British Journal of Education
Vol.11, Issue 13, 57-81, 2023
Online ISSN: 2054-636X (Online)
Print ISSN: 2054-6351(Print)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development-UK

Corroborating Magnusson's PCK Model for Teaching Genetics at The Ghanaian Senior High School Level

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doi: https://doi.org/10.37745/bje.2013/vol11n135781 Published October 08 2023

Citation: Wilmot D., Owusu K.A. and Ayimbila E.A. (2023) Corroborating Magnusson's PCK Model for Teaching Genetics at The Ghanaian Senior High School Level, *British Journal of Education*, Vol.11, Issue 13, 57-81

ABSTRACT: *Confirmatory factor analysis was conducted on survey data from 149 Senior High School biology teachers in Ghana to validate Magnusson's framework of pedagogical content knowledge (PCK) in science teaching. The questionnaire aligned with Magnusson's conceptualization of PCK, encompassing components like teaching orientations, knowledge of students' understanding, instructional strategies, assessment, and science curriculum within genetics. The results affirmed the integrative model of PCK, indicating strong interactions among its components. While the transformative model also showed relevance, its imposition led to a notable decrease in goodness of fit. This underscores the applicability of Magnusson's integrated PCK model for understanding Ghanaian SHS teachers' PCK in genetics instruction. The findings emphasize the importance of integrated training in knowledge domains like assessment, instruction, curriculum, and understanding to foster effective teaching.*

KEYWORDS: PCK, pedagogical content knowledge, teacher knowledge, assessment, instructional strategies, teaching orientations, integrative PCK, transformative PCK

INTRODUCTION

Research is replete with examples that demonstrate the impact of teacher knowledge (Begle & Geeslin, 1972, Eisenberg, 1977; Clark & Peterson, 1986; Hill et al., 2005; Tchoshanov, 2011). One type of teacher knowledge that has gained research attention over the years, was pedagogical content knowledge or PCK, suggested by Shulman (1986). Shown to affect student understanding(Olfos et al., 2014), this knowledge was originally suggested to describe the professional knowledge that sets a teacher apart from an ordinary content specialist.

(Shulman, 1986b) originally described PCK as a mix between pedagogy and content knowledge and suggested it was subject specific and comprised of two components, namely;

1) Instructional strategies: defined as the knowledge of the most useful forms of teaching topics in one's content/subject area.
2) Learning difficulties: defined as knowledge of what makes topics easy or difficult for students.

Others that followed Shulman both agreed and disagreed with the nature of PCK as Shulman described. While some argued that PCK was subject specific (Hashweh, 1985; Van Driel et al., 1998; Kind, 2015) others (Fernández-Balboa & Stiehl, 1995; Farré & Lorenzo, 2009) argued that PCK has a generic nature and results from the integration of different components and others.

If PCK is generic in nature, as adopted by Wu (2013), it relies on the skill of the teacher to combine different components, drawing on subject matter, pedagogy and context and integrating them as needed. Evidence for generic PCK has been demonstrated by (Barendsen and Henze, 2019) who observed generic PCK or GPCK for a teacher's PCK-on-action, or articulated PCK. Similarly, Nind (2019) also documented generic PCK mostly under organizational aspects of teaching. This included, for example, decisions on when group work might be needed, how to pace lessons, how to plan scaffolding, etc, were all generic and not specific to topics.

If PCK is subject specific, it means that a teacher possesses separate PCK packets for teaching different subjects and different topics as well. Nind (2019) also reported topic-specific PCK or TSPCK when looking PCK in practice. It is important to note that Shulman's original conceptualization of PCK was in fact subject specific in nature. Several studies have also assessed and observed TSPCK in teachers ((Mavhunga, 2014; Miheso & Mavhunga, 2020; Ndlovu, 2017; Stender et al., 2017).

It is important to note that these conceptions of PCK are not necessarily mutually exclusive. Nor is one, either generic or topic-specific, unanimously accepted as the de-facto conceptualization of pedagogical content knowledge. But rather, as some literatures suggests, a teacher may possess both as observed by Nind (2019). As explained, Nind (2019) documented GPCK the planning or organization of teaching, but observed TSPCK when teachers were teaching. Both TSPCK and GPCK may be important for effective teaching. Nevertheless, at a meeting of researchers in science and mathematics PCK, known as the PCK Summit (Berry, Friedrichsen & Loughran, 2015) held in Colorado, 2012, there was an attempt to come to a consensus on this issue. One of the consensuses arrived at, was that PCK is specific to particular subject matter (Gess-Newsome, 2015). However, this "consensus" model and its ideas about the topic-specificity of PCK not necessarily correspond to the widely held beliefs of the larger community of science PCK researchers (Barendsen & Henze, 2019; Davis & Krajcik, 2005; Nind, 2019).

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Aside whether PCK is generic or subject specific, there is also the issue of whether PCK exists as a knowledge base or is only an ad-hoc integration of other types of teacher knowledge. The former refers to the transformative model of PCK which defines PCK as the "transformation" of the individual knowledge bases of subject matter, pedagogical knowledge and knowledge of contexts into the new knowledge, PCK (Kind, 2009). To explain this Gess-Newsome (1999) likened transformative PCK to "a chemical compound, in which elements cannot easily be separated: Gess-Newsome describes them as being ―inextricably combined into a new form of knowledge, PCK" (Gess-Newsome, 1999, p. 11) On the other hand, the integrative model of PCK does not view PCK as a distinct, separate knowledge component. But rather, this type of PCK exists as an integration of subject matter knowledge, pedagogy and context knowledge. Each of these separate knowledge bases return their distinctiveness and are called into play as the teacher teachers. This model, described again by Gess-Newsome is like a "chemical mixture in which components retain their individual identities, but are indistinguishable on a macroscopic level" (Gess-Newsome, 1999, p. 11).

It is again, important to note, that while these models of PCK represent two traditionally extreme ends of the PCK spectrum (Gess-Newsome, 1999) there have been attempts to reconcile them. According to Mientus et al. (2022), there is a consensus among PCK researchers that different knowledge bases constitute PCK. There also seems to be a consensus that more pronounced knowledge bases contribute to more pronounced PCK (Mientus et al., 2022). This is in contradiction with Park and Suh (2019) who suggest, arguing in favour of an integrative model of PCK, that a teacher's PCK level depends on the interaction and coherence between the components of PCK than on the individual components themselves.

In light of these the framework for PCK suggested by Magnusson et al. (1999) becomes all the more relevant for PCK research. Magnusson et. al. (1999) proposed that PCK includes five components which were particularly important for science teachers. The components of PCK, according to Magnusson's framework consisted of Orientations to teaching science (OTTS), knowledge of science curricula (KISC), knowledge of assessment of scientific literacy (KAS), knowledge of instructional strategies (KIS) and knowledge of students' understanding of science.

This framework could be said to be integrative in nature, emphasizing connections between the components and topic-specific, in that it looked at PCK specifically for science topics as applied in research (Akın & Uzuntiryaki-Kondakci, 2018; Park & Suh, 2019; Şen et al., 2022). Majority of the studies that have evaluated PCK using this framework have done so mostly qualitatively ((Akın & Uzuntiryaki-Kondakci, 2018; Park & Chen, 2012; Park & Suh, 2019; Şen et al., 2022) and have implicitly assumed that Magnusson's framework along with the suggested interactions is objectively reliable.

There is the need therefore to confirm Magnusson's framework to verify whether the components and the hypothesized interactions between them is mathematically sound. In order to do this, Magnusson's framework was applied to Ghanaian SHS genetics teachers' PCK. Genetics, with many applications in disease (Ober, 2005; Longdon et al., 2014), agriculture (Qaim, 2009; USAID, 2007), sociology, etc., was chosen because it has been included in the

West West African Senior School Certificate Examinations (WASSCE), consistently from 2008 to 2021. Labelled under "Heredity" in the Ghana education service syllabus for SHS, for year 3 students, it includes concepts such as the definition of genetics, chromosomes, inheritance, mendelian genetics, sex-linked characters, gene interactions, genetic variation, and recombinant DNA technology. Underscoring the importance of this section, consistently, questions from this section of the syllabus have featured in the West African Senior School Certificate Examinations (WASSCE). Also consistent over the years has been reports from the Chief Examiner (WAEC 2012; WAEC, 2014; WAEC 2017; WAEC 2018; WAEC 2020; WAEC 2021) of students struggling with genetics concepts like the genetic engineering, transcription, Mendel's laws, hybridization and test cross.

This research therefore seeks to assess whether Magnusson's framework will be confirmed, particularly for looking at the PCK of Ghanaian SHS genetics teachers.

Research Questions

As such, the following research question guided the study

1. How does the PCK of Ghanaian SHS genetics teachers fit with Magnusson's five-component integrative framework?
2. To what extent does Magnusson's model of PCK align with either an integrative or transformative framework?

Significance of the Study

If Magnusson's integrative framework is corroborated and a better fit than the transformative model for the PCK of the teachers who teach these students, it could pave the way for an in-depth look into the professional teaching knowledge of Senior High School genetics teachers and possibly offer a point of intervention to affect the understanding of SHS students. Specifically, it would emphasize the need for training programs to focus on the interaction between the knowledge bases and not only on the development of the individual knowledge bases. The confirmation of this framework and the instrument that will be based on it will also allow precise, consistent measurements of the PCK science teachers for genetics and adapted/replicated for other topics. Overtime, the model can also be used to make predictions about how different variables, and in-fact specific components will affect other components of the framework.

LITERATURE REVIEW

To Shulman's original PCK components (instructional strategies and learning difficulties), Grossman (1990) added two other components (that is *knowledge of curriculum* and *knowledge of purposes for teaching*). Grossman's conceptualizations were made in the field of languages. Magnusson et al. (1999) then followed with a elaboration on PCK in the field of science education. In their since very influential conceptualization of PCK, Magnusson et. al. (1999), building upon the work of Grossman (1990) and Tamir (1988), proposed that PCK includes five components which were particularly important for science teachers. The components of PCK, according to Magnusson et al. were,

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i. Orientations to teaching science

ii. Knowledge of science curricula

iii. Knowledge of assessment of scientific literacy

iv. Knowledge of instructional strategies and,

v. Knowledge of students' understanding of science

In agreement with Magnusson et al. (1999), Park and Oliver (2008) identified five components of PCK: *knowledge of students' thinking about science , knowledge of science curriculum, knowledge of scientific instructional strategies, knowledge of assessment of students' science learning, and orientations to teaching science*. These elements, described further below, are crucial, according to Davis et al. (2011), because together, they assist teachers in presenting specific subject matter in ways that make it understandable to students.

Orientations Toward Teaching Science and Learning (OTTS)
This component of PCK refers to teachers' knowledge and beliefs about the purposes and goals for teaching science at a specific level (Magnusson et al., 1999). Grossman had initially defined this knowledge as the understanding of the goals for teaching a topic at a certain level or the "overarching concepts" of teaching a specific subject. In other words, this represents a teacher's perspective or conceptualization of scientific instruction. This "orientation" a teacher possesses may be thought of as a "conceptual map" that informs instructional decisions such as daily objectives, the substance of student assignments, the use of textbooks and other curricular resources, and student learning evaluation (Borko & Putnam, 1996). Initially Magnusson prescribed nine different teaching orientations. However, as Cobern et al. (2014) explained, one of the first decisions a teacher will make, whether overtly or implicitly, is whether to present and explain scientific concepts and principles directly to the students, or to have the students explore and discover the scientific explanations for themselves. Based on this, Cobern et al. (2014) classed teaching techniques as direct and inquiry. Figure 1 illustrates four common instructional orientations that resulted from the division of these two dimensions into two versions each. Compared to Magnusson's original nine orientations, this taxonomy of scientific teaching orientations is both shorter and more focused. Also, the visions of inquiry outlined in reform documents suggest a desire to move away from more lecture-based forms of instruction,

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Fundamental epistemic mode	Variant for each mode	Operationalized description (abbrev.)
Science presented as factual knowledge... *"Ready-Made-Science"*	1 Didactic Direct	Teacher presents and explains science content directly... illustrates with example or demo. No student activities.
	2 Active Direct	Teacher presents and explains science content directly... students actively engage in verification/confirmation.
Science as developed by process of scientific inquiry... *"Science-in-the-Making"*	3 Guided Inquiry	Students actively explore phenomenon or idea with teacher guidance toward desired science content.
	4 Open Inquiry	Students actively explore phenomenon or idea as they choose... teacher facilitates process but does not prescribe.

