UNIVERSITY OF CAPE COAST

ASSESSING BIOLOGY TEACHERS' PCK FOR TEACHING GENETICS AT THE SENIOR HIGH SCHOOL LEVEL IN GHANA

DENNIS WILMOT

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BY

DENNIS WILMOT

A thesis submitted to the Department of Science Education, Faculty of Science and Technology Education, College of Educational Studies, University of Cape Coast in partial fulfilment of the requirements for the award of Doctor of Philosophy Degree in Science Education

MAY 2020

DECLARATION

Candidate's Declaration

I, Dennis Wilmot, hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ……………………… Date: ……………….......

Name: Dennis Wilmot

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: ……………… Date: …………….

Name: Professor Christian Anthony-Krueger

Co-Supervisor's Signature: …………………………. Date: …………….

Name: Dr. Kofi Acheaw Owusu

ABSTRACT

Genetics has been identified as a topic that Ghanaian students writing the Biology exam of the West African Senior School Certificate Examinations struggle with. A cross-sectional survey was conducted among 149 senior high school biology teachers sampled from three selected administrative regions in Ghana to investigate their Pedagogical content knowledge (PCK) for teaching genetics. PCK was assessed as comprising of knowledge of students' understanding of science (KSU), of science curriculum (KSC), of assessment in science (KAS), of instructional strategies (KIS) and orientations to teaching science (OTTS), hypothesized by Magnusson et al. (1999). This model of PCK, the nature of its components, their interconnections and differences across different demographics of teachers was assessed using a 43-item multiple choice questionnaire. The five-component model of PCK was confirmed by Confirmatory Factor Analysis. Pearson's correlation also revealed significant correlations among the five components of PCK, with KIS making the most connections followed by OTTS. This PCK of Ghanaian biology teachers, teacher-centred in its orientations and instructional strategies was the same regardless of the professional training or years of teaching experience. The findings of this research suggest the need for a shift from the traditional teacher-centred orientations and instructional strategies towards more student-centred, activity-based learning environments that are characteristic of inquiry-based reform teaching.

KEYWORDS

Confirmatory factor analysis

Genetics

PCK

PCK components

Pedagogical content knowledge

Science education

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My heartfelt gratitude also goes to my parents, siblings, colleagues and friends whose physical and spiritual support have seen me through to the completion of my research.

DEDICATION

This work is dedicated to my family.

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CHAPTER ONE

INTRODUCTION

Questions arose about the usefulness of schools and teachers in student learning after Coleman et al. (1966) analysed data from about 600,000 students and 60,000 teachers across more than 4,000 schools and reported that only about 10 % of variance in achievement could be explained by school factors. Perhaps in rebuttal to this, research over the years has established the usefulness of teacher knowledge in influencing student performance (Begle & Geeslin, 1972; Clark & Peterson, 1986; Eisenberg, 1977;). With the importance and relevance of teacher knowledge established, the question then was which aspect of teacher knowledge best predicts student performance.

In came Shulman's (1986b) concept of "pedagogical content knowledge" (PCK). It could be said that prior to Shulman, some approached teaching by only focusing on content or by exclusively focusing on pedagogy. Shulman (1987, p. 8) defined PCK as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding." In simple terms, what a teacher knows (content knowledge) combined with the ability of the teacher to teach what he knows (pedagogical knowledge) make the teacher professionally competent to be effective in class. Not only was Shulman's conceptualization very pivotal in the wave of research into teacher knowledge, but the conceptualizations by Shulman and his colleagues of content knowledge and pedagogical content knowledge and the distinction between them threw the brightest light on how teacher knowledge could influence teaching. Discussions between researchers about the type of knowledge teachers need about content for teaching were also started across several content domains, e.g., history, mathematics, etc (Ball, 1988; Grossman, 1990; Wilson & Winneburg, 1981). It can even be suggested that the conceptualization of technology pedagogical content knowledge (TPACK) (Koehler & Mishra, 2008; Mishra, Koehler, & Henriksen, 2011) was influenced in part by the PCK conceptualization.

However, according to Wilmot (2008), some of the past conceptualizations have presented teacher knowledge as a domain/content-neutral construct making it virtually impossible for it to be objectively measured (Grossman & Richert, 1988; Grossman, 1990; Shulman, 1987). As a result, several attempts to measure teacher knowledge have relied on proxy measures such as the number of university courses taken, the type of degree the teachers have, to name a few.

This meant that there was the need for re-conceptualization of teacher knowledge in ways that are not only domain specific but also allow its components to be measured. In the field of science, pioneer work done by Grossman (1990) and expanded on by Magnusson, Krajcik, and Borko (1999) suggests that the components of PCK for science teachers comprises five types of knowledge which are:

i. Orientation 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

It is within the context of biology, and specifically the topic of genetics, that this study examines whether the five domains hypothesized by

Magnusson et al. (1999), henceforth also referred to as Magnusson's framework, will be validated in the field of biology, specifically genetics.

Background to the Study

Research is replete with examples underlining the usefulness of teacher knowledge in influencing student performance (Begle & Geeslin, 1972; Clark & Peterson, 1986; Eisenberg, 1977). Darling-Hammond (1999) and Yara (2009) claim that even schools can make a tremendous transformation in students' learning with a considerable portion of that difference ascribed to teachers. This indicates a changing in tide as it is in stark contrast to the findings of Coleman et al. (1966) which played down the impact of school factors to a mere 10%. Schools, the teachers in the schools and for that matter the knowledge of the teacher matter and affect student performance. Teacher knowledge has been found not only affecting student performance but also how teachers themselves teach (Ambrose, 2004; An, Kulm, & Wu, 2004; Hill & Ball, 2004; Ross, McDougal, Hogaboam-Grey, & LeSage, 2003; Stipek, Givvin, Salmon, & MacGyvers, 2001). Thus, in moving away from traditional teaching towards reform-oriented teaching (Jacobs, Hiebert, Givvin, Hollingsworth, Garnier, & Wearne, 2006), teacher knowledge should be targeted, studied and developed in order to aid their operative evolution.

Shulman (1986a) then sought to characterize teacher knowledge, believed to be the "missing paradigm" in research and practice on teaching, in order for teachers to be effective in the classroom. Prior to his characterization, teaching was either approached by only focusing on content or by exclusively focusing on pedagogy. Shulman's belief was that neither approach grasped every aspect of teachers' knowledge base. Shulman therefore proposed pedagogical content knowledge (PCK) as the teacher knowledge required for successful teaching. Shulman argued that PCK is "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). The two components that Shulman (1986b) distinguished in PCK were, on one hand, the most useful forms of representing the topics in one's subject area and, on the other hand, an understanding of what makes these topics easy or difficult for students.

Pedagogical content knowledge (PCK), as conceptualized by Shulman (1986a, 1986b, 1987), originally came about as one of the seven categories of "teacher knowledge". In making his proposal, Shulman was participating in a US-centred debate about the status of teaching as a profession. At issue was whether school teachers could be regarded as "professionals", aligned with doctors or lawyers, or if they were simply "skilled workers." In earlier papers, Shulman (1986b) had highlighted the transition from the 1870s, when teacher training was based solely on factual knowledge, to the mid-1980s examination of general understanding of educational issues. Shulman was concerned about the shift of focus to pedagogy away from subject matter and asked "Where did the subject matter go?" (Shulman, 1986b, p. 5). To address this supposed "missing paradigm" in teacher education, Shulman proposed three categories of "content Knowledge" for teachers;

a. Subject-matter content knowledge

b. Subject-matter pedagogical knowledge

c. Curricular knowledge

Subject-matter content knowledge (SMCK) as noted by Shulman meant the “amount and organization of knowledge per se in the mind of the teacher” (Shulman, 1986b). This knowledge of the teacher may reasonably be equal to that of a non-teacher or “lay” professional. It is the knowledge about the principles, concepts and theories in a given subject area. Teachers are expected to demonstrate mastery in their chosen subject areas. Subject-matter pedagogical knowledge on the other hand was explained by Shulman as “the ways of representing and formulating the subject that make it comprehensible to others” (Shulman 1986b, p. 9), and includes the analogies, illustrations, examples, explanations and ideas that a teacher uses in lessons. The third category, “curricular knowledge” includes the teacher’s knowledge of current materials including textbooks, software, laboratory demonstrations and other ephemera available to use in the classroom (Kind, 2009).

Shulman (1987) then expanded his three categories into seven constructs. The seven constructs are:

a. content knowledge;
b. general pedagogical knowledge;
c. curriculum knowledge;
d. pedagogical content knowledge (PCK), that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding;
e. knowledge of learners and their characteristics;
f. knowledge of educational contexts, ranging from the workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures; and

g. knowledge of educational ends, purposes, and values, and their philosophical and historical grounds. (p 8)

Shulman argued that PCK exists as a separate unique form of knowledge from content knowledge/subject matter knowledge (SMK), pedagogical knowledge and the other four forms of knowledge identified. PCK, according to Shulman (1986a, 1987) comprises two components labelled "representations" but often referred to more frequently as "instructional strategies" (Kind, 2009) and knowledge of students' subject matter "learning difficulties".

Since Shulman's initial conceptualization of PCK however, other researchers have adopted the concept, resulting in both theoretical developments and empirical research. Theoretical elaborations on Shulman's initial framework of PCK, like the work of Grossman (1990) added on other components (*knowledge of curriculum* and *knowledge of purposes for teaching*) to Shulman's original PCK components. While Grossman's conceptualizations were made in the field/context of languages, Magnusson, Krajcik, and Borko (1999) also elaborated on Grossman's work in the field of science education.

Magnusson et al. (1999) proposed that PCK includes five components which were particularly important for science teachers. The components of PCK, according to Magnusson and his colleagues, were;

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

These components by Magnusson et al, from here on also referred to as Magnusson's framework, included two from Shulman's original list of seven types of teaching knowledge, originally placed outside PCK, in the components or ingredients of PCK. They did however decide to keep subject matter knowledge (SMK) outside of PCK.

Contrary to the conceptualization of PCK by Magnusson et al. (1999) and Shulman (1987), other researchers, however, include SMK, called content knowledge by Shulman, in PCK (Fernandez-Balboa & Stiehl, 1995; Koballa, Graber, Coleman, & Kemp, 1999; Marks, 1990). Marks (1990), for example, renames *instructional strategies* "instructional processes" and *learning difficulties* as "students' understanding." Marks also adds "*media for instruction*", which aligns with Grossman's curricular knowledge to mean knowledge about texts and materials. Marks includes SMK in PCK because according to him, teachers' own personal understanding of content concepts was taken for granted. Marks (1990) found out that teachers did not describe their teaching in terms of transforming mathematical knowledge, but emphasized pedagogy, focusing on "justifications", "important ideas", "pre-requisite knowledge"; and knowledge of "typical school math problems" (p. 5). Marks therefore believed that teachers demonstrated that their SMK and PCK were not so clearly distinguished knowledge components. With the components of PCK elaborated on by several researchers, the issue now is how to measure these components.

After conceptualizing and delineating PCK, researchers sought how best the constructs could be assessed. Researchers have frequently used qualitative methods that focus on the examination of collaborative conversations, lesson plans, case narratives, and other performance assessments to measure teachers' PCK (e.g., Angeli & Valanides, 2009; Harris, Grandgenett, & Hofer, 2010; Koehler, Mishra, & Yahya, 2007; Mouza & Wong, 2009). The use of qualitative methods to assess PCK are important because they give an idea of what PCK looks like in practice and not merely at a theoretical level. Yet these approaches are time consuming for researchers and participants, thereby making them difficult to implement with large groups of teachers in a quick, efficient, and reliable way (Albion, Jamieson-Proctor, & Finger, 2010).

On the other hand, researchers like Abdullah and Halim (2010) developed an instrument specifically to measure level of teachers' PCK on Environmental Education. By determining the constructs or components of PCK from literature, the authors came up with a survey instrument containing 86 items grouped according to their corresponding PCK component. Using factor analysis, they analysed the items for their validity and reliability to assess suitability of their instrument in measuring PCK.

Statement of the Problem

The scope of content for the teaching syllabus for Biology in Senior High Schools in Ghana is divided into seven sections, of which genetics is included under one section titled "Genetics and Evolution". Genetics also occupies a good proportion of the West African Senior School Certificate Examination's elective biology syllabus. In the section A of the paper, one out of seven sections is dedicated to genetics under "Biology of Heredity". Again, in the section B of that same paper, genetics is still placed among the nine topics to be assessed as “Genetics and Evolution”.

Genetics and the increasing knowledge about it, has become a major influence on modern society with numerous applications. It presents an exciting opportunity to contribute to the development of Africa. In fact, genetics has been identified as a possible solution to the resolution of the African food and nutrition security problem (USAID, 2007). In fact, there is evidence that there are several positive socioeconomic effects associated with genetics technology (Subramanian & Qaim, 2009). These potential benefits of genetics technology for the economy, for a developing country like Ghana, are very relevant.

Perhaps it is in agreement with the importance of genetics then, that consistently, from 2008 to 2018 West African Senior School Certificate Examination’s Biology paper has included questions from genetics labelled “Biology of Heredity" in the syllabus. However, the chief examiners’ report has revealed students struggle with genetics concepts such as the monohybrid test cross (WAEC, 2018), Mendel’s laws (WAEC, 2018), a gene (WAEC, 2017), transcription of DNA into mRNA (WAEC, 2014), terms like co-dominance, sex-linked characters,), genetic engineering (WAEC, 2012) and translation (WAEC, 2011).

Research has established that student performance is affected by the quality of teaching and by what teachers know (Blömeke, Olsen & Suhl, 2016; Darling-Hammond, 2000; Sirait, 2016). What the teacher knows constitute the teacher’s PCK. Teachers’ PCK for teaching genetics could explain the quality of teaching in Ghana and perhaps explain the performance of students seen at the SHS level in genetics. Since in Ghana, with specific attention to genetics teaching, we do not know the quality of teaching at the SHS level, it is prudent to assess Biology teachers' PCK for teaching genetics which could go a long way to help proffer a possible solution to the difficulties that students have in genetics at the WASSCE, as identified in the Chief Examiners' reports, from the teacher's perspective.

Purpose of the Study

The purpose of this study is to assess the PCK of Ghanaian SHS teachers for teaching genetics based on the five components of PCK hypothesized by Magnusson et al. (1999).

Research Questions

The following research questions were considered:

1. Does Ghanaian biology SHS teachers' PCK for teaching genetics corroborate Magnusson's five component (OTTS, KSU, KIS, KSC and KAS) framework of PCK?
2. What is the PCK of Ghanaian high school biology teachers teaching genetics based on the five-component model of PCK (OTTS, KSU, KIS, KSC and KAS) hypothesized by Magnusson et al. (1999)?
3. What is the relationship amongst the five components of PCK (OTTS, KSU, KIS, KSC and KAS) hypothesized by Magnusson et al. (1999)?

Hypotheses

The following hypotheses guided the study:

1. There is no significant difference in the PCK of SHS teachers with professional training in education and those without professional training in education for teaching genetics.

2. There is no significant difference between the PCK of senior high school biology teachers who have varying numbers of years of teaching genetics.
3. There is no significant difference in the PCK of male and female SHS biology teachers for teaching genetics.
4. There is no significant difference in the PCK of SHS biology teachers teaching genetics in all female, all male and mixed schools
5. There is no significant difference in the PCK of SHS biology teachers teaching genetics in category A, B or C schools.

Significance of the study

Within the rapidly developing field of genetics, it is unclear whether academically weak SHS biology students' understanding of genetics concepts is as a result of the PCK of biology teachers. Therefore, assessing the PCK of biology teachers in genetics could also help in understanding the quality of genetics teaching at the SHS level in Ghana.

The instrument used in measuring PCK for genetics can also be adapted for other concepts in biology since no such instrument has been developed in the Ghanaian context. This can enable educators and researchers to delineate teachers' PCK in the various content areas as well as concepts to help strategize appropriate in-service training and professional development programs for teachers.

Delimitation

Essentially, the study is designed to assess teachers' PCK for teaching genetics at the senior high school level in Ghana in the light of the Magnusson framework. To do this, only senior high school teachers of biology were allowed to participate in the study.

This study was delimited to senior high schools in only three regions of Ghana (Western, Central and Ashanti). In these three regions, 149 teachers in 43 schools will be targeted. The topic used as the focus of the study was genetics.

This means that in describing the PCK of teachers (research question 2), and whether it fits Magnusson's model (research question 1) generalisations cannot be made to other topics or subjects. Furthermore, in looking at the relationship between the five components (research question 3), only those components elaborated on by Magnusson's framework will be looked at for Ghanaian SHS Biology teachers.

Also, the only teacher-related factors that were considered in this study are teachers' gender, their teaching experience and their academic qualifications These factors were used because literature reveals that they are important determinants of what students learn. Conclusions made about differences in the PCK of teachers across these demographics, as already stated, cannot be generalized to teachers teaching different topics across similar or different levels of Ghanaian education. This also holds for comparisons between different categories of schools.

This research only looked at the PCK of Ghanaian Biology teachers, based on Magnusson's framework with specific focus on genetics, at the SHS level.

Limitations

One of the major limitations of this study was the relatively small number of participating teachers. This in a way could place a limitation on the outcome of the study in that if a large number of teachers were involved it could have given different results. It was also not possible to include schools from all the senior high schools in the country.

In considering the professional qualifications of teachers, it is also possible that some teachers, while they may not be professional teachers, may have received in-service training on education. It is possible that these teachers who have received in-service training may exhibit traits similar to those trained professionally.

As such, these factors could limit the generalizability of the result of this study. Discussions of the results will thus be made bearing in mind the limitations inherent in this study.

Definition of Terms

For the purpose of this study, the following terms are defined as follows:

1. Academic qualification: this is the highest level of education attained by the teacher.
2. Professional qualification: this is the highest level of professional education attained by a teacher. Teachers were classified according to whether the teacher holds a degree/diploma/certificate in education or not.
3. Teaching experience: the number of years that a particular teacher has taught biology at the senior high school level regardless of his or her level of education.

Organization of the study

Apart from the 'Introduction' chapter, there are four other chapters made up of Review of related Literature (Chapter 2), Methodology (Chapter 3), Results and Discussion (Chapter 4) and Summary, Conclusions and

Recommendations (Chapter 5). The literature review chapter takes a critical look at the relevant literature that is related to this research.

The methodology chapter describes the research design and the broad paradigm under which this study falls; data collection procedure, sample and sampling technique, the instrumentation process and how data was analysed.

The results and discussion are also presented where the results of this study are interpreted, discussed and compared to existing literature. What follows then is a summary of the work and the recommendations that stem out of this research.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents literature on conceptualisations of teaching and teacher knowledge as well as pedagogical content knowledge (PCK), which is itself a type of teacher knowledge which sets them apart from other content specialists and other professionals (Shulman, 1986a).

This literature review is thus organized into four parts. In Part I, literature on how teachers and teacher knowledge took centre stage in attempts to explain student performance is looked at. Also, in Part I, an overview of research on teacher knowledge, a broad concept, is presented. Part II then narrows down on a synopsis on PCK, its initial conceptualizations and implications as well as the various definitions of PCK. This leads into Part III which looks at the conceptualization of PCK and its components proposed by Magnusson et al. (1999) as well as literature on the definitions and inter-relatedness of these individual components. Part IV then looks at modern methods of measuring PCK. The overall goal of this review is to shed light on the theoretical foundations upon which this research is built and to show similar work done on PCK and to highlight how this research is different from past research.

Part I: Teachers and Teacher Knowledge

As already stated, this section looks at how teachers and teacher knowledge came to take centre stage in attempts to explain student performance. An overview of research on teacher knowledge, a broad concept, is also presented

The Importance of Teachers

There has been a plethora of resent research findings indicating that teachers are essential to student performance (Blömeke, Olsen, & Suhl, 2016; Darling-Hammond, 2000; Sirait, 2016). In fact, studies conducted by Darling-Hammond (1999) and Yara (2009) claim that even schools can make a tremendous transformation in students' learning with a considerable portion of that difference ascribed to teachers. With the importance of teacher knowledge to student performance established, research suggests that teacher knowledge even affects how teachers themselves teach (see for example Ambrose, 2004; An, Kulm, & Wu, 2004; Hill & Ball, 2004; Ross, McDougall, Hogaboam-Grey, & LeSage, 2003; Stipek, Givvin, Salmon, & MacGyvers, 2001). This means, particularly in moving away from traditional teaching towards reform-oriented teaching, a process which in itself is delaying (Jacobs, Hiebert, Givvin, Hollingsworth, Garnier, & Wearne, 2006), teacher knowledge should be targeted, studied and developed in order to aid their operative evolution. But research about student learning outcomes did not always identify teachers or teacher knowledge for that matter as a factor that affects student performance.

In 1966, J. S. Coleman and colleagues seemed to suggest, through their then ground-breaking research, that school related factors (which include teachers) had only a 10% impact on student performance (Coleman et al., 1966). This meant that schools, the teachers in the schools and for that matter the knowledge of the teacher have no significant impact on student performance. This was fodder for the debate of whether schools mattered in student learning. Wilmot (2008) has argued that, "such negative findings and views about schools and teachers in particular could be the impetus of early attempts at conceptualizing the knowledge base for teaching that was spearheaded by Shulman (1986a; 1986b; 1987)" (p. 33). However early conceptualizations of teachers did not initially concentrate on teacher knowledge but more on teacher "characteristics" and their effect on learning.

Teacher Characteristics

In a recent review of literature targeting specific teaching skills and classroom behaviour of teachers, Creemers and Kyriakides (2012) draw on their own work as well as other past work (for example, Brophy & Good, 1986; Creemers, 1994; Creemers & Kyriakides, 2008; Creemers & Reezigt, 1996; Muijs & Reynolds, 2010) to highlight the practices that research has shown to positively impact student achievement. These include the quantity and pacing of instruction, providing tasks appropriate to the level of students to succeed, the smooth organisation and management of the classroom environment, systematic evaluation and reflective inquiry to improve practice, clarity of presentation and good communication with students, as well as the thoughtful use of asking questions and giving feedback to measure student understanding. The development of PCK, linked with the collaborative activities that teachers engage in beyond their individual classrooms, has been identified as an important contributor to these effective teaching skills in the TALIS (Teaching and Learning International Survey)

Formerly, studies on teacher knowledge, from as early as the 1920s, were initially in the form of process-product research (Brophy & Good 1986; Doyle, 1977; Gage, 1978). Process-product studies tried to establish a direct link between the processes or actions of teacher in the classroom and student performance. The processes of the teacher were coded by researches and related to measured student outcomes. With the benefit of hindsight, it seems coding teacher actions in this manner was only rudimentary in its indirect attempt to break down which aspects of teachers' knowledge are transformed into their teaching experience (Wilmot, 2008). One of the criticisms of the process-product design, among many, was that it was based on the idea of causality implied in the process-product research paradigm (i.e., their over reliance on correlational methods) (Gage & Needels, 1989). Correlation does not imply causation.

As a result of these criticisms, a slight shift in the design of the studies occurred (Berliner, 1979; Peterson & Swing, 1982). Berliner (1979) and his colleagues in the Beginning Teacher Evaluation Study (BTES) for instance, introduced Academic Learning Time (ALT) as a variable in their modification of the process-product design. One important aspect of ALT is what the BTES program refers to as *engaged time*, the actual time students spend on tasks provided by the teacher in learning a particular content. According to Berliner and his colleagues, if a student spent a lot of time on easy items over a long period, that student's academic performance will not be improved to any marked extent. On the other hand, if a student's time is spent on items that are too difficult for him/her, that student will not be able to master the extra concepts, skills and operations needed for good performance at that grade level. This academic learning time then, was the link between student performance and teacher behaviour and an operational indicator of students learning. Unfortunately, the ALT constructs failed to show the type of knowledge teachers must possess to effectively judge the right type of difficulty of tasks to give students to improve their learning and when to move on to new materials.

Teacher Knowledge

The precursors for Shulman's focus on teacher knowledge focussed on the mental life of the teacher (Peterson & Clark, 1978; Putnam, 1987). The argument is that the knowledge of experienced teachers is organized in packages of question and explanations that make it possible for them to enhance student learning (Putnam, 1987; Shulman, 1987). Putnam (1987) refers to these packages as "curriculum scripts" and argues that teachers' agenda for teaching is shaped by the richness of their curriculum scripts. In other words, the ability of a teacher to adopt flexible and interactive approaches to teaching depends on the richness of his/her curriculum scripts. To these researchers, the thought process of teachers before, during and after teaching could be rightly studied in order to understand how teachers transform their knowledge into their teaching practice.

To this end, Shulman (1987) proposed his seven types of teaching knowledge which are content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge (PCK), knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational ends.

Shulman and his colleagues conceptualized that content knowledge and pedagogical content knowledge are distinct forms of knowledge that differentiate the professional and the teacher. This meant for example, that there was a type of knowledge that the "biology" teacher had that the ordinary biology major did not have. This shed light on how teacher knowledge specifically could influence teaching and brought the attention of researchers in several content domains to issues involving the type of knowledge teachers need about content for teaching, different from what an ordinary adult may have (Ball, 1988; Wilson & Winneburg, 1981; Grossman, 1990).

As such, what teachers know, teacher knowledge, has been established by research to influence student performance (Begle & Geeslin 1972; Eisenberg, 1977; Clark & Peterson, 1986). Darling-Hammond (1999) and Yara (2009) claim that even schools can make a tremendous transformation in students' learning with a considerable portion of that difference ascribed to teachers. What teachers know has even been found to affect how teachers themselves teach (Ambrose, 2004; An, Kulm & Wu, 2004; Hill & Ball, 2004; Ross, McDougall, Hogaboam-Grey & LeSage, 2003; Stipek, Givvin, Salmon, & MacGyvers, 2001). In fact, over the last three decades or so, research has consistently pointed at differences in teacher behaviour, rather than differences at the school level, as ultimately more important in explaining variance in student outcomes (Kyriakides, Campbell, & Gagatsis, 2000; Muijs & Reynolds, 2010; Scheerens & Bosker, 1997). This is why it makes sense to target teacher related factors or measures of quality in trying to understand which features are more likely to impact student outcomes in the desired way.

Part II: The missing Paradigm

This section provides literature on PCK and sheds light on modern conceptualizations of PCK and its role in student learning.

What is PCK?

As earlier stated, teaching was either approached by only focusing on content or by exclusively focusing on pedagogy. Shulman's belief was that neither approach grasped every aspect of teachers' knowledge base. That is why Shulman saw PCK as "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding". Further, according to Shulman's original conceptualization, PCK: is a subcategory of content knowledge, is *subject specific* and includes two further components/subcategories. The two components that Shulman (1986a) distinguished in PCK were, on one hand, the most useful forms of representing the topics in one's subject area (*instructional strategies*) and, on the other hand, an understanding of what makes these topics easy or difficult for students (*learning difficulties.*)

Topic Specific vs. Generic PCK

The topic specific nature of PCK has however been contested over the years by other researchers, creating a dichotomy of ideas. Some (Fernandez-Balboa, & Stiehl, 1995) arguing that PCK has a generic nature and results from the integration of different component and others (Hashweh, 1985; Van Driel, Verloop, & De Vos, 1998) arguing that it is topic specific.

Arguing in favour of generic PCK, Fernández-Balboa and Stiehl (1995) assert that PCK is generic rather than subject specific. According to Fernández-Balboa and Stiehl (1995) this generic PCK comprises knowledge about subject matter, students, instructional strategies, context and teachers' own teaching purposes and is all-encompassing in nature. However, if PCK is this all-encompassing generic form of teacher knowledge and beliefs, it losses its significance. In effect, generic PCK, would become equal to teacher knowledge and beliefs, and even practices for some.

Van Driel, Verloop and De Vos (1998) argued however, that "the value of PCK lies essentially in its relation with specific topics." In support of this they presented the topic-specific PCK for teaching chemical equilibrium in Chemistry. In fact, the first study that identified a construct essentially PCK (termed subject matter pedagogical knowledge) (Hashweh, 1985), described it as the topic-specific knowledge that a teacher develops and accumulates in relation to teaching that topic.

Transformative PCK and Integrative PCK

Gess-Newsome (1999b), in reviewing work that had been done on PCK, identified two main distinct conceptualizations of PCK. The first conceptualization of PCK, which agrees with Shulman's idea of PCK is that PCK is "transformative". According to the transformative model of PCK, the independent knowledge bases of subject matter, pedagogy and context, while they exist, are dormant and only useful when transformed into pedagogical content knowledge. As such, an expert teacher possesses PCK for all the subjects that he/she teachers. To further explain the transformative model, Gess-Newsome uses the concept of a "chemical compound," which by nature resists easy separation into its component parts, hitherto individual elements, but now inextricably combined for from one new molecule, to describe PCK. In a transformative model, subject matter knowledge or content knowledge is used in creating PCK but is separate from PCK and its components (Kind, 2015)

The second conceptualization, argues that PCK is "integrated". By this, PCK by itself does not exist as a domain of knowledge, but rather is created "ad-hoc" depending on how the teacher draws upon independent knowledge bases of subject matter, pedagogy, and context as needed to teach effectively. Conversely, Gess-Newsome uses the analogy of a "chemical mixture" to underscore the ability, according to the integrative model of PCK, of the individual components of PCK to maintain their individual identities, while remaining virtually indistinguishable (as separate entities) at the macroscopic level. Garritz (2015) agreed with the exclusively integrative nature of PCK. Describing PCK in the words of Farré and Lorenzo (2009), Garritz (2015) also asserts that PCK is a result of "chemical change" in which the reaction of "content" and "pedagogy" creates a new substance called PCK. In this model however, SMK is a part of PCK. The logic behind the inclusion of SMK in PCK, as argued by Berry, Friedrichsen and Loughran (2015) is that PCK comprises the entirety of a teacher's knowledge bases, which would include SMK, and further implies that PCK does not exist as a separate knowledge base.

Lee and Luft (2008), in reconciling the two approaches, suggest that the integrative model of PCK may be for pre-service teachers, while the transformative model may best describe the PCK of in-service teachers. Consequently, work done by Nilson (2008) supported the notion of integrative PCK in student teachers. Kind (2009) found evidence that suggested the opposite for preservice teachers. Kind (2009) observed that pre-service teachers struggled in making decisions on how much content knowledge or the kind of content knowledge to include in teaching from the teacher's entire repository of content knowledge. On the other hand, when it came to teaching "non-specialist" topics, these pre-service teachers did not struggle so much with choosing the appropriate instructional strategies. This evidence suggested, according to Kind (2009), that pre-service teachers were actively and intentionally selecting SMK into PCK, suggesting that PCK and SMK were separate and hence, PCK is transformative for pre-service teachers.

Ultimately, whether PCK is transformative or integrative in nature is an ongoing debate. The integrative model suggests PCK does not exist as a separate knowledge base and recognized SMK as part of PCK. As suck, PCK is based on the skill of the teacher in drawing on subject matter, pedagogy and context and integrating them as needed. As such PCK is the same regardless of the subject matter being treated. This in turn limits the importance of content over pedagogy, resulting in teaching that has little regard for content structure, context and the classroom audience (Gess-Newsome & Lederman, 2001). In this case the specific PCK of teachers for teaching a particular subject, would not be possible. While the transformative model of PCK is good for understanding the PCK for teaching specific topics, it means that generalisations cannot be made across different fields. The transformative model also potentially ignores context and suggests that correct teaching practices exist for certain topics to certain audiences (Gess-Newsome & Lederman, 2001).

All this considered, this research looks at PCK to be transformative in nature. Therefore, generalisations made from this study are only made in the field of genetics, with particular emphasis on teaching at the Senior High School level.

Part III Pieces of the PCK Puzzle

This section looks at some relevant different additions to PCK suggested by literature over the years.

Components of PCK

Pedagogical content knowledge as a construct is conceptualized by Shulman to be an amalgam comprising of different components. However, there is no consensus on the components that form PCK. Gudmundsdottir (1990, 1995) expressed her disagreement with the components Shulman proposed to constitute PCK. She made case for adding components to PCK that were related to the value-laden and narrative nature of teacher professional knowledge. By her argument PCK has a component related to the teacher's belief about subject matter. This would include the teacher's teaching orientations. Prior to this, Shulman and his colleagues had also begun to consider adding the teacher's orientation to subject matter to PCK (Grossman, Wilson, & Shulman, 1989)

Other theoretical elaborations on Shulman's initial framework of PCK, like the work of Grossman (1990) added two other components (that is *knowledge of curriculum* and *knowledge of purposes for teaching*) to Shulman's original PCK components (*instructional strategies and learning difficulties*). While Grossman's conceptualizations were made in the field/context of languages, Magnusson, Krajcik, and Borko (1999) also elaborated on Grossman's work 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,

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

These components included two off of the original list of Shulman's seven types of teaching knowledge, originally placed outside PCK, in the components or ingredients of PCK. They did however implicitly agree with placing the remaining types of knowledge firmly outside PCK. Most notable of these was subject matter knowledge. Although their conceptualizations were not to define the exact and entire components of PCK, but to add to it, Magnusson in the field of science education and Grossman in languages, they did not include SMK (also called content knowledge in this study).

The following includes conceptual descriptions and illustrations provided by Magnusson's framework, and their relationships, as well as supporting literature review of relevance.

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 particular level (Magnusson et al., 1999). Grossman had designated this knowledge beforehand, as consisting of the knowledge of the purposes for teaching a subject at a particular level or the "overarching concepts" of teaching a particular subject. Simply put, this describes a teacher's way of viewing or conceptualizing science teaching. This "orientation" a teacher has can be seen as a "conceptual map" that guides instructional decisions like daily objectives, the content of student assignments, the use of textbooks and other curricular materials, and the evaluation of student learning (Borko & Putnam, 1996).

Table 1: Magnusson's nine different orientations to teaching science

ORIENTATION	GOAL OF TEACHING SCIENCE
Process	Help students develop the "science process skills" (e.g., SAPA)
Academic Rigor	Represent a particular body of knowledge (e.g., chemistry)
Didactic	Transmit the facts of science.
Conceptual Change	Facilitate the development of scientific knowledge by confronting students with contexts to explain that challenge their naïve conceptions
Activity-driven	Have students be active with materials; "hands-on" experiences.
Discovery	Provide opportunities for students on their own to discover targeted science concepts
Project-based Science	Involve students in investigating solutions to authentic problems.
Inquiry	Represent science as inquiry
Guided Inquiry	Constitute a community of learners whose members share responsibility for understanding the physical world, particularly with respect to using the tools of science.

Source: Magnusson et al., 1999.

According to Cobern et al. (2014) one of the first choices that a teacher will make, either implicitly or explicitly, is whether to present and explain scientific concepts and principles directly to the students, or have the students play some role in exploring and finding out the scientific explanations themselves. Based on this, Cobern et al. (2014) broke teaching orientations into two; direct and inquiry. These two dimensions were then broken down into two variations each, thus providing four common teaching orientations as presented in Figure 1. This classification of science teaching orientations is more concise and classified than Magnusson's original nine orientations. Aside that, visions of inquiry put forth in reform documents indicate an aspiration to move towards more inquiry-based forms of instruction.

For the purpose of this research, then, the model used by Cobern et al. (2014) is favoured. The items used under "teaching orientations" are therefore more concerned, as was done by Cobern et al. (2014), with measuring which way teachers of different demographics align with either direct or inquiry-based instruction.

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.

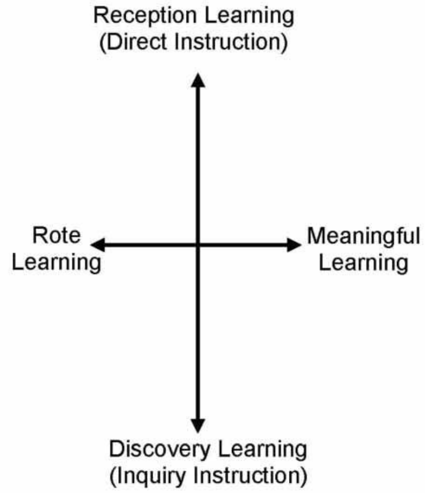

Figure 1: Teaching Orientations and Ausubel's axes. Source: Cobern et al. (2014)

The categories (didactic direct, active direct, guided inquiry and open inquiry) proposed by Cobern, et al. (2014) and explained in Figure 1 are not to be seen as rigid compartments, but as a useful way of broadly characterizing instructional approaches found in practice. Items developed based on this basic set of approaches, allow for science teaching to be identified, quantified and teaching orientation profiles to be obtained.

Knowledge of Science Curriculum (KSC)

Originally placed as a separate knowledge base outside of PCK by Shulman (Wilson, Shulman, & Richert, 1988) as *curriculum knowledge*, it was defined to mean having a particular grasp of the materials and programs that serve as tools of the trade for teachers. Included in PCK by Grossman (1990), Magnusson defines it by breaking it into two; *mandated goals and objectives*, and *specific curricular programs and materials* and includes it in PCK because it represents knowledge that distinguishes the content specialist from the pedagogue.

The *Knowledge of Goals and Objectives* refers to the knowledge that teachers have about the goals and objectives in the subject(s) they are teaching, as well as the articulation of those guidelines across topics addressed during the school year. Naturally, this would include knowledge that teachers have concerning what students learned in the previous years and what they are expected to learn in later years (Grossman, 1990). The sources for this knowledge would include national, regional or even school level documents or programs outlining goals for science curriculum and instruction. In Ghana, such knowledge will be obtained from the syllabus for the various subjects as well as other ministry of education and Ghana Education Service's policy guidelines.

"*Knowledge of Specific Curricular Program*" as the name suggests, consists then of knowledge of the specific programs or materials relevant to teaching in the particular domain of science. For example, a senior high school chemistry teacher might be expected to be knowledgeable about the West African Examination Council (WAEC) syllabus for teaching senior high school chemistry.

Shulman (1986b) originally classified curricular knowledge into four components (shown in Table 2).

Table 2: Curricular knowledge according to Shulman

Component	Excerpts from p.10 of Shulman (1986) *Curricular Knowledge* is
Programs and Materials (P & M)	Knowledge of "the full range of programs designed for the teaching of particular subjects and topics at a given level [and] the variety of instructional materials available in relation to those programs."
Indications & Contraindications (I & C)	Knowledge of: "the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances."
Lateral (LC)	Knowledge of: "curriculum materials under study by his or her students in other subjects they are studying at the time." (*Lateral curricular knowledge*)
Vertical (VC)	Knowledge of: "familiarity with topics and issues that have been and will be taught in the same subject area during the preceding and later years in school, and the materials that embody them" (*Vertical curricular knowledge*)

Source: Shulman, 1986a

Shulman's (1986b) description of Curricular Knowledge includes programs and materials, objectives and goals (vertical and lateral curriculum) and indications and contraindications which are also included in Magnusson's description of curricular knowledge.

This research views "curricular knowledge" also as curricular tools that teachers can use. Specifically, this research looks at whether teachers use lateral curriculum (science or non-science) or vertical curriculum (past knowledge or advanced knowledge) in teaching topics to students. For the purpose of this research then, questions under this component are set to find out which of the tools of curricular knowledge teachers fall on across a selection of "difficult" topics.

Knowledge of Students' Understanding of Science (KSU)

According to Magnusson et al. (1999), this component of pedagogical content knowledge refers to the knowledge teachers must have about students in order to help them develop specific scientific knowledge. It includes two categories of *knowledge: requirements for learning specific science concepts*, and *areas of science that students find difficult*. This component is one of the original two components of PCK according to Shulman's conceptualization of PCK named as *knowledge of students' subject matter "learning difficulties*".

In the domain of science education then, *Knowledge of Requirements for Learning* comprises teachers' knowledge and beliefs about prerequisite knowledge for learning specific scientific knowledge, as well as their understanding of the variations in students' approach to learning as they grapple with the development of knowledge within specific topic areas (Magnusson et al., 1999). Teacher *knowledge of prerequisite knowledge* *required* for students to learn specific concepts includes the knowledge of the abilities and skills that students might need. For example, students who are to learn about temperature by observing thermodynamic changes must be helped first to develop skills to collect and interpret temperature data such as reading the thermometer. Knowledge of variations in approaches to learning includes knowing how students of differing developmental or ability levels or different learning styles may vary in their approaches to learning as they relate to developing specific understandings (Magnusson et. al., 1999). For example, a teacher would need to understand that certain students can understand genetics by reading text whilst others might only understand if a visual representation is provided. The other category of knowledge of students' understanding of science is the *Knowledge of Areas of Student Difficulty*. It describes knowledge of the science topics or topics that students find difficult to learn.

Literature suggests that teachers can use Bloom's taxonomy to write learning objectives that describe the skills and abilities that they desire their learners to master and demonstrate (Adams, 2015). Likewise, for the purpose of this research, teachers' understanding of student ability or the pre-requisite knowledge for specific genetics topics can be classified according to the different levels of blooms taxonomy. The topics selected for the questions included test cross, independent assortment, segregation, ABO blood system, etc., identified in the chief examiner's report and from literature as difficult topics for students. The question was do teachers expect students to, or do students find difficulty in, for example,

A) define terms under a topic (remember)

B) differentiate between ideas (understand)

C) identify examples in nature (apply)

D) make inferences to different topics and scenarios (analyse)

The action verbs chosen to represent the four first levels of blooms taxonomy were chosen from literature (Anderson & Krathwohl, 2001).

Knowledge of Assessment in Science (KAS)

Originally proposed by Tamir (1988), Magnusson et al. (1999) conceptualize this knowledge as consisting 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.*

Knowledge of Dimensions of Science Learning to Assess is described within the context of what is considered to be a major goal of school science, producing scientifically literate citizens (Hurd, 1989). The National Assessment of Educational Progress (NAEP), USA, identified conceptual understanding, interdisciplinary themes, nature of science, scientific investigation, and practical reasoning as important dimensions of science learning to assess (Champagne 1989). At the time when Magnusson et al. (1999) conceptualized this component, they also did not describe a particular framework of assessment in science to define teacher knowledge relative to this category. They suggested rather that it was important for teachers to be knowledgeable about "some" conceptualization of scientific literacy to inform their decision-making relative to classroom assessment of science learning for specific topics. As such for the purpose of designing the instruments for this study, all dimensions were considered. An effective teacher should know what dimensions or aspect of a dimension of scientific literacy should be assessed in a particular unit (Magnusson et al., 1999). Some dimensions are more applicable to certain topics than others. For example, it is difficult to empirically investigate the solar system, but less difficult to investigate another phenomenon like gravity. Because of this, an effective teacher would know how to assess students' understanding as they engage in such investigations during the study of gravity, and how to assess their study of the solar system.

The knowledge of how to assess the specific aspects of student learning important to a particular unit of study was called *Knowledge of Methods of Assessment* by Magnusson. There are a number of methods of assessment, some of which are more appropriate for assessing some aspects of student learning than others. For example, students' conceptual understanding may be adequately assessed by written tests whereas their understanding of scientific investigation may require assessment through a laboratory practical examination (e.g., Lunetta, Hofstein, & Giddings, 1981; Tamir, 1974) or laboratory notebook.

Again, bloom's taxonomy was used here to find out which types of understanding teachers normally assess and which specific science methods they use in assessing them.

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*. *Topic specific strategies* were defined to refer to teaching particular topics within a domain of science, whiles subject specific strategies were defined to be broadly applicable to the teaching of science itself as opposed to teaching other subjects.

Knowledge of Subject-specific Strategies

Strategies included in this category represent general approaches to or overall schemes for enacting science instruction. Perhaps crucial to the inclusion and description of this component in their conceptualization of PCK was that Magnusson and colleagues believed that teachers' knowledge of subject-specific strategies is related to the "orientations to teaching science" component of pedagogical content knowledge. This is because they believe that there are general approaches to science instruction that are consistent with the goals of particular orientations. Again, a teacher's orientation to teaching science has the tendency to influence his/her choice of teaching approaches.

Specifically, for science education, a number of subject-specific strategies have been developed. Some of these teaching strategies are inquiry-based student-centred strategies. In these approaches, students are allowed to explore, discover and construct their knowledge. These strategies have been used for discovery and inquiry-oriented instruction, as well as conceptual change-oriented instruction (Tobin, Tippins, & Gallard, 1994, pp. 76-79). These approaches seek to emphasise the process of science. An example is the "learning cycle," a three-phase instructional strategy consisting of exploration, term introduction, and concept application (Karplus & Thier, 1967; Lawson, Abraham, & Renner, 1989).

Active, student-centred learning strategies that engage learners have also been identified to be vital for STEM (Science, Technology, Engineering and Mathematics) based instruction (Avery, 2013; Dede & Eisenkraft, 2016). Some of those include approaches such as the aforementioned inquiry-based strategies, problem base learning, collaborative learning, etc.

According to Magnusson, teachers' *knowledge of subject-specific strategies* for science teaching consists of the ability to describe and demonstrate a strategy and its phases. For the purpose of this study, it is then crucial that a teacher describing a particular strategy should able to outline the different phases involved in this strategy.

Knowledge of Topic-specific Strategies

This category of pedagogical content knowledge refers to teachers' knowledge of specific strategies that are useful for helping students comprehend specific science concepts. There are two categories of this type of knowledge; representations and activities. Although they are not mutually exclusive (e.g., specific activities may involve particular representations of a concept or relationship) it is conceptually useful to consider them as distinct categories.

Since there are various instructional strategies, what is of interest in this research is which instructional approaches, common to the Ghanaian context, that teachers mostly use in teaching different genetics topics.

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 these five components but did not show such linkages in their model. A schematic illustration of this conceptualization is presented in Figure 2.

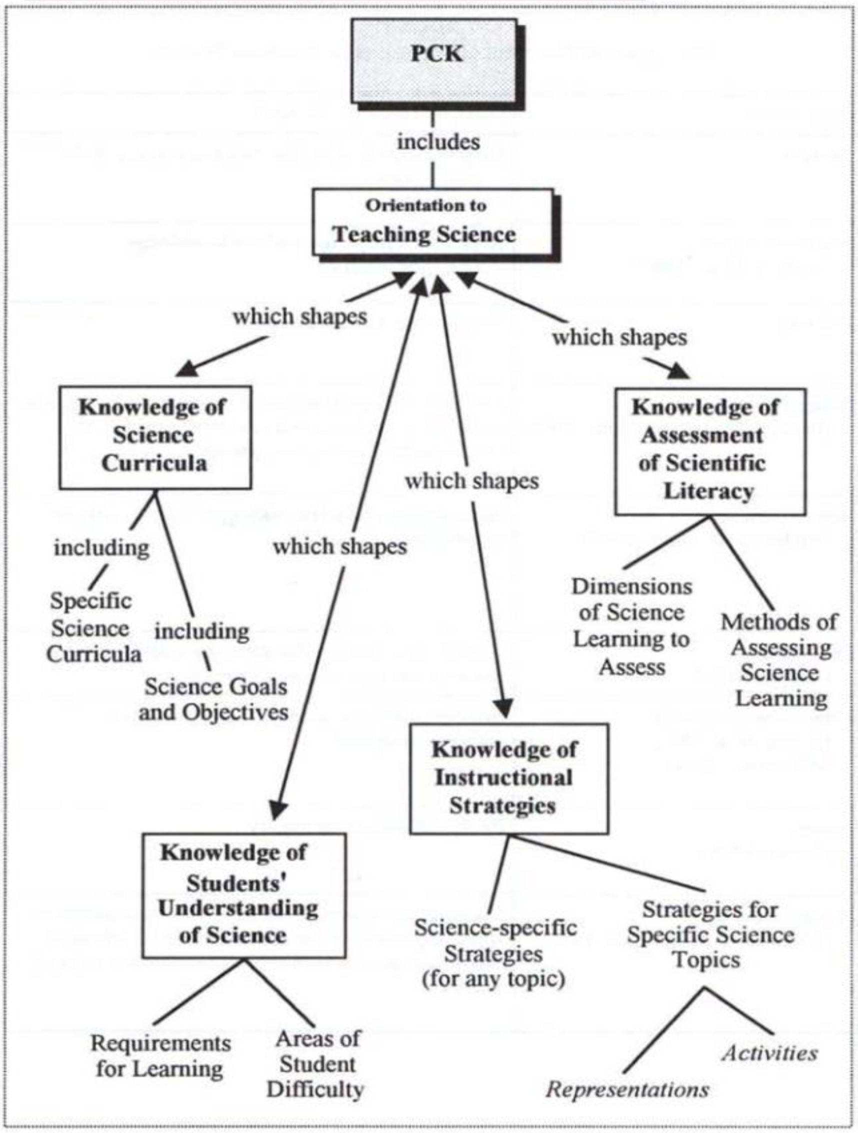

Figure 2: Conceptual framework of the components of PCK. Source: Magnusson et al. (1999)

Importance of Magnusson's Framework to this Study

The focus on this research is on PCK from the viewpoint that SMK (subject matter knowledge) is a separate form of knowledge from PCK (Magnusson et al., 1999; Shulman, 1987). Specifically, the components conceptualized Magnusson's framework are applicable to the teaching of science.

It is also important to note that PCK is not merely the sum of pedagogical knowledge, curricular knowledge and content knowledge, but rather the knowledge of how to combine those types of knowledge to teach. In teaching then, a good teacher is the one who has the ability to blend these three types of knowledge into a *new* form of knowledge. According to Wilmot (2008), his personal intellectual work got him to think about the teacher knowledge in terms of connected or overlapping packages of knowledge (Ma, 1999) or curriculum scripts, to use the words of Putnam (1987).

According to Magnusson et al. (1999), the component that unites all of these is the orientation to teaching science. The reason why a science topic is being taught, in the mind of the teacher, should be the anchor upon which all the components hold on to. However, this central role of orientations in their model of PCK, highlighted by Magnusson et al., emphasized the interaction only between Orientations to Teaching Science and each of the other four components and consequently ignored the interaction among the four components (Friedrichsen et al., 2011). This research then is of the view, just like the pentagon model presented by Park and Oliver (2008), that the interrelatedness among the different components is also important and must be studied.

Additions to Magnusson's Framework

Building off the descriptions of PCK from the work of Grossman (1990), Tamir (1988), and Magnusson et al. (1999), Park and Oliver (2008) described the interrelatedness of PCK components in a model they called the "pentagon model of PCK. They 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). In other words, the quality of PCK depends on the successful integration of these five components and not necessarily a high amount of a supposed "PCK" knowledge or another metric. This "pentagon model" was first created through a comprehensive literature review and then elaborated through empirical tests against the model (Park & Oliver, 2008). Presented again by Park and Chen (2012) this model (Figure 3), at least in their initial conceptual framework did not show direct linkages between OTTS and every other component.

Nevertheless, Park and Chen (2012) did identify linkages and cross linkages between all the different components of PCK in their study on mapping out the integration of all the components of PCK.

In fact, even though their PCK model did not reflect it, Magnusson et al. (1999) also acknowledged the importance of the interaction and coherence between these five components.

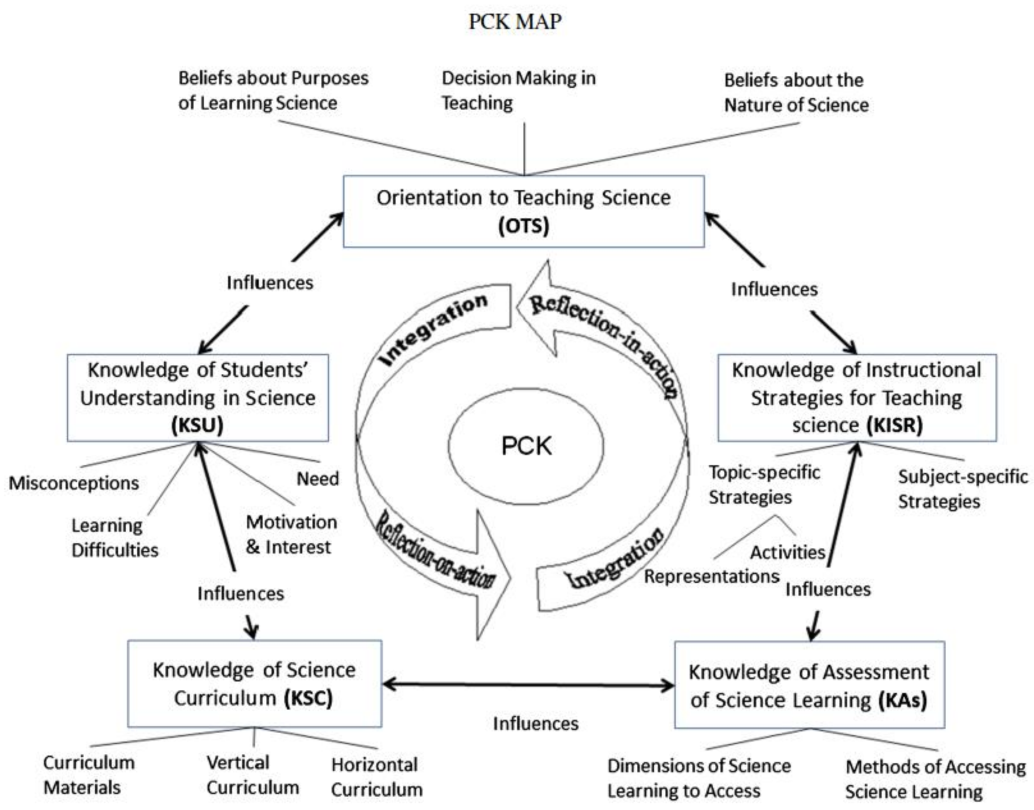

Figure 3 Pentagon model of PCK for teaching science. Source: Park and Chen (2012).

Part IV: Taking measurements

This section looks at how PCK, particularly of a topic specific nature has been measured according to literature.

Measuring PCK in Science Education

Park and Oliver (2008) in agreeing with viewpoint of Magnusson et al. (1999) also identified five components of PCK; *knowledge of students" thinking about science, knowledge of science curriculum, science-specific instructional strategies, assessment of students' Science learning* and *orientations of teaching science*. Davis, Beyer, Forbes, and Stevens (2011) also viewed these components imperative because they work together to help teachers represent specific subject matter in ways that make it comprehensible to students.

Even though Magnusson et al (1999) and others describe components of PCK in the field of science education, different from Shulmans initial domain neutral description of PCK, the issue has always been how to assess it. There have been, over the years, a myriad of methods exploring and measuring PCK. Literature on these methods classifies them into three groups; studies exploring PCK *in situ*, those using standardized prompts and those using a questionnaire instrument.

Measuring PCK *in situ*

In situ studies commonly involve investigating how teachers teach science in classroom/laboratory settings. Researchers have normally used two different approaches to measure PCK *in situ*.

One method of eliciting PCK *in situ* draws on established methodologies in social science research (Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein, & Glutting, 2013). One example is work done by Jong, Van Driel and Verloop (2005) on trainee teachers. Their study looked at the results of interview data obtained by teachers teaching aspects of chemistry that involve the "macro-micro" shift. This describes the ability to visualize matter and chemical reactions as tiny, "micro" particles rather than "macro", undivided units with physical characteristics like colour, etc. Jong, Van Driel and Verloop (2005) observed that the process of teaching itself enhanced the awareness of trainee teachers of difficulties associated with teaching abstract concepts. Other similar, preceding research (Tuan et al., 1995; Veal, Tippins, & Bell, 1999) also looked at the change in PCK of trainee teachers as they gathered more teaching experience.

Park and Chen (2012) have also looked at the nature of the integration of the five components of pedagogical content knowledge (PCK): (a) Orientations toward Teaching Science, (b) Knowledge of Student Understanding, (c) Knowledge of Instructional Strategies and Representations, (d) Knowledge of Science Curriculum, and (e) Knowledge of Assessment of Science Learning. Within the context of the photosynthesis and heredity instruction of four teachers, this research used lesson observations, semi-structured interviews, lesson plans, instructional materials, and students' work samples. What they found was that the quality of PCK depends on the coherence among the components as well as the strength of individual components.

Another *in situ* method of assessing PCK involves more novel "rubrics" specifically designed for PCK research (Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein & Glutting, 2013). Loughran, Mulhall, and Berry (2006) developed a method of identifying topic-specific PCK and portraying it in a way that is useful to teachers. They developed rubrics known as Content Representations (CoRes) and Pedagogical and Professional experience Repertoires (PaP-eRs). A CoRe is a detailed description tabulating the big ideas or concepts relating to a topic being taught against points such as what exactly students have to learn about each big idea; their possible difficulties with each concept; why it's important for them to know these concepts; how these concepts fit in with others; and any knowledge the teacher holds that connects the big ideas in this CoRe to others. A PaP-eR is a narrative document, written in a teacher's voice, annotated by a researcher. The PaP-eR highlights the teacher's SMK, showing how s/he is thinking about teaching the content to students. The CoRe is presented to a teacher as a blank table for completion. (Shinas et al., 2013).

CoRes are however, challenging and require extra training, making the task of completing one intimidating to some teachers, such as those lacking confidence in their abilities, new to teaching or resistant to producing a lengthy, detailed document just for a research project. While Loughran et al. (2006) originally developed CoRe and PaP-eR to describe the PCK of experienced teachers, others (Nilsson & Loughran, 2012; Hume & Berry, 2013; Bertram & Lourghran, 2014) have used them with pre-service science teachers. In their application of CoRe and PaP-eR to study the PCK of pre-service teachers, Hume and Berry (2013) noted that pre-service teachers found them to be challenging and struggled to complete them without appropriate scaffolding.

Measuring PCK using prompts

Prompt studies are further divided into two types. There are those that use probes to examine the PCK teachers perceive in lesson records or video extracts and those examining changes in PCK following or during an intervention (Kind, 2009).

An example of probes to study PCK can be seen in the work done by Ahtee and Johnston (2006) who used a video of 10-year-olds being taught physics to interview Finnish and UK trainee teachers about PCK and SMK. In this case, the teachers were interviewed and also assessed using a questionnaire to compare their attitudes towards teaching with those toward teaching other subjects. With the approach of Ahtee and Johnson (2006) they were able to identify more negative attitudes towards teaching physics in the Finnish trainee teachers compared to their UK counterparts. Probe studies are advantageous in the sense that they can be deployed in a wide range of settings, such as across different countries, allowing researchers to compare the PCK of teachers across diverse contexts (Kind, 2009). The main disadvantage is that it only assesses PCK perceived in the probe material. As such, the full range of PCK a teacher possesses cannot be elicited with this approach (Kind, 2009).

An example of an intervention, which follows a “before” and “after” pattern of investigation, the micro-macro shift (see explanation above) explored by Van Driel, Jong and Verloop (2002) used a workshop as an intervention to develop teachers’ PCK. To assess the effect of this intervention, data was collected at three specific points during a one-year chemistry teacher education program. Interviews and questionnaire data were obtained over that period. The authors noted that the workshops had a significant impact on the practice of the trainee teachers. Another intervention explored was of teachers who were assessed by Justi and Van Driel (2005) after collecting data from their students and writing a report. The authors in this case noted the value of encouraging teachers to practice reflective teaching, which in this case was done through report-writing. Intervention studies, like these ones using probes, are advantageous because they can be used with trainee and experienced teachers alike. However, because the long-term effects of the intervention may be absent, limiting the impact to the short-term, the procedure is open to "Hawthorne effect". This describes when something new generates immediate positive outcomes in participants, due perhaps to their awareness of being observed. As such, the intervention in this case may claim many immediate changes as "marked" improvements on previous practice when perhaps teachers are merely responding to the fact that their being observed (Kind, 2009)

Measuring PCK using questionnaires

Questionnaires can be used in combination with a variety of different approaches such as those described earlier (Van Driel, Jong & Verloop, 2002; Ahtee & Johnson 2006) or alone as has been done by researchers like Abdullah and Halim (2010). Abdullah and Halim (2010) developed an instrument specifically to measure level of teachers' PCK on Environmental Education. By determining the constructs or components of PCK from literature, the authors came up with a survey instrument containing 86 items grouped according to their corresponding PCK component. Using factor analysis, they then analysed the items for their validity and reliability to assess suitability of their instrument in measuring PCK. Factor analysis as a statistical technique is favoured for validating instruments used to measure PCK because it helps to determine items of the instrument that have the same features and which therefore go together (that is load together). In factor analysis the features of the items that load together on each factor is used to label or describe the factor or variable.

Measuring PCK: the approach of this research

In situ approaches like CoRe and approaches that use standardized probes (qualitative in nature) are excellent in exploring/understanding the

PCK of teachers but do not necessarily "measure" their PCK (Kind, 2009). Other methods aimed at measure other forms teacher knowledge, such as TPACK have also used qualitative methods. Researchers have frequently used qualitative methods that focus on the examination of collaborative conversations, lesson plans, case narratives, and other performance assessments (e.g., Angeli & Valanides, 2009; Harris, Grandgenett, & Hofer, 2010; Koehler, Mishra, & Yahya, 2007; Mouza & Wong, 2009).

Qualitative methods are important because they give an idea of what PCK looks like in practice and not merely at a theoretical level. Yet these approaches are time consuming for researchers and participants, thereby making them difficult to implement with large groups of teachers in a quick, efficient, and reliable way (Albion et al., 2010).

Summary of Literature Review

As seen from literature, researchers agree that the teacher is the most important factor that influences students' achievement (Mullens, Murnane & Willet, 1996; Sanders & Rivers, 1996). For instance, teachers' subject matter knowledge was found to be a better predictor of students' achievement than other home-based factors (Mullens et al., 1996). In another breadth, Rowan et al. (2002) claims that even teachers' years of teaching experience was found to be a better predictor of students' achievement than subject matter competency.

In trying to avoid the use of proxy measure to measure teacher knowledge (PCK), this study adopts the conceptualization of PCK that is specific to science teaching proposed by Magnusson et al. (1999) and endeavours to measure its defined components.

CHAPTER THREE

RESEARCH METHODS

This chapter describes the methodology that was used in the study. It focuses on the research design, population, sample and sampling procedure, instrumentation, data collection procedure and ends with issues on data analysis.

Research Design

This study aims at assessing senior high school biology teachers' PCK for teaching genetics. To accomplish this, the 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 (Cohen, Marion, & Morrison, 2000; Creswell, 2003; Fraenkel & Wallen, 2000; Mitchell & Jolly, 2004; Nworgu, 2006). Furthermore, this design is more economical because it enables 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).

The cross-sectional survey design was capable of providing descriptive, inferential and explanatory evidence that can be used to establish correlations and relationships between the components of PCK and other themes of the research (Cohen, Manion, & Morrison, 2000). There is greater anonymity associated with surveys. They also provide consistent and uniform measures and respondents are not affected by the presence and or attitudes of the researcher (Sarantakos, 2013). So, for this study, maximum anonymity was ensured. The choices of the teachers were also not affected by the presence of the researcher since they answered the questions alone by themselves.

On the other hand, surveys also have their own deficiencies among which are the inability to ask probing questions as well as seek clarifications, inability to determine the conditions under which the respondent responded to the questionnaire items as well as the ability to generate high unresponsive rate (Sarantakos, 2013).

It must, however, be noted that since data is meant to be collected at only one point in time, the design cannot permit the study to account for any possible changes that may occur in the knowledge and beliefs of the participants after the study.

Population

The target population included all Senior High School biology teachers in Ghana. Based on the content of genetics in the biology syllabus (labelled biology of heredity), the researcher used only teachers teaching biology in the selected schools.

Sampling Procedure

Data collection was done between October, 2018 and April, 2019. A multi-stage sampling technique was used to arrive at the schools that participated in the study (Shaughnessis & Zechmeister, 1994).

First, three regions were selected from a ballot of ten (10) administrative regions that existed in Ghana at the time. Since school-type based analysis will be conducted, stratified sampling procedure was used to select senior high schools in the three selected regions from the three categories: A, B, C (classified by Ghana Education Service). Within each of these categories, schools were stratified into single-sex male, single-sex female and co-educational.

The advantage of stratified sampling in this case was that it helped to narrow the differences between the different categories or groups of schools, by selecting sample sizes that are representative of each group. But since the classification was done by the Ghana Educational Service, by their own standards, it is only assumed by this research that each school under each classification is more or less the same.

Simple random sampling through computer generated random numbers was then used to select the schools. This was to avoid any bias on the part of the researcher in selecting the schools themselves. In all, ten single-sex female, eight single-sex male schools and 25 co-educational schools were selected to participate in the study (Table 3).

Table 3: Summary Demographics of schools selected

		Single-sex female	Single-sex male	Co-educational	Grand Total
School	A	6	6	3	15
Category	B	4	2	10	16
	C			12	12
	Grand Total	10	8	25	43

Source: Field data, Wilmot, 2019

So, to recap, from each selected school, all available biology teachers were recruited. Out of these forty-three schools, one hundred and forty-nine teachers out of one hundred and fifty-two were able to complete the questionnaire. One hundred and sixteen (116) of these teachers were male and thirty-three of them were female. Thirty-seven were from single sex male schools, thirty-eight from single sex female schools and seventy-four were from mixed gender schools. Table 4 shows the teachers who responded to the questionnaire according to their school type and gender

Table 4 Summary Demographics of Respondents

	School Sex			
	Single Sex Male	Single Sex Female	Mixed	Total
Male	27	28	61	116
Female	10	10	13	33
Total	37	38	74	149

Source: Field data, Wilmot, 2019

Data Collection Instrument

The instrument for the study was a questionnaire to assess teacher's beliefs and preferences according to Magnusson's framework. The study adapted topics from WASSCE and the Ghana Education Services biology syllabus to fit the five components theorized by Magnusson's framework through consultation of experts in content, curriculum and pedagogy. 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, knowledge of science curriculum, knowledge of students' understanding, knowledge of assessment in science and knowledge of instructional strategies. These are described below.

For the teaching orientations of teachers (OTTS subscale), the options were organized under four main orientations; didactic direct, active direct, guided inquiry and open inquiry. Teachers would choose how they would teach a particular topic in a particular scenario. Ten questions of this kind were originally included in the questionnaire. An example of questions used in the questionnaire to test OTTS is provided below.

1. You are introducing SHS students to Mendel's law of segregation, and have two models of chromosomes available to you. How would you approach this lesson?
   A. I'd write a clear statement of Mendel's law and explain to students. I would demonstrate the law by separating the chromosomes
   B. I'd write a clear statement of Mendel's law of segregation and explain it. Students will verify the law by pulling apart the chromosomes.
   C. I'd ask "what will happen to alleles of a gene on separate chromosomes upon Meiosis". The students can then pull the chromosomes apart to answer the question and propose the law.
   D. Students can explore by playing with the chromosome models. Afterward we would have a class discussion of their findings.

The options under questions measuring the KSU subscale were organized in order of increasing levels of cognitive tasks; remembering, understanding, applying and analysing. The teachers were to choose which level was most difficult for their students to perform. There were originally nine questions of this kind under KSU. As an example, presented below is one of the questions measuring KSU.

2. Which of the following implications of meiosis will be most difficult for students to grasp?
   A. The end products of meiosis (remembering)
   B. The difference between meiosis and mitosis. (understanding)
   C. The benefits of meiosis (applying)

D. The implications of meiosis in gamete formation, sexual reproduction and fertilization (analysing)

For the knowledge of assessment of scientific literacy (KAS) subscale, teachers were presented questions with options prevalent in the Ghanaian context. What was of interest was to see which method of assessment teachers would employ. The options were organized in order of increasing student participation. Eight questions of this kind were originally included in the questionnaire. An example is presented below.

3. Their ability to incorporate their understanding of genetics concepts into solving everyday problems

A. Paper and pencil-based tests

B. Written take-home assignments

C. Presentations by students

D. Observe student performance on simulations of lab procedure

For the knowledge of instructional strategies subscale, options were organized in terms of increasing student involvement/participation. Teachers were asked how they taught certain sub-topics under the broad topic of "biology of heredity" in the WASSCE syllabus. What was of interest was whether teachers employ more student-centred or teacher-centred approaches in teaching their students. There were originally seven (7) questions of this nature in the questionnaire. An example is shown below.

4. Mendel's experiments

A. A well-organized lecture

B. Class assignments

C. Classroom discussions among students

D. Lab experiment

Under the KSC subscale, items were designed to assess whether teachers consulted vertical (VC) or lateral curriculum (LC) in teaching to students. Options were structured as either vertical curriculum (past knowledge of students), vertical curriculum (advanced future knowledge), lateral curriculum (other science topics) or lateral curriculum (non-science topics). Nine questions of this nature were included originally in the questionnaire. An example is presented as follows.

5. When teaching students about the relationship between a gene and an allele,

A. I compare it to the relationship between chemical elements and their isotopes. (LC Science)

B. I will compare it to the relationship between the concept of country and the fact that different countries exist. (LC non-Science)

C. I will talk about biological characters inherited from parents and the different shapes and sizes of that character that exist. (VC past knowledge)

D. I will give an example of a specific gene and a particular allele of that gene, for example, blood antigens. (VC advanced knowledge)

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

Validity

Content validity of the instruments was established by presenting the tests and its scheme to supervisory team. The researcher's team of supervisors also ensured that the types of knowledge hypothesized by Magnusson et al. (1999) were satisfactorily covered and well structured.

Pilot testing

When the instrument was improved upon by professional advice, it was field tested. This test was administered to 30 senior high school biology teachers in the Cape Coast Metropolis in order to determine its reliability.

Reliability

The reliability of the instrument for measuring the five components of PCK was assessed using Cronbach's alpha. Different authors have different interpretations of what is an acceptable value for Cronbach's alpha. Pallant (2013) asserts that Cronbach's alpha coefficient reported of 0.7 is acceptable; however, values above 0.8 are preferable. Others are also of the position that a Cronbach's alpha of values 0.6 and above are also acceptable (Griethuijsen et al., 2014). In calculating the reliability of the items in measuring the same construct, items that negatively affected Cronbach's alpha were removed.

Orientations to Teaching Science

According to Griethuijsen et al. (2014), a Cronbach alpha coefficient reported of 0.6 is acceptable. In this study, since the Cronbach alpha coefficient for this subscale which consisted of nine items was 0.654 (Table 5), the items can be said to be measuring the same subscale.

Table 5: Reliability of "Orientations to Teaching Science" Subscale

Cronbach's Alpha	N of Items
0.654	9

Source: Field data, Wilmot, 2019

Knowledge of Science Curriculum

From Table 6 it can be seen that the Cronbach alpha coefficient for this subscale was 0.713. According to Griethuijsen et al. (2014), a Cronbach alpha coefficient reported of 0.6 is acceptable. The items can thus be said to be measuring the same subscale

Table 6: Reliability of "Knowledge of Science Curriculum" Subscale

Cronbach's Alpha	N of Items
0.713	9

Source: Field data, Wilmot, 2019

Knowledge of Students' Understanding

The Cronbach alpha coefficient for this subscale (consisting of eight items) was 0.692 (Table 7). The items can thus be said to be measuring the same subscale since values above 0.6 are acceptable (Griethuijsen et al., 2014)

Table 7: Reliability of "Knowledge of Students' Understanding" Subscale

Cronbach's Alpha	N of Items
0.692	8

Source: Field data, Wilmot, 2019

Knowledge of Assessment in Science

According to Griethuijsen et al. (2014), a Cronbach alpha coefficient reported of 0.6 is acceptable. The Cronbach alpha coefficient for this subscale (which consisted of 7 items) was 0.686 (Table 8). The items can thus be said to be measuring the same subscale.

Table 8: Reliability of "Knowledge of Assessment in Science" Subscale

Cronbach's Alpha	N of Items
0.686	7

Source: Field data, Wilmot, 2019

Knowledge of Instructional Strategies

From Table 9 it can be seen that the Cronbach alpha coefficient for this subscale was 0.939. This value (above 0.8) according to Pallant (2013), is preferable. By this value it can be said that the items (7 items) are measuring the same subscale.

Table 9: Reliability of "Knowledge of Instructional Strategies" Subscale

Cronbach's Alpha	N of Items
0.939	7

Source: Field data, Wilmot, 2019

Summary of reliability analyses

The reliability of the instrument for measuring the five components of PCK was assessed using Cronbach's alpha. In cases where an item reduced the reliability of the subscale it was in, that item was removed. Therefore, any analyses performed on the subscales were done without the removed items. In all after reliability analyses and removal of items OTTS had nine items (instead of 10), KIS had seven, KAS had seven (instead of 8), KSU had 8 (instead of 9) and KSC had nine items.

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) by presenting an introductory letter (see Appendix B) signed by the senior supervisor of this study, explaining the nature of the research. All available biology teachers were summoned by the school leadership (the headteachers/assistant headteachers/ heads of science departments). In most cases, not all the teachers teaching biology could be accessed. The available teachers were briefly taken through the questionnaire and encouraged to answer individually. Their phone numbers were then taken, along with that of the head of department. A later date was set f\or the collection of the filled questionnaire.

For the purpose of confidentiality of teachers, responses and names of teachers along with their schools were not recorded in the instruments to allay their fears of being exposed

Data Processing and Analysis

The options provided under the questions in the instrument were neither wrong nor right. Data from this study was thus quantitative in nature. Data was obtained both from participants' responses to the demographic survey questions, and participants' responses to the content items on the instruments.

To assess whether the questionnaire items fully conform to the five-component model of PCK (research question 1), 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).

In testing research question two, the PCK of Ghanaian is to going to be described by looking at the mean values obtained for the individual subscales. Since the options were organized into increasing levels of cognition or student participation and coded as ordinal data, the means give a good indication of where the teachers align with regards to their PCK. Pearson's product moment correlation was used to assess the relationship between the different components of PCK (research question 3). Pearson's correlation is used this case, with assumptions met, because of its superiority over Spearman's and Kendall's correlation (Chok, 2010),

Differences in PCK across different demographics of teachers and schools were assessed using MANOVA. However, because there was no composite PCK score, differences were calculated based on the average scores of the five individual components.

Summary of Demographics

As stated, the questionnaires were administered with the intention of measuring Ghanaian SHS biological science teachers' PCK for teaching genetics. Data was collected across three regions in Ghana. Forty-three schools were targeted.

Out of these forty-three schools, one hundred and forty-nine teachers out of one hundred and fifty-two were able to complete the questionnaire. One hundred and sixteen (116) of these teachers were male and thirty-three of them were female. Thirty-seven were from single sex male schools, thirty-eight from single sex female schools and seventy-four were from mixed gender schools. Table 10 below shows the teachers who responded to the questionnaire according to their school type and gender

Table 10: Summary Demographics of Respondents

		Single Sex Male	Single Sex Female	Mixed	Total
	Male	27	28	61	116
	Female	10	10	13	33
Total		37	38	74	149

Source: Field data, Wilmot, 2019

CHAPTER FOUR

RESULTS AND DISCUSSION

The purpose of this study was to assess the PCK of Ghanaian biology SHS teachers for teaching genetics based on the five components of PCK hypothesized by Magnusson et al. (1999) and the relationship that existed between these five components. To do this, a questionnaire containing 43 items was administered to measure the way teachers aligned under these five components. The word aligned here is important because this research was not so much interested in measuring the amount of knowledge that teachers possessed in these five components but rather the nature of their PCK. As such, this research does not seek to make claims about high or low scores of PCK or PCK components. The options provided under the questions were neither right nor wrong but were simply options available to the teacher in the context of "Genetics" and teaching at the SHS level.

Because the study was about Senior High School biology teachers' PCK for teaching genetics, it focused on biology teachers already teaching in the field (in-service teachers). Specifically, teachers were chosen to explore the impact of teaching experience, training in education, gender, the types of schools (single-sex or mixed) and the category of schools on their PCK. In addition to this, the interrelationships between the different PCK components were also examined to see where Ghanaian biology SHS teachers aligned with regard to their PCK for teaching genetics.

Confirmatory factor analysis was also done to confirm five component model of PCK, after which the questionnaires for this research were shaped, to confirm the fit of the questionnaires to this model.

Research Question 1: Does Ghanaian SHS biology teachers' PCK for teaching genetics corroborate Magnusson's five component framework of PCK?

Confirmatory factor analysis was conducted to investigate whether the PCK of Ghanaian biology teachers for teaching genetics can truly be explained by Magnusson's framework. To do this, confirmatory factor analysis was performed on the goodness-of-fit of the model (shown in Figure 4) of five 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) and Bollen's Incremental Fit Index (IFI) are presented in Table 11

Table 11: Goodness-of-fit Indicators of the Five Component Model of PCK

GFI	RMSEA	IFI	TLI	CFI	AGFI
.789	0.036	0.917	0.908	0.914	0.763

Source: Field data, Wilmot, 2019

Literature suggests that RMSEA values less than 0.05 are good, values between 0.05 and 0.08 are acceptable (Fabrigar, MacCallum, Wegener, & Strahan, 1999). Therefore, the RMSEA value of 0.036 in this sample indicates a good fit. The GFI value of this sample, 0.79, is below 0.9, but the GFI and AGFI are known to depend on the sample size (Mulaik, James, Van Alstine, Bennett, Lind & Stilwell, 1989) 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).

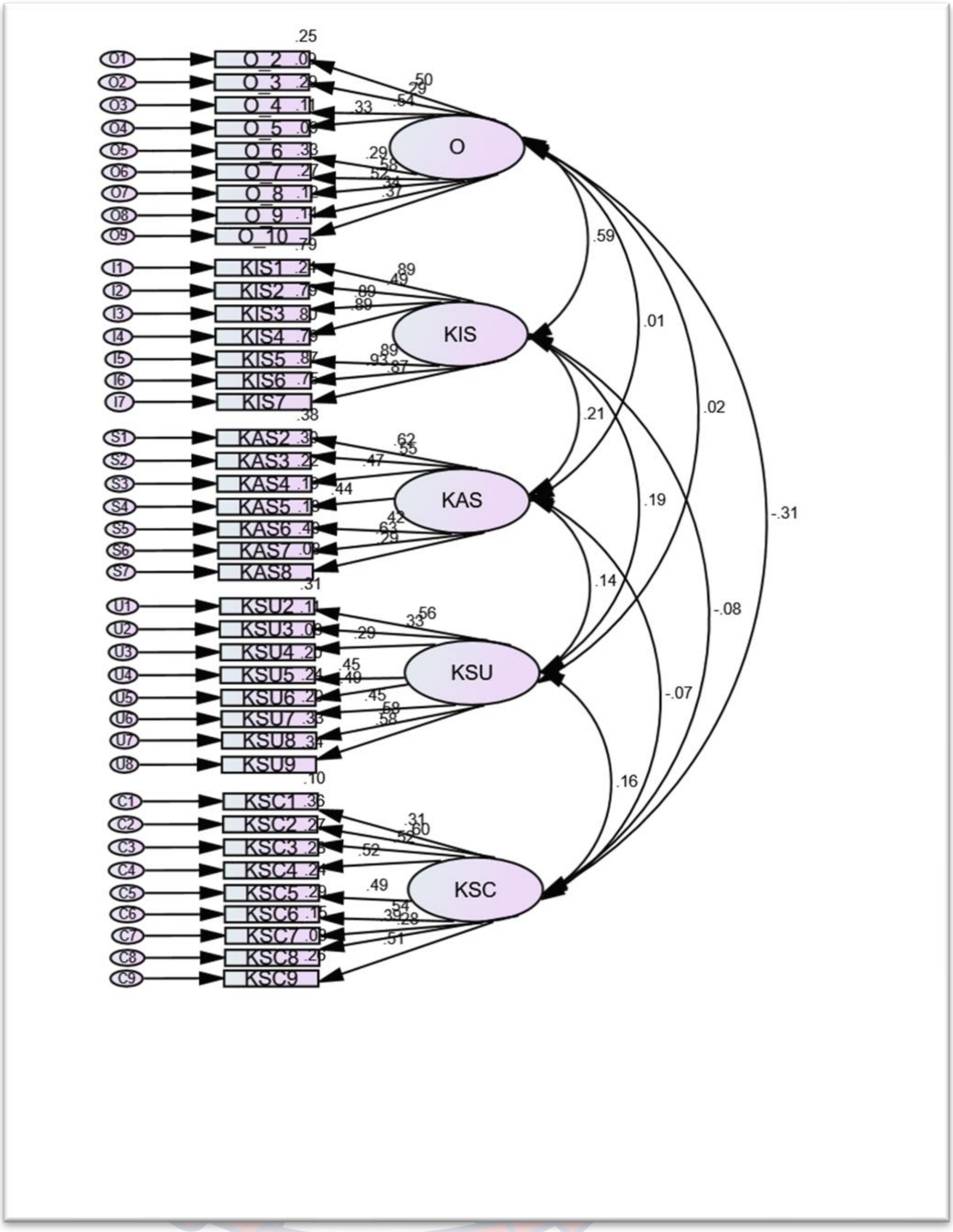

Figure 4: Results of the confirmatory factor analysis of for PCK components. (Source: Field data, Wilmot, 2019)

(O=Orientations to teaching science, KIS=Knowledge of instructional strategies, KAS=Knowledge of assessment in science, KSU= Knowledge of student understanding, KSC=knowledge of science curriculum)

Ghanaian biology SHS teachers' PCK for teaching genetics can be explained by Magnusson's framework

Shulman's introduction of PCK led to a plethora of different PCK models (Appleton, 2003; Friedrichsen et al., 2009; Hashweh, 2005; Magnusson et al., 1999; Park & Oliver, 2008) which were unified by their modifications of the constituents of PCK. All the different descriptions of the constituent components of PCK were possible because of the underlying idea that PCK is a synthesis of the components constituting PCK (Abell, 2008; Lee & Luft, 2008).

As stated earlier, Shulman (1986) originally included three components in the original model of PCK: (1) knowledge of topics regularly taught in one's subject area, (2) knowledge of forms of representation of those ideas, and (3) knowledge of students' understanding of the topics. Grossman (1990) then went on to add four central components adding on "conceptions of purpose for teaching subject matter". Tamir's (1988) clarification of science PCK components include "evaluation" which Grossman did not but left out "purpose of teaching".

Based on Grossman's (1990) and Tamir's (1988) models of PCK, Magnusson et al. (1999) came up with their model of five components. Other models of PCK exist (see for example, Marks, 1990; Andrews, 2001). Both Tamir's (1998) and Magnusson at al.'s (1999) models focused on science teaching and one model is not inherently better than the other. However, the widespread use of Magnusson et al.'s (1999) PCK model in the subject area of science (see for example, Hanuscin, Lee, & Akerson, 2011; Henze, van Driel, & Verloop, 2008; Jong, Driel, & Verloop, 2005; Käpylä, Heikkinen, &

Asunta, 2009) and even in mathematics (see for example, Akkoç & Ye, 2010; Bukova-Güzel, Kula, Uğurel, & Özgür, 2010) makes it more of a suitable framework.

Confirmatory factor analysis was chosen then, as a method of confirming the fit of the questionnaires to this already existing model of PCK. Confirmatory factor analysis (CFA) method is used to verify the factor structure of a set of observed variables (Hair, Sarstedt, Pieper & Ringle, 2012). Based on the indices of fit, the five-component model of PCK for the instrument administered. This meant that explanations on the relationship between the components and differences in the components, as far as this study is concerned, could be explained based on the model hypothesized by Magnusson et al. (1999)

Research Question 2: What is the PCK of Ghanaian high school biology teachers teaching genetics based on the five-component model of PCK hypothesized by Magnusson et al. (1999)?

The choices for each question under their scales were summed up to get an idea of where teachers aligned under each component. This was based on the ordinal-type numbering (from 1 to 4) assigned to each of the options. The mean score for each component was then computed by finding the average score from each item under each subscale for all of the teachers.

Orientations to teaching science

Mostly, teachers were more "active direct" in their teaching approach. This was followed by "guided inquiry" and "didactic direct" (Table 12). The least chosen orientation was "open inquiry". The mean score for teachers' orientations, 2.34, suggests that most teachers are more teacher-centred in their orientations to teaching.

Table 12: Teaching Orientations

ITEM	Didactic direct	Active Direct	Guided Inquiry	Open Inquiry	Total Responses
OTTS 2	36	49	42	22	149
OTTS 3	31	50	46	22	149
OTTS 4	32	51	46	20	149
OTTS 5	26	58	45	20	149
OTTS 6	29	54	38	28	149
OTTS 7	31	52	38	28	149
OTTS 8	32	63	37	17	149
OTTS 9	27	62	40	20	149
OTTS 10	42	62	26	19	149
Total count	286	501	358	196	1341
Percentage	21.3	37.4	26.7	14.6	
MEAN	2.34				

Source: Field data, Wilmot, 2019

Knowledge of science curriculum

From Table 13, it can be seen that in terms of what type of curricular tools teachers draw on when teaching, most teachers drew on lateral non-science curriculum followed by backwards vertical curriculum and forward vertical curriculum. Teachers drew on lateral science curriculum the least. The mean score for teachers' knowledge of science curriculum, 2.37, also suggests that teachers are more comfortable with the use of vertical curriculum when teaching.

Table 13: Teachers' Use of Curriculum

ITEM	Vertical curriculum forward	Vertical curriculum backwards	Lateral curriculum (non-science)	Lateral curriculum (science)	Total Responses
KSC 1	30	45	43	31	149
KSC 2	41	38	45	25	149
KSC 3	36	37	50	26	149
KSC 4	48	40	37	24	149
KSC 5	39	39	43	28	149
KSC 6	41	42	36	30	149
KSC 7	44	37	46	22	149
KSC 8	32	43	47	27	149
KSC 9	46	40	40	23	149
Total count	357	361	387	236	1341
Percentage	26.6	26.9	28.9	17.6	
MEAN	2.37				

Source: Field data, Wilmot, 2019

Knowledge of students' understanding

Most teachers identified that their students mostly struggle with (in order or decreasing frequency) applying, understanding and analysing the content in "biology of heredity" (Table 14). Comparatively, fewer teachers identify that their students struggle with "remembering" information. The mean score for KSU, 2.64, reveals that teachers believe that students struggle with "applying", and by implication, higher cognitive tasks when it comes to genetics.

Table 14: Teachers' Knowledge of Students' Understanding (Difficulties)

ITEM	Remember	Understand	Apply	Analyze	Total responses
KSU 2	29	35	36	49	149
KSU 3	27	42	43	37	149
KSU 4	20	48	53	28	149
KSU 5	26	38	44	41	149
KSU 6	28	42	43	36	149
KSU 7	29	50	32	38	149
KSU 8	19	39	48	43	149
KSU 9	23	42	39	45	149
Total count	201	336	338	317	1192
Percentage	16.9	28.2	28.4	26.6	
MEAN	2.65				

Source: Field data, Wilmot, 2019

Knowledge of assessment in science

Most teacher assess their students through "written class tests". "Written take-home assignments" and "lab procedures" followed. Few teachers assess their students through "presentations" (Table 15). The mean score, 2.54 also reveals that, in total, teachers do not favour more student-centred methods of assessment.

Table 15: Popular Assessment Methods

ITEM	Paper and Pencil based tests	Written take-home assignment	Presentations by students	Observe student performance on simulations of lab procedure	Total Responses
KAS 2	30	47	28	44	149
KAS 3	32	45	45	27	149
KAS 4	23	46	44	36	149
KAS 5	32	43	42	32	149
KAS 6	37	40	38	34	149
KAS 7	37	32	41	39	149
KAS 8	29	42	40	38	149
Total count	220	295	278	250	1043
Percent	21.1	28.3	26.7	24.0	
MEAN	2.53				

Source: Field data, Wilmot, 2019

Knowledge of instructional strategies

It can be seen from Table 16 that most teachers employ "a well-organized lecture" in teaching their students. "Class assignments" and "classroom discussions among students" follow as the second and third teaching approach. "Lab experiments" was the least chosen instructional approach. Teachers' instructional strategies were revealed to also be mostly teacher-centred by a mean score of 1.66.

Table 16: Instructional Strategies

ITEM	A well-organized lecture	Class assignments	Classroom discussions amongst students	Lab experiment	Total Responses
KIS 1	99	26	13	11	149
KIS 2	57	16	69	7	149
KIS 3	96	29	13	11	149
KIS 4	101	24	17	7	149
KIS 5	95	30	10	14	149
KIS 6	104	21	7	17	149
KIS 7	98	27	15	9	149
Total count	650	173	144	76	1043
Percentage	62.3	16.6	13.8	7.3	
MEAN	1.66				

Source: Field data, Wilmot, 2019

The PCK of Ghanaian SHS biology teachers for teaching genetics according to Magnusson's components

This research revealed that the PCK of Ghanaian biology teachers for teaching genetics was teacher-centred in its orientations and instructional strategies. It was also revealed that teachers are more likely to use vertical (what students are supposed to already know and what they must know in the future) curriculum in teaching. Teachers also revealed that they believe that students struggle most with higher cognitive tasks such as “application” of genetics knowledge. The assessment methods used by the teachers were also revealed to favour more teacher-centred methods of assessment.

Of course, PCK is never just the sum of individual components but rather a mixture or amalgamation, to borrow from Shulman, of these components into a type of practical knowledge that teachers use to teach. Therefore, while it is important to look at where teachers align in the different components, it is also worth noting that the PCK of the teacher can be further understood by looking at the interplay between the components, further investigated through research question 3.

Research Question 3: What is the relationship amongst the five components of PCK?

Correlation between the subscales was assessed to investigate the relationship amongst the five components of PCK. To arrive at this correlation, subscale scores were obtained. Because the number of items under each subscale varies from subscale to subscale, an average of the scores of each item under a subscale was computed as the score for the subscale. Table 17 shows the Pearson correlation values between the five components of PCK for teaching genetics at the SHS level, as revealed by the PCK instrument (N=149). Namely, Orientations to teaching Science (shown in table as OTTS), Knowledge of Science Curriculum (shown as KSC), Knowledge of Students' Understanding (shown as KSU), Knowledge of Assessment in Science (KAS) and Knowledge of Instructional Strategies (KIS)

The significance of the correlations is also indicated by asterisks in the table. A single Asterisk (*) indicates that correlation is significant at the 0.05

level (2-tailed).and double Asterisk (**) indicates that correlation is very significant at the 0.01 level (2-tailed).

Table 17: Pearson's Correlation between the Five Components of PCK

	OTTS	KSU	KSC	KAS	KIS
OTTS	1	.002	.189*	.013	.471**
KSU	.002	1	.110	.095	.170*
KSC	.189*	.110	1	.027	-.065
KAS	.013	.095	.027	1	.170*
KIS	.471**	.170*	-.065	.170*	1

Source: Field data, Wilmot, 2019

According to Cohen (2013), a correlation coefficient of .10 is thought to represent a weak or small association; a correlation coefficient of .30 and above is considered a moderate correlation; and a correlation coefficient of .50 or larger is thought to represent a strong or large correlation. From Table 17 it can be seen that there is a significant ($p<0.05$) but small (less than 0.3) negative correlation between OTTS and KSC. There is also a very significant ($p<0.01$) but moderate correlation between OTTS and KIS. A significant but small correlation can also be seen between KSU and KIS as well as between KAS and KIS.

Correlations between the five components of PCK

It can be seen that each subscale is at least correlated with one other subscale. The exception of course is KIS which is correlated to three other subscales and OTTS which is correlated to two other subscales. Specifically, there was a significant ($p<0.05$) but small (less than 0.3) correlation between OTTS and KSC. There is also a very significant ($p<0.01$) but moderate correlation, the strongest link, between OTTS and KIS. A significant but small correlation can also be seen between KSU and KIS as well as between KAS and KIS. Magnusson et al. (1999) did acknowledge the importance of the interaction and coherence among the components but did not describe an interlinkage amongst the other four blocks in their model. In their model, the five components were presented in a linear way which only emphasized the interaction OTTS and each of the other four components (Friedrichsen, Van Drivel & Abell, 2011).

Orientations to Teaching Science did not play a central role in the connections between other components.

From the interconnections observed in this study, the component that made the most connections was KIS, followed then by OTTS. In this way, the findings of this research disagree with Magnusson's model in that it removes the central role played by orientations to teaching science. Magnusson et al. (1999) hypothesized that "teaching orientations act as 'conceptual maps' guiding the decisions about learning objectives, implementation of curricular materials, and evaluation of students' learning." On the other hand, KAS, or "evaluation of students' learning", did not make a connection to OTTS in this study. In fact, Park and Chen (2012) also noted this diminished role of OTTS as well as the central role of the "Knowledge of Instructional Strategies and Representations."

One possible explanation is not that while "orientations to teaching science" is a single variable on its own, perhaps its ability to influence the other factors depends on the value it possesses. For example, from the answers chosen in questionnaire, it can be seen that most of the teachers were "active-direct" and hence teacher centred in their orientation. In fact, when teachers had to choose an instructional strategy, they chose the more teacher centred option, of "a well-structured lecture". Teacher-centred approaches rely on the behaviourist theory which is based on the idea that behaviour changes are caused by external stimuli (Serin, 2018). As such, teacher centred approaches are more concerned with imparting ideas or information. As a result, it does not actively cater to the problems with higher cognitive functions that the teachers claim students have difficulty in (KSU). This would explain why OTTS had no correlation with KSU or KAS and a small correlation with KSC (which in this case took into account prior experience of students). This means that teachers' teaching orientations, shown to be mostly teacher-centred, do not match the way they assess their students nor does it match the problems they have identified in their students' understanding. In fact, Park and Chen (2012) argued that "when a teacher held a strong didactic orientation toward teaching science, that orientation significantly controlled KISR (knowledge of instructional strategies and representations) and consequently isolated KISR which prevented it from interacting with other components. Park and Chen's (2012) explanation would explain the small correlation between KIS ⇔ KSU and KIS ⇔ KAS.

Linkages between KAS ⇔ KSU, KIS ⇔ KSC and KAS ⇔ KSC, which are non-existent suggest that the effect of a teacher-centred teaching orientation, produces teacher-centred instructional strategies (KIS), which do not actively engage students in using what they know (KSC), and assessment methods (KAS) which are not useful in testing the conceptual understanding that students need (KSU) in making sense of genetics.

By this OTTS can be seen to be still vital but limited in making connections to the other components when it is mostly teacher-centred. Teachers with a teacher-centred orientation will therefore possess low PCK because the level of a teacher's PCK depends on the degree of the integration and coherence among the components as well as the possession of individual components (Friedrichsen et al., 2009; Krauss et al., 2008; Park & Oliver, 2008).

Instruction was central, but assessment was not connected to students' understanding

In connection to the diminished connections observed by OTTS, was the prominent role of KIS. In this case, the strongest link to KIS was OTTS. Which as explained earlier was predominantly teacher-centred. It is without surprise that OTTS has a strong connection to KIS which was also teacher-centred. In fact, Park and Chen (2012) also report a dominant role for KIS (which they term Knowledge of Instructional strategies and representations) as well as KSU. But in this case, because of the teacher centred approach, the link between KSU and KIS is relatively "small." Because teachers need to know what students already know and what they are likely to have difficulty in learning a particular topic in order to generate appropriate teaching strategies, the small linkage here suggests that the teaching approach does no pay much attention to what students already know or have difficulty in.

The link between KIS and KAS was also shown to be small. Even though the most popular methods of assessment were "written" tests, instead of the more student-activity driven "presentations" and "lab experiments," there wasn't that much of a difference. Teachers showed they employ a wide range of methods of assessment in students, and the small link here between KAS and KIS suggest that perhaps teachers, are not fully aware of establishing a link between their methods of instruction, that is how they teach, and how that should inform how they assess. In fact, Abbatt and McMahon (1993) say that "assessment must be carefully planned so that it supports the learning we want to see." The link between assessment and a teaching and learning is vital. But in this case, we can see instruction it has a small connection to assessment and no connection at all with students' understanding.

Knowledge of Science Curricula had a small role to play in PCK interconnections.

Knowledge of Science Curriculum refers to teachers' understanding of both the horizontal and vertical curricula for a subject and curriculum materials available for teaching a particular subject matