The schools were visited before the data collection. These visits gave an insight into the ways the classes were conducted at different schools and context of each school as a whole. The classes were run as normal during the data collection period. The data collection took place in three stages: pre-observation interviews; classroom observation and post-observation interviews. The Interviews were conducted at each teacher's school which took around twenty minutes and were audiotaped. The observation of two lessons was done with each teacher and with each lesson taking about fifty minutes. The observation (videotaped) was meant to capture the transformed SMK as it manifested through teachers' explanations of the concepts during the teaching. Semi-structured interview was employed due to its flexibility as it enables the researcher to probe for more insight in an idea (Opie, 2004). The interviews probed on some unclear statements or explanations done by the teachers during the teaching and their reasons behind some incidents observed during the lesson. Both the audio and video recordings were then transcribed and analysed.

DATA ANALYSIS

Data Analysis Background

The study addressed the research question: What is the teachers' transformed knowledge structure of Doppler Effect? In attempting to answer this question concepts maps were constructed from teachers' classroom observation and interviews transcripts. The concept maps therefore represented the transformed knowledge of the teachers for teaching Doppler Effect. The concept maps were then analysed in order to identify the structure of teacher knowledge and the knowledge gaps and misconceptions that the teachers could have. The concept maps in this study were not used as data collection method as normally used, but as data analysis tool and this is described in details in the sections that follow.

Construction of Concept Maps

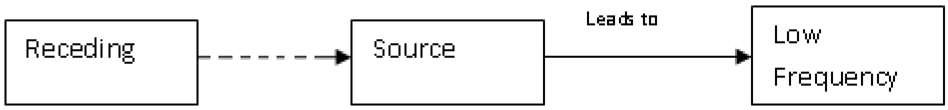
The concept maps in this study were constructed from teacher interviews, any writing that the teachers made (mainly on chalk board) and from the observation transcriptions. As described in the previous paragraph and under literature review, this was regarded the best way to represent teachers' transformed knowledge about Doppler Effect. The concept maps also assisted in reducing the amount of transcribed data into what Kinchin, Streatfield and Hay (2010; p53) call "structural summaries of knowledge" (information held and the way in which knowledge is structured and individual concepts connected to each other)".

The procedure followed in constructing the concept maps in this study was adapted from Novak and Musonda (1991), Kinchin et al. (2010) and Iuli and Helldén (2004). In their study Novak and Musonda (1991) began the concept map construction by first identifying the statements that represented the participants' ideas about the objects or events picked from the verbatim transcriptions. The starting point is always the most inclusive or general concept covered during the interview or observation.

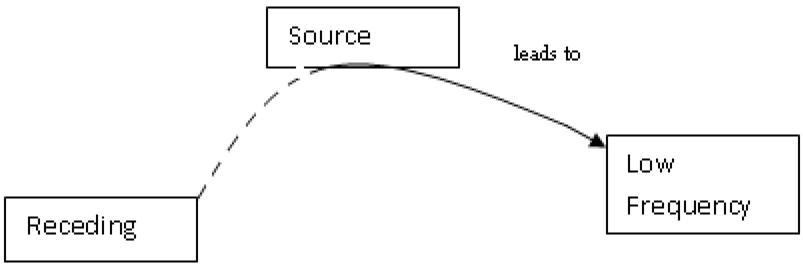
In this study the concept maps were constructed by the researcher with the help of concept map expert who was also a physical science specialist working at the university. The process started with verbatim transcripts of interviews and observations. The concepts within Doppler Effect were first identified. These were the main ideas that were covered within the interviews or lesson observation as observed from transcripts. These main concepts were later represented as nodes on the concept maps. Subsequently the way in which the teacher linked the concepts was identified and used to construct the propositions which eventually led to the structure of the whole map. The propositions represented the teacher's ideas about the Doppler Effect.

As a guideline from Novak and Musonda (1991) suggested, a first draft was constructed and revised by going through the transcriptions, video tapes, and voice recorder that contained original records of data. The adjustments were then made to the concept maps to the satisfaction of both the researcher and the expert. In cases where there were disagreements between a researcher and the expert, the propositions were reviewed until the consensus was reached.

During the concept map construction the researcher realised that teachers mostly used different words to refer to the same idea. For an example, the teachers would use the words like a car, siren, an ambulance, a police car to refer to the source of sound or frequency. All these words or terms were represented with a one word 'source' on the concept maps. Furthermore, there were situations where the two concepts would not need a linking word. In such cases a dotted line was used. For instance, one teacher used the concepts receding, low frequency and source. The connection made between the concepts was as follows;



The dotted lines were also used where the arrows crossed each other or went through some nodes because of complication of the concept map. In cases where there were many arrows connecting several nodes to one, it was important to show the propositions with continuous bending arrows. For instance, the propositions below would read as; receding source leads to low frequency.



The propositions like this one were done where the node like 'source' in this case was linked to many other nodes.

Experts' Map as Point of Reference

The scores obtained from concept maps become meaningless if there is no comparison or some sort of point of reference. Normally concept maps are compared with an expert map which is taken as a reference. Then, the similarity index is calculated (Chang, Sung, Chang and Lin, 2005), or closeness index (Goldsmith, Johnson and Acton, 1991). The starting point in most studies is the expert map. However, in this study the expert concept map was constructed using nodes from teachers' concept maps. This was done to accommodate different nodes used by different teachers. For an example; Mr Libele used terms such as 'produced frequency', 'perceived frequency' while other teachers used terms such as 'increasing frequency', 'decreasing frequency', 'higher frequency', 'lower frequency' and others. These terms could not be represented by a single term because that would change the meaning altogether. For instance, 'increasing frequency' is totally different from 'higher frequency' in the context of Doppler Effect.

In addition to using teachers' existing nodes for construction of expert's concept maps, nodes from new concepts were added. These were the concepts that the researcher and the high school physics expert who was also a researcher found to be necessary according to physical science school curriculum. For instance, when Mr Tseki discussed the applications of Doppler Effect, only redshift was mentioned. The national curriculum statement clearly states that the applications should include both redshift and blue shift; therefore blue shift was added on the expert map. Moreover, nodes and links that were found to be incorrect were replaced with correct one so that the concept map propositions could be correct. For an example, Mr Liephe had node 'distance' where the proposition read as follows "Doppler Effect is caused by distance between listener and source". Distance was then

Table 1. Concept maps scores

Teacher	Number of nodes	Number of links with no linking words	Number of incorrect links	Number of superficial links	Number of scientific links	Number of all Cross-links	Number of correct cross-links	Number of chunks	Number of chunks links	Width	Depth
Mr Libele	26	3	2	0	22	1	1	2	8	7	6
Mr Tseki	18	0	2	3	18	6	1	3	13	7	6
Mr Liephe	24	2	5	2	21	6	2	6	12	8	8
Mr Skeby	25	4	0	0	20	2	2	6	19	5	8

Table 2. Teacher concept map scores

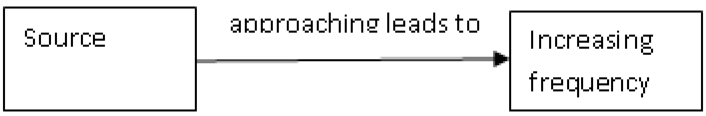
Teacher	Complexity	Connectedness	Correctness
Mr Libele	42	11	365
Mr Tseki	252	17	455
Mr Liephe	384	20	375
Mr Skeby	80	27	336

substituted with 'relative movement' which made the proposition to be correct. Furthermore, there were instances where teachers did not make links between concepts that appeared on their lesson. In cases like that the researcher and physics expert made such links where possible. For instance, Mr Skeby did not link the nodes 'longer wavelength' and 'lower pitch' which were considered related. Subsequently the expert maps were scored for correctness, complexity and connectedness.

Analysis of Concept Maps

The concept maps were scored using rubric first developed by Novak and Gowin (1984) and adapted by Rollnick, Mundalamo and Booth (2009), Pitjeng and Rollnick (2010) and later Pitjeng (2011). This rubric used the constructs; complexity, connectedness and correctness.

The concept map scores were validated by two colleagues who were physics specialists and researchers. Prior to scoring the concept maps three of us discussed the way the rubric would be used. Then each of us took the four concept maps and scored them independently. The team then came together for comparisons of scores and discussed why each of us scored each map the way it was scored. There were some disagreements about certain aspects of scoring in some cases. In such cases three of us would engage in discussion about the best possible way of scoring such an aspect until a consensus was reached. For an example, two of the colleagues had classified the link between the two concepts shown below as correct.



However, after intense discussion the trio then decided that this was an incorrect link.

RESULTS AND DISCUSSIONS OF SCORING CONCEPT MAPS

A closer look at the concept maps yielded the information that is presented on the **Table 1**. This information was then used to come up with the scores for the concept map using different constructs.

The scoring of the concept maps using the information in **Table 1** yielded the figures that are shown in **Table 2**.

Complexity

It can be seen from **Table 2** that the two teachers' complexity scores were very low while the other two had high scores. Mr Libele had the lowest complexity score while Mr Liephe had the highest one. All four teachers had almost the same value of width and depth. Therefore the large difference observed on their complexity scores was due to cross-links. Novak (1998) argues that cross-links show the creativity hence the higher the number of cross-links the more creative the teacher is. Two teachers had 6 cross-links; one had two while one had one cross-link. The two teachers who had lowest number of cross-links were the ones who had two lowest scores on complexity.

This therefore means teachers ability to make cross-links between concepts was responsible for the difference in the scores observed. According to Safayeni, Derbentseva and Canas (2005) being able to show the relationship between the concepts is associated with insight of topic involved. Hence teachers with high number of cross-links had a better understanding of how to teach Doppler Effect while those with low number of cross-links have less understanding for teaching the topic.

Concept maps structures are normally classified as spokes, chain and network. The spokes and chain concept maps are taken to reflect less complicated knowledge structure (Kinchin, Hay & Adams, 2010; Hay & Kinchin, 2006). On the other, network structures are taken to be the evidence of deep, integrated and holistic understanding of the topic (Kinchin et al., 2010; Kinchin, 2008). The network structures are associated with cross-links between concepts. Therefore, the teachers (Mr Tseki and Mr Liephe) with more cross-links had concept maps which were more of network than chain or spoke. On the other side few cross-links meant concept maps being either more linear (chain) or spoke. This was the case with the other two teachers (Mr Libele and Mr Skeby). Based on this observation alone Mr Tseki and Mr Liephe were supposed to have a better understanding of Doppler Effect than Mr Libele and Mr Skeby.

Connectedness

Connectedness is calculated by counting the number of chunks, their correct links and the number of correct cross-links. These are then added together to get connectedness. Connectedness was meant to show how good the teachers were in terms of recognizing the relationship between concepts by making links between them. Kinchin et al (2010) and Safayeni et al. (2005) argue that a sophisticated understanding and high quality teachers knowledge is revealed in concept maps that are strongly connected. Thus, high connectedness score reflected good understanding of a topic.

The four teachers had a wide range of connectedness (**Table 2**) with Mr Libele getting the lowest score while Mr Skeby had the highest score. These results therefore indicate that Mr Skeby had a better knowledge of Doppler Effect while Mr Libele had a relatively weak knowledge compared to the four other teachers. The teachers' connectedness difference was mainly caused by difference in the number of chunks and their links since there was only small difference in terms number of cross-links (**Table 1**). Teachers' concept maps had more chunks compared to the number of cross-links. The chunks alone (without cross-links) would give the overall concept map structure that would be described as spoke. This type of concept map structure is an indication of low level of understanding of a topic (Doppler). Therefore considering the number of cross-links for the teachers' concept maps it is possible that teachers did not have enough knowledge regarding the relationship between the concepts they used.

Correctness

Correctness of the concept map is calculated by counting the number of links and cross-links. The links are then classified and given different scores. Incorrect links were given a score of 0. If the link did not have words it was given a score of 1. If the link represented superficial idea it was given a score of 2. Finally, the link that represented a detailed and sophisticated understanding or what could be described as scientifically rich link was given a score of 4.

Table 2 correctness scores show that teachers had relatively good understanding of Doppler Effect. This can be seen from the fact that there were few incorrect and superficial links that the teachers made between concepts. Only one teacher (Mr Skeby) did not have what could be described as incorrect link or superficial link, an indication that he had a good understanding of the topic. A small number of nodes, high number of incorrect links and few superficial links between nodes could suggest that Mr Liephe's knowledge of Doppler Effect was limited. Mr Libele and Mr Tseki had high number of links that represent scientifically rich links between the concepts. That could mean they had a good understanding of Doppler Effect. However, the presence of incorrect links between the concepts could mean that there were some aspects of Doppler Effect that they did not understand the way the teachers are expected to understand. The knowledge of the three teachers with incorrect links could therefore be classified as limited.

Content Experts as a Yardstick for Teachers' Knowledge

The inconclusive nature of using complexity, connectedness and correctness individually to determine the structure hence knowledge of teachers deemed it necessary to make a comparison with experts' concept maps. The teachers' scores for complexity, connectedness and correctness were compared to that of experts. This was done to gauge the highest possible scores that each teacher could have got. **Figure 1** shows such scores. It is however important to note that this figure was not meant to compare the scores among the teachers.

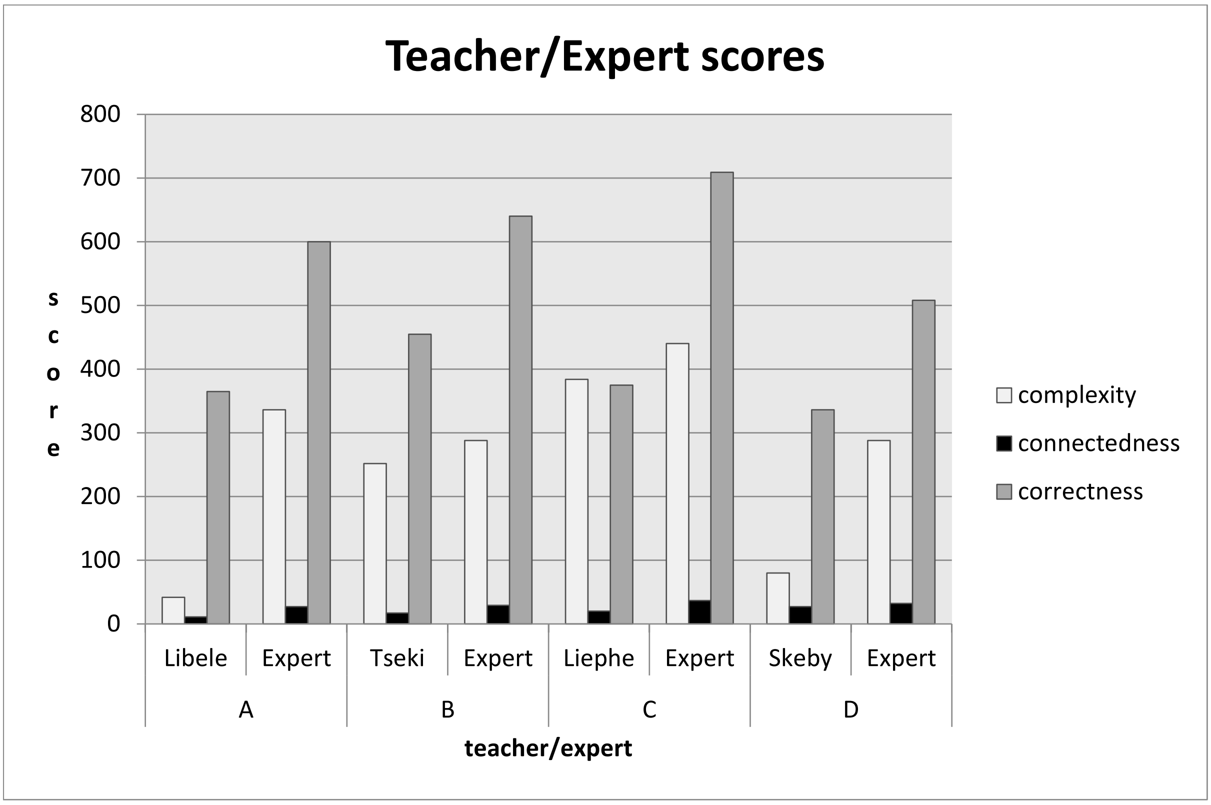


Figure 1. Teacher/expert concept map scores

The difference in terms of complexity, connectedness and correctness between the teachers and experts (**Figure 1**) was an indication that teachers knowledge of Doppler Effect lacked in terms of its accuracy, structure and quality (Safayeni et al., 2005). The lower teachers' correctness scores were mostly a result of teachers either using concepts that were considered unscientific and incorrect, an indication of superficial understanding of the topic (Lachner & Nuckles, 2014). However, Mr Skeby's lower score was attributed to lack of links between some concepts which were deemed necessary by the researcher and as demanded by the curriculum. It is however important to highlight that there was no evidence to indicate that such links were omitted because the teacher did not know that the concepts could be linked. However, the omission of such links was likely to deny pupils to develop a complete and coherent understanding of the topic.

Generally there was some difference between the teachers and the expert in terms of connectedness. This is an indication that teachers lacked the understanding of the relationships between the concepts hence lack of deep understanding of the topic as a whole. However, unlike with 3 other teachers, there was an insignificant difference between Mr Skeby's and the expert's score (**Figure 1**). This could be attributed to the higher number of chunks and the links between them indicating a good understanding of concepts involved.

The complexity was meant to show the depth and width of teachers' knowledge structure. However, the fact that its scoring did not exclude incorrect links and concepts, meant higher scores even for the teachers with superficial understanding of the topic. For instance, **Figure 1** shows Mr Liephe with the highest complexity score hence well-structured knowledge of the topic while the same structure has been mainly contributed by incorrect concepts and links (as shown on **Table 2**). The complexity scores are therefore only reliable where correct concepts and links are used.

CONCLUSIONS

Based on the analysis of the teachers' and expert's maps it can be concluded that teachers showed lack of coherent knowledge. The lack of such coherence as Koponen and Pehkonen (2010) put it, is unlikely to help pupils create organised knowledge themselves necessary for deep understanding of Doppler Effect. As this incoherence emanates from teachers' raw SMK it is highly likely that such knowledge is also incoherent (Bartos & Lederman, 2014). The lack of links and coherence among some concepts which was also likely to hinder the conceptual understanding of such concepts by pupils was found to be the low key point for the teachers. Teachers' low correctness scores, a result of using incorrect or not scientifically accepted notions and ideas, was a common feature for the case teachers. Only one teacher, Mr Skeby was found to have scientifically acceptable ideas about Doppler Effect and related concepts. His lower score was therefore attributed to failure to link some of the concepts which would improve the coherence of the topic as whole. However, it was not established whether such failure was because of lack of knowledge regarding existence of such links or not.

Furthermore it was established in this study that even though the use of construct complexity was a common feature when scoring concepts among researchers its inclusion of incorrect cross-links is a limitation. Hence, it might be appropriate that incorrect cross-links are omitted to improve the reliability of the scoring. This limitation is also an indication that the constructs (complexity, connectedness and correctness) cannot be used in independent of each other.

Even though the case teachers in this study had long teaching experience the fact that their transformed knowledge structures did not match that of experts could be an indication that there is an improvement needed with regard to their teaching. Teachers are normally taken through few days (2-5 days) workshops by the Department of Basic Education to be prepared for new curriculum content. However, the findings of this study, though small sample was used, deem more workshops or training on how to teach new topics a necessity.

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APPENDIX A

Rubric (Rollnick, Mundalamo & Booth, 2008)

Definitions

Node – a word/concept linked to one or more other words/concepts

Link – a direct connection between two nodes on successive levels

Cross-link – a connection between two nodes on either the same level or other levels

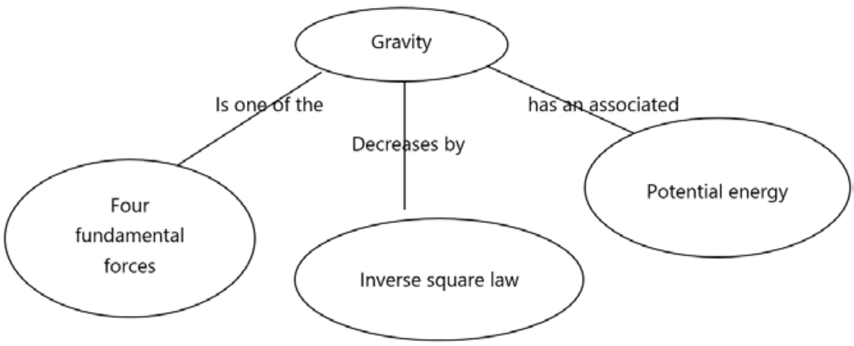
Successor – a linked word one level down from a node

Width – the greatest number of concepts at one particular level on the map

Depth – the length of the longest chain on the map

Chunk – a group of linked concepts for which the leading concept has at least two correct successors

In an example below ***gravity*** is a chunk because it has **3** successors with correct links.



Analysis

A. Correctness

1. All links are assessed for correctness (cross-links and links)
2. The following rating is provided for each link :

   0 = the link is missing or incorrect

   1 = a link is present, but there are no words or propositions on the link

   2 = the link is represents a basic or superficial idea that while acceptable shows limited or "scientifically thin" knowledge.

   4= the link shows a detailed and sophisticated understanding that is "scientifically rich"
3. All of the scores are added for each link and cross-link, and the final score is divided by the number of nodes. This corrects for the fact that some teachers chose to add extra nodes. The formula is: (L1) + (L2)…)/total number of nodes x 100= Correctness

B. Connectedness

1. The correct chunks are determined and the number of correct links (do not include cross links in this count) for each chunk are counted (CNL). A chunk is a group of linked concepts for which the leading concept has at least two *correct* successors.

   Procedural note: in cases where links can be assigned to more than one node always select the link that creates a chunk if applicable

2. The correct cross-links are determined (CCL).
3. A score for the connectedness is:

   nCNL + nCCL= connectedness

C. Complexity

Procedural note: when redrawing the map in hierarchical form nodes are assigned to a hierarchical level based on their distance from the overarching concept.

1 The width of the concept map is assessed (W). This is the greatest number of concepts at one particular level on the map.

2 The depth of the concept map is assessed (D). This is the length of the longest chain on the map.

3 The numbers of cross-links are counted (CCL).

4 The formula: (W x D) x CCL =complexity