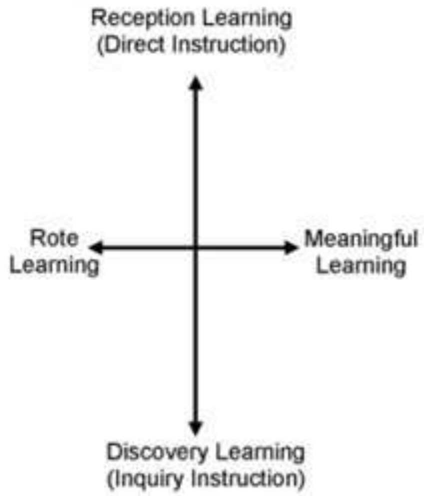

Figure 1. Teaching Orientations and Ausubel's axes (Cobern et al., 2014)

This conceptualization has been used by researchers over the years to study teaching orientations (Güven et al., 2019; Ladachart, n.d.; Sahingoz & Cobern, 2020; Sondlo & Ramnarain, 2020). For example, (Güven et al., 2019) used this conceptualization to identify the influence of science learning experiences on science teaching orientations. For this subscale, the interest of this research was whether a teachers taught topics under genetics with “didactic direct”, “active direct”, “guided inquiry” or “open inquiry” orientations.

Knowledge of Science Curriculum (KSC)

This component was originally explained by Magnusson and colleagues as comprising of two components. These included “mandated goals and objectives” and “specific curricular programs and materials”. Consistent with Shulman (1986a), Grossman (1990) also suggests that this knowledge includes what teachers know about what students have learnt in the past and what they will learn in the future. Using this framework, Park and Oliver (2008) and later (Park & Chen, 2012) measured Teachers’ curricular knowledge by assessing teachers’ vertical and horizontal curricular knowledge and curricular saliency. Vertical curricular knowledge was explained by Shulman (1986a) as the knowledge of curricular materials and topics that students have handled and will handle in the future in the same subject area. Lateral curricular knowledge describes the knowledge of the teacher on materials and topics being taught in other subjects that students are studying at the same time.

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In light of this, this current study viewed "curricular knowledge" from the perspective of whether teachers use vertical curriculum (past knowledge or advanced knowledge) or lateral curricular knowledge (science or non-science) in teaching specific genetics concepts.

Knowledge of Students' Understanding of Science (KSU)
Magnusson and his colleagues described this knowledge as the type of knowledge that teachers need to have about students in order to help students develop an understanding of science. This was teachers' knowledge about students' understanding and it included "knowledge requirements for learning specific science concepts" and "areas of science that students find difficult." Research has shown that teachers are able to consider appropriate teaching strategies that fall in line with objectives when they pay attention to student learning difficulties (Bayram-Jacobs et al., 2019). In looking at objectives for learners, one useful framework has been Bloom's taxonomy (Bloom, 1956) and the later revised Bloom's taxonomy (Krathwohl, 2010). This taxonomy allows for learning goals to be established so that learners and students are on the same page about what is to be learned (Armstrong, 2010). As such it is useful to design assessment tasks and strategies (Armstrong, 2010). In fact, the teaching syllabus for biology at the Senior High School in Ghana prescribes that evaluation be done according to "profile dimensions" based on bloom's taxonomy(Ministry of Education Ghana, 2010). Based on this, in keeping with Magnusson's original conceptualization of this components, items were designed to measure teachers' knowledge of students learning (KSU) by asking multiple-choice questions that assessed level of Bloom's taxonomy students found most difficult under certain concepts in genetics. These profile dimensions were "remembering", "understanding", "applying" and "analyzing". The instruments were designed for teachers to choose which level was most difficult for their students to perform or which type of cognitive ability was pre-requisite to understand a particular topic.

Knowledge of Assessment in Science (KAS)
This type of knowledge was also conceptualized by Magnusson and colleagues to comprise of two categories: "knowledge of the dimensions of science learning that are important to assess" and "knowledge of the methods by which that learning can be assessed".

Magnusson's framework, while it did not prescribe specific dimensions that are important to assess, agreed that it was important for teachers to be knowledgeable about some conceptualization of scientific literacy. Teachers' understanding of scientific literacy would then inform how they assessed science learning for the individual topics the teach. On scientific literacy Gormally et al. (2012), designed an instrument to test scientific literacy skills. This instrument however measures skills in a broad domain neutral sense. Park and Oliver (2008) on the other hand measured teacher knowledge of assessment by examining the assessment methods and the learning goals that were important to assess. Within the context of Ghana, these dimensions have been specified for the individual topics but the "profile dimensions" used to describe each major subtopic under the topic under study (Ministry of Education Ghana, 2010).

Different levels of knowledge are assessed by different assessment tools (Sewagegn, 2020). Some of these assessment tools used around the world include written tests, reports, presentations and lab work (Keshavarz, 2011). Using lesson objectives based on action verbs under Bloom's taxonomy Gormally et al. (2012) have also designed a tool that maps objectives to appropriate assessment. Another way of differentiating between assessment is by grouping assessment into traditional versus alternative or authentic assessment(Nasab, 2015). Traditional assessment typically includes a test or quiz and alternative assessment uses other methods such group projects, research projects, student portfolio etc. Alternative assessment encourages open-ended, creative answers and spurs the student to apply knowledge to solve a problem (Nasab, 2015). As such, while traditional assessment is quick and allows a quick measurement of student performance, authentic assessment allows for more variety in student expression of what they know (Nasab, 2015).

Within the context of Ghana, this component then was assessed by asking teachers how they would assess certain profile dimensions of genetics knowledge using tools of assessment that are relevant to the Ghanaian context. These tools, similar to those identified by Keshavarz (2011) but relevant to Ghana. These tools were chosen to reflect two typical traditional assessment methods (paper and pencil-based tests" and "written take-home assignments") and two authentic assessment methods ("presentations by students" and "observe student performance on simulations of lab procedure").

Knowledge of Instructional Strategies (KIS)

Originally included in Shulmans (1987) components of PCK, Kassem (1992, p. 45) defines "teaching techniques", later called instructional strategies by Magnusson et al. (1999), as teacher's activities in the class to involve students in the subject matter, and requires that students participate in learning activities, share equally with other learners, and react to the learning experience.

According to Magnusson et al. (1999), the "knowledge of instructional strategies" component of PCK is comprised of two categories: *knowledge of subject-specific strategies*, and *knowledge of topic-specific strategies*.

For science teaching, some of the identified effective instructional strategies include hands-on activities, teacher-led discussions, and inquiry-based activities (Ferlazzo, 2021). Within the Ghanaian context also, calls have been made for teachers to avoid teacher-centred instructional methods (Ngman-Wara, 2015) and adopt interactive instructional strategies (Yeboah et al., 2019). As such for this component, this research looked at how teachers taught certain topics in genetics using either teacher centred of student-centred activities given their different effects on performance of students (Ezurike & Ayo-Vaughan, 2020) and teacher identities (Keiler, 2018). These, by order or increasing student centred ness included "a well-organized lecture", "take home reading assignments", "classroom discussions" and "lab experiment"

Relationships between the Five Types of Knowledge

According to Magnusson's framework, the prime component of PCK is OTTS which is interlinked with all the other components; KSC, KSU, KAS and KIS. Magnusson et al. (1999) also acknowledged the importance of the interaction and coherence between all of these five components but did not show such linkages in their model. A schematic illustration of their initial conceptualization is presented in Figure 2.

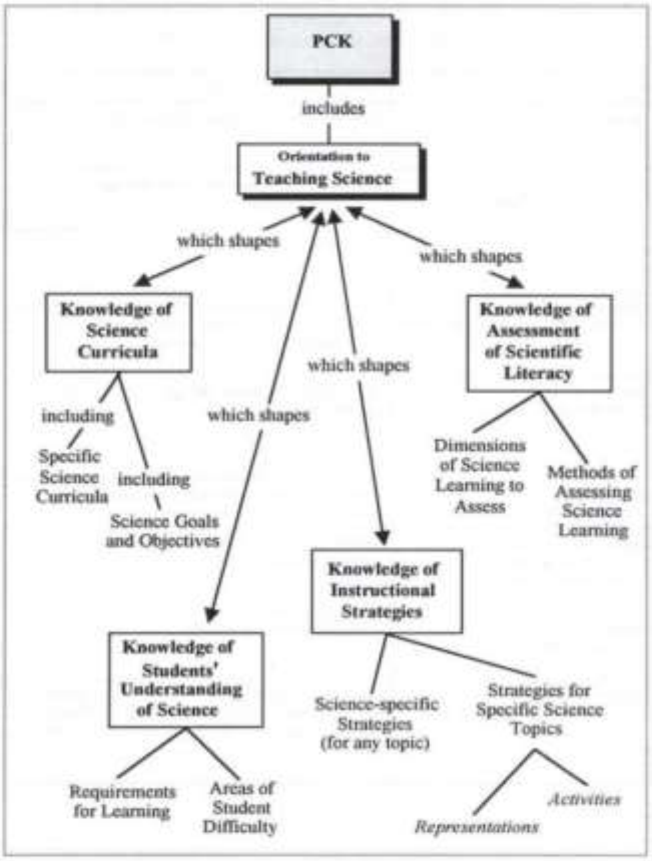

Figure 2. Magnusson et al.'s (1999) five-component model of PCK

Even though a central role for teaching orientations is shown, as per their own description cross-linkages between all components were seen as a vital part of this model. Magnusson's model therefore describes a PCK that is constituted of teachers' teaching orientations, knowledge of instructional strategies, knowledge of assessment in science, knowledge of science curricula and teachers' knowledge of student understanding interacting with each other, or having an influence on each other, to produce effective teaching. While not explicitly stated this model suggests a PCK that is integrative in nature. Based on this, Park and Oliver (2008) came up with a model of the five interacting components of PCK which they termed the "pentagon model" of PCK. This integrative approach to the model has been used by other researchers to map out (Park & Chen, 2012)and create measures of PCK (Park et al., 2018).

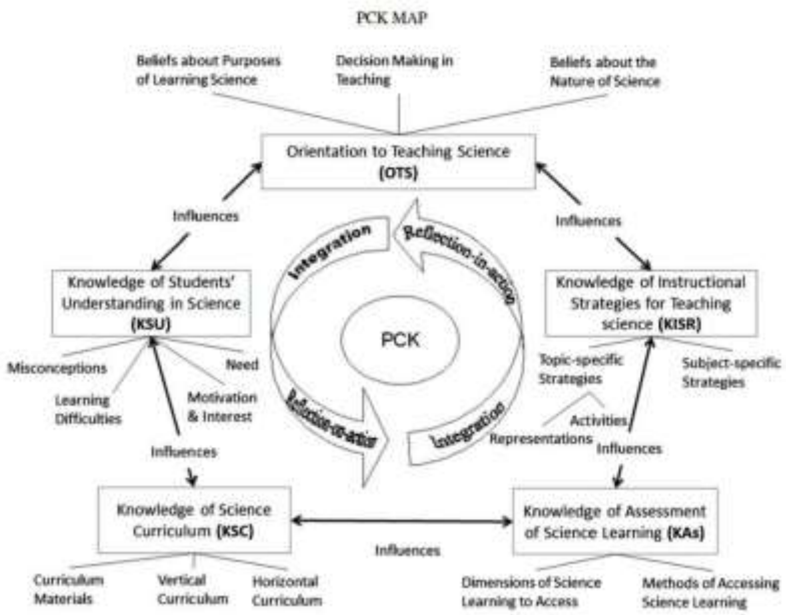

Figure 3. Pentagon Model of PCK (Park & Oliver, 2008)

While studies have mostly looked into measuring PCK through Content Representations (CoRes) and Pedagogical and Professional Experience Repertoires (Loughran et al., 2006), questionnaires (Abdullah and Halim, 2010) collaborative conversations, lesson plans, case narratives, and other performance assessments (e.g., Angeli & Valanides, 2009; Harris et al., 2010; Koehler et al., 2007; Mouza & Wong, 2009). Few have looked into corroborating the framework according to the components and their proposed interrelationships. This research looks confirm whether model for PCK conceptualised by Magnusson's framework will be corroborated in SHS teachers' PCK for teaching genetics.

METHODOLOGY

Research Design

Churchill's (1979) paradigm for construct development and measurement was used as a framework for the design of this research, which is shown in Figure 4. As such we first reviewed literature on the components of Magnusson's framework; both to understand the framework and to ascertain current research opinions on the individual components and their make-up. The literature conducted is shown in the literature review for the paper. From this, the construct was then operationalized into an initial questionnaire consisting of fifty items, ten per component.

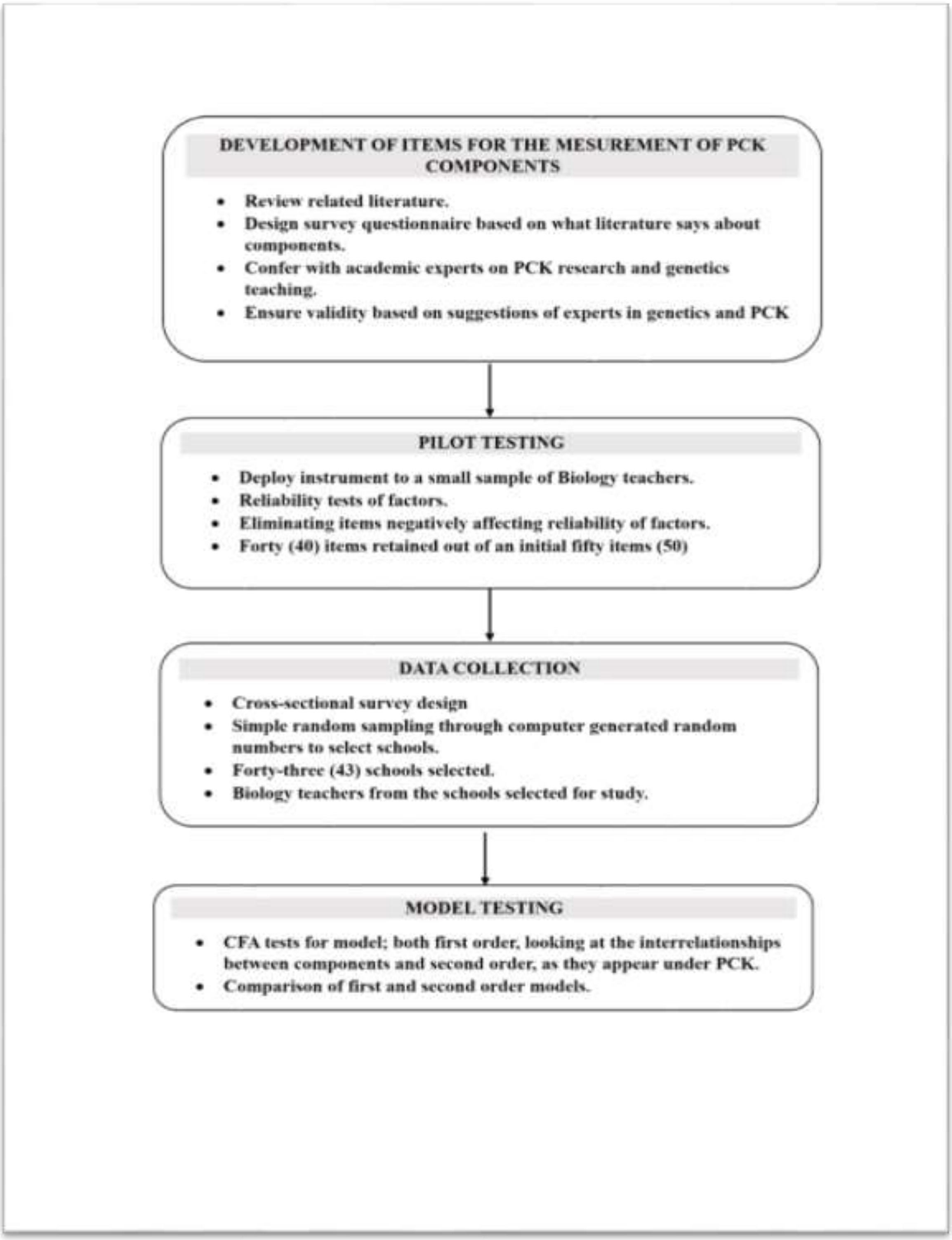

Figure 4. Framework for the design of this research,

These items were then evaluated for validity with regards to the content of genetics taught at the SHS level, third year, by meeting and engaging with experts in teaching SHS biology. Following this, engagements between a team of two experts in pedagogical content knowledge were consulted to ascertain whether the questions fit under the PCK construct itself. Items were then streamlined in accordance with comments from experts in SHS biology teaching and PCK research.

The instrument was pilot-tested on 30 senior high school biology teachers in a region that was not selected to be part of the main study. The results of the pilot test helped to finetune the instrument. The reliability of the instrument for measuring the five components of PCK was assessed using Cronbach's alpha. Ghazali (2008) and Griethuijsen et al. (2014) are of the position that a Cronbach's alpha of values 0.6 and above are acceptable. After piloting, the 40 of the 50 items under the instrument were retained. All subscales obtained Cronbach's alpha above 0.6; with OTTS reporting 0.654, KSC reporting 0.73, KSU, KSU reporting 0.692, KAS reporting 0.686 and KIS reporting a 0.939 value

For the study itself, in order confirm Magnusson's model in Ghanaian biology teachers' genetics PCK, a cross-sectional survey was chosen. A cross-sectional survey was found to be suitable for this study because it allows for collecting data from a sample of biology teachers without altering their aforementioned knowledge (Nworgu, 2006; Mitchell & Jolley, 2004; Creswell; 2003; Cohen, Marion, & Morrison, 2000; Fraenkel & Wallen, 2000). Furthermore, this design enabled data to be collected on the sampled teachers (i.e. a snapshot of teachers in the three selected regions) at only one point in time (Mitchell & Jolley, 2004).

Simple random sampling through computer generated random numbers was used to select the schools from the regions. Forty-three schools were randomly selected across the three regions in Ghana.

From each selected school, all available biology teachers were recruited. There were 152 biology teachers in these selected schools. Out of these 152 biology teachers, 149 were able to complete the questionnaire. One hundred and sixteen (116) of these teachers were male and thirty-three of them were female.

Data Collection Instrument.

The instrument for the study was a 40-item multiple-choice questionnaire developed to assess teachers' PCK for teaching genetics according to Magnusson's framework. The instrument was multi-dimensional in nature with the components of PCK as the various subscales. Thus, there were items measuring orientations to teaching science (OTTS), knowledge of science curriculum (KSC), knowledge of students' understanding (KSU), knowledge of assessment in science (KAS) and knowledge of instructional strategies (KIS).

For the "orientations to teaching science" subscale (OTTS), the stem of the multiple choice items were contexts containing scenarios that describe genetics concepts. The options were organized under four main orientations, originally conceptualized by Cobern et al. (2014); didactic direct, active direct, guided inquiry and open inquiry. Teachers would choose how they would teach a genetic concept in a particular scenario. This subscale had nine items after pilot. Responses to this subscale were assigned numerical codes; 1 for didactic direct, 2 for active direct, 3 for guided inquiry and 4 for open inquiry.

The items under the KSU subscale, eight in number, presented topics and scenarios under genetics. The options were organized in order of increasing levels of cognitive tasks. These were; “remembering”, “understanding”, “applying” and “analyzing”. The teachers were to choose which level was most difficult for their students to perform or which type of cognitive ability was pre-requisite to understand a particular topic. Responses to this subscale were assigned numerical codes; 1 for remembering, 2 for understanding, 3 for applying and 4 for analyzing.

The knowledge of assessment of scientific literacy (KAS) subscale had seven items and sought to identify methods of assessment teachers would employ in assessing student performance in genetics topics identified in the SHS biology syllabus. The options were organized in order of traditional vs authentic assessment. They were; ”paper and pencil-based tests” (later coded as 1) and “written take-home assignments” (later coded as 2), which are traditional assessment methods, against “presentations by students” (later coded as 3) and "observe student performance on simulations of lab procedure” (later coded as 4) which are examples of authentic assessment.

For the knowledge of instructional strategies subscale (KIS), teachers were asked how they taught certain sub-topics under the broad topic of “biology of heredity” in the biology syllabus. What was of interest was whether teachers employ “a well-organized lecture” (later coded as 1), “classroom assignments” (later coded as 2), “class discussions among students” (later coded as 3) or “laboratory experiment” (later coded as 4) in teaching their students. These options were organized in terms of increasing student participation to ascertain whether teachers used student-centered or teacher-centered approaches in teaching their students. This subscale had seven items after pilot.

Under the KSC subscale, questions were interested with whether teachers consulted vertical (VC) or lateral curriculum (LC) in teaching genetics concepts to students. Options were structured as either vertical curriculum (past knowledge of students, later coded as 1), vertical curriculum (advanced future knowledge, later coded as 2), lateral curriculum (other science topics, later coded as 3) or lateral curriculum (non-science topics, later coded as 4). This subscale had nine items after pilot

In summary, the options under the questions were organized in order of increasing levels of cognitive tasks for KSU, from teacher centered to student centered (OTTS, KAS & KIS) and from vertical to horizontal curriculum (KSC). As such, data for the responses of the questionnaire were assigned ordinal-type numbering when coding into SPSS. .

Data collection Procedure

To gain access to the teachers, who are the units of measurement of this study, contact was made with the school leadership (headteachers or their assistants) explaining the nature of the research through an in-depth information sheet. An “introductory letter” signed by the Department of Science Education, UCC and explaining the nature of the research was

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presented to school leadership. When school leadership was satisfied with the ethical issues, teachers were provided with information sheet and consent forms to read and sign. Teachers who consented to be part of the study were provided with the questionnaire and encouraged to respond individually.

Data Processing and analysis

To assess whether the genetics PCK Ghanaian SHS biology teachers fully conform to the five-component model of PCK, confirmatory factor analysis was done. Indices of fit generated by the analysis confirmed whether the teachers answered the questionnaire according to the pre-supposed five components of PCK. Confirmatory factor analysis (CFA) is used because it allows for formal testing, and confirmation of multiple aspects of hypothesized models (in this specific case, Magnusson's framework) (Lahey et al., 2012). This sets it apart from other methods of factor analysis such as principal components analysis (PCA) which are only exploratory in nature (Lahey et al., 2012).

RESULTS

Research question 1

To answer the question of whether Magnusson's integrative framework is corroborated by Ghanaian SHS genetics teachers' PCK Confirmatory factor analysis was conducted on the first order model which describes the integrative nature of PCK. That is, PCK itself doesn't exist, but is explained by the interaction between the five tangible knowledge types; OTTS, KSC, KSU, KAS and KIS. To do this, confirmatory factor analysis was performed on the goodness-of-fit of the first order model (shown in Figure 5) of five inter-related factors factors. The values of six model fit indices Root mean square error of approximation (RMSEA), Goodness-of-fit index (GFI), Adjusted goodness-of-fit index, Comparative fit index (CFI), Tucker-Lewis Index (TLI), Standardized Root Mean Square Residual (SRMR) and Bollen's Incremental Fit Index (IFI) are presented in Table 1

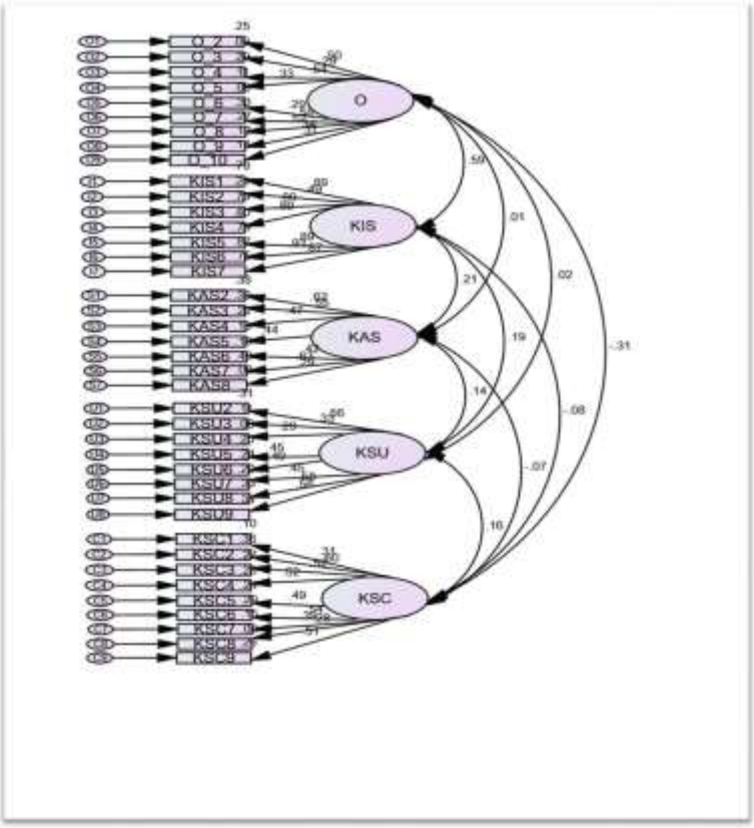

Figure 5. First-order model of PCK showing components as observed factors

RMSEA	IFI	TLI	CFI	AGFI	Standardized RMR
0.036	0.917	0.908	0.914	0.763	.0763

Table 1. Goodness-of-fit Indicators of the Five Component Model of PCK

Literature suggests that RMSEA values less than 0.05 are good, values between 0.05 and 0.08 are acceptable, values between 0.08 and 0.1 are marginal, and values greater than 0.1 are poor (Fabrigar et al, 1999). Therefore, the RMSEA value of 0.036 in this sample indicates a good fit. The CFI value is 0.914, which shows a relatively good fit (Bentler, 1990). The other fit indices, IFI and TLI, should be over 0.9 for a good fit (Bentler, 1990). Others have also suggested (Hu & Bentler, 1999; Kyndt & Onghena, 2014) that the SRMR value should also be less than 0.08. As such the SRMR value for this model is good and the first order model (shown in Figure 4) is accepted.

Research question 2

To answer the question of whether a transformative PCK model is a better or worse model of PCK, the second-order model, where the five components are latent factors under PCK itself, as would be the case for a tangible, transformed model of PCK, shown in Figure 5, was also evaluated with CFA analysis.

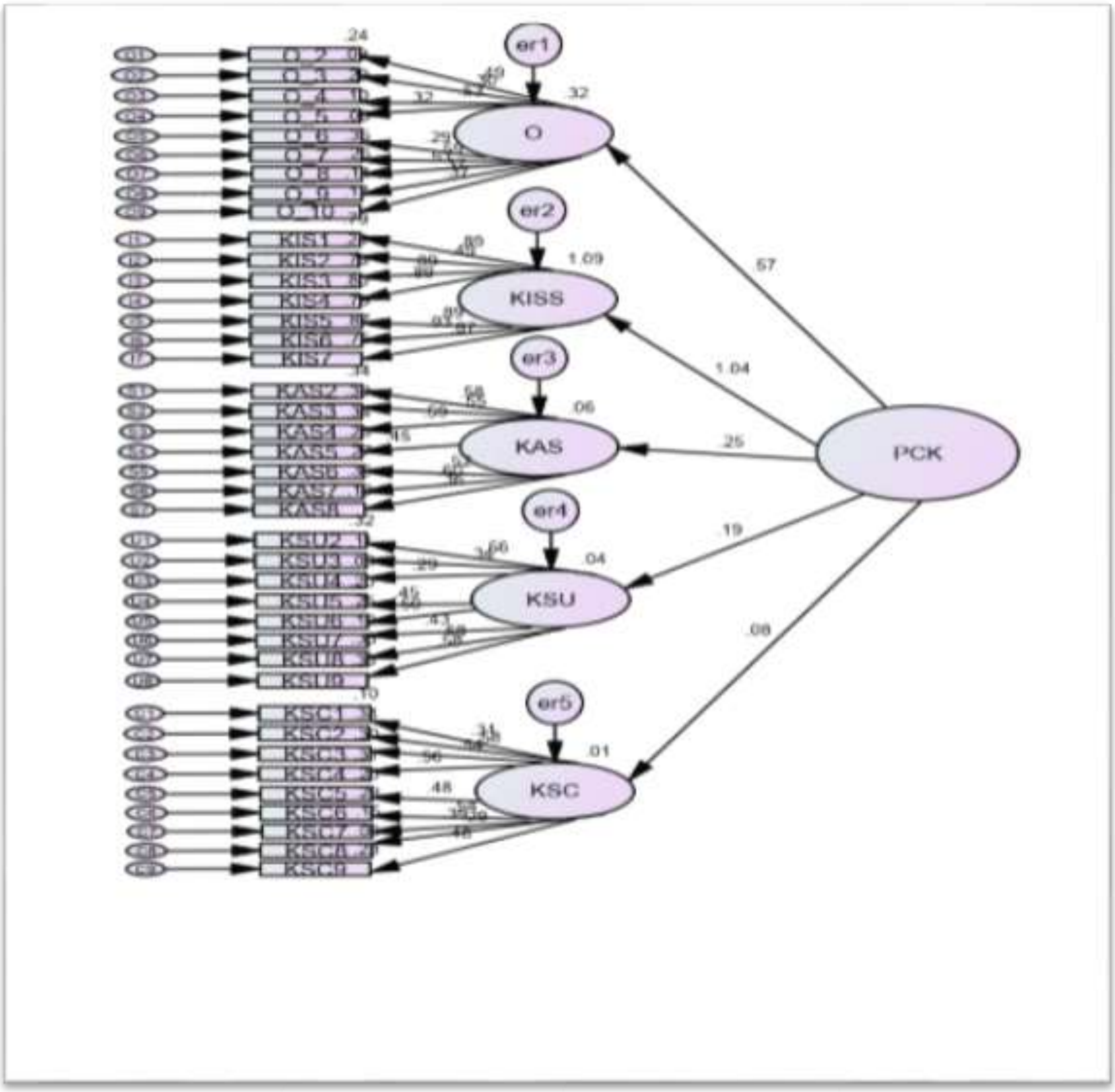

Figure 6. Second-order model showing components as latent factors under the observed PCK construct.

The RMSEA value of the second-order model, shown in Table 2, of 0.037, indicates a good fit. The CFI value is 0.912 which is also a good fit (Bentler, 1990). Likewise the TLI, IFI and CFI are all above 0.9 and also indicate a good fit (Bentler, 1990). The SRMR is also less than 0.08 (Hu & Bentler, 1999; Kyndt & Onghena, 2014), further suggesting that the second order model is a good fit.

RMSEA	IFI	TLI	CFI	AGFI	Standardized RMR
0.036	0.912	0.904	0.910	0.760	.0796

Table 2. Goodness-of-fit Indicators of the Five Component Model of PCK

To test whether the imposition of a the second-order factor model results in a significant decrease in fit relative to the first-order model the chi-square difference test has been suggested by Brown (2006). A significant difference in the two models would suggest that the model with less degrees of freedom fits the data better than the model with more degrees of freedom (T. A. Brown, 2006). The results of the chi-square difference test, shown in Table 3, show a significant ($p<0.05$) value and therefore suggest that the first order model, fits the data better than the second order model.

Model	Chi-square	*df*	*p*-value
First Order	876.049	730	0.0379
Second Order	887.831	735	
Difference	11.783	5	

Table 3. Chi-square difference test

The results suggest that while the second order model, which shows the five components of PCK as latent (transformed) factors under an observed or tangible PCK is a good fit to the data, the first order model which shows the integration these five components as observed factors is a significantly better fit.

DISCUSSION AND IMPLICATION

The results suggest that with respect to Ghanaian SHS biology teachers' genetics PCK, Magnusson's framework, that is the description of the components and their relationships with each other, is a practical way of thinking about teachers' PCK. Specifically, Ghanaian genetics teachers PCK is best thought of as a result of the interaction of teachers' teaching orientations, teachers' knowledges of instruction, of assessment, of science curricula and of students' misunderstanding/understanding. All of these components work with each other in an interrelated manner where, for example, a teacher's orientations have an influence on the kind of instructional strategy he uses and vice versa and a teachers' knowledge of students' misunderstanding has an influence on their teaching orientations and vice versa. In fact, others like (Park & Oliver, 2008) described the interrelatedness of PCK components in a model they called the "pentagon model of PCK". They also defined PCK as an integration of the five components, just as described by Magnusson et al. (1999), namely; (a) Orientations toward Teaching Science (OTTS), (b) Knowledge of Students' Understanding in Science (KSU), (c) Knowledge of Science Curriculum (KSC), (d) Knowledge of Instructional Strategies and Representations (KISR), and (e) Knowledge of Assessment of Science Learning (KAS). It suggests then that the quality of PCK depends on the successful integration of these five components and not necessarily a high amount of knowledge on a component of PCK or another metric.

The implications of this are that fluctuations in one component can affect the other components. For example, if a teacher is completely didactic in nature, it is likely that their instructional strategies and assessment strategies might be teacher-centred and not specifically cater to student deficiencies or misunderstanding. This is because teacher-centred approaches rely on the behaviourist theory which is based on the idea that behaviour changes are caused by external stimuli (Serin, 2018) and not by individuals' prior knowledge or level of understanding. These predictions are possible given the interrelatedness of the individual components as confirmed by this study.

Owing to this integrative nature of PCK, it is also possible that even for the same teacher, linkages might exist in different ways for different topics that they treat as identified by Park and Chen (2012). As such the model confirmed by this study does not in any way suggest that there will be significant interrelatedness between components at all times for all topics taught by a single teacher. This study presents that linkages are possible between all the five components of PCK. In fact, this has been the practice of many researchers looking into PCK component interactions. Tufail et al. (2022) for example, in examining PCK of chemistry teachers, found that the teachers combined different aspects of PCK for particular teaching episodes. PCK component interactions were also observed to vary for different topics by Aydin and Boz (2013).

On the other hand, while the transformative model is not the best fit for describing Ghanaian SHS genetics teachers' PCK, it was a good fit. This indicates that perhaps it is useful to think of the aforementioned teachers' PCK, with some limitations, in a transformative manner. Especially in the sense that all the components are part of a tangible, synthetized knowledge base, which is PCK. The evidence, as shown by the significantly better integrated model are perhaps best thought of also as tangible and observable and not latent as explained by Gess-Newsome (1999). They are therefore useful and can be studied on their own outside the context of the five component model of PCK even in topic-specific scenarios. As has been done by (P. Brown et al., 2017) who examined connections between knowledge of student understanding, knowledge of instructional strategies and teaching orientations. Similarly, teaching orientations to nature of science have been studied, observed and developed in in-service teachers outside of the full construct of PCK (Faikhamta, 2013).

CONCLUSION

In summary the corroboration of this integrative model of PCK implies that with respect to teacher training, knowledge bases, such as assessment, instruction, etc would be best taught in an integrated fashion. Traditional patterns of pre-service teacher preparation are characterized by temporal and spatial separation of subject matter, pedagogical and contextual issues (Gess-Newsome, 1999a). As such traditional teacher training programs do not concern themselves with the full integration of these forms of teacher knowledge into PCK.

The findings of this research also mean then, that an individual would develop better PCK with more teaching experience so long as they practice the integration of the components. Earlier on, others (Friedrichsen et al., 2009; Tuan et al., 1995; Veal et al, 1999) even observed the change in PCK of trainee teachers as they gathered more teaching experience especially in the way the individual components interacted with each other. Friedrichsen et al. (2009) did not note any significant difference in individual components however as both experienced and inexperienced teachers both held on to didactic orientations.

Ethical Statement

This research was approved by the Faculty of Science and Technology Education in accordance with the ethics requirements for research conducted with human participants at the faculty. Permission was also sought from headteachers of all of the schools that were included in the study before teachers were interviewed. Written informed permission was obtained after each respondent received a briefing on the study's methodology. Respondents were instructed to answer anonymously without providing any information on their identity or that of their school and location.

Statement on originality of work

Data collected for this study and the analysis of such data, have been presented in an unpublished Doctoral thesis written and defended by one of the authors of this article (Author, year) . The thesis in question has been cited in this article. It is important to state however, that the authors of this article consider it a valuable and original contribution to scientific discourse.

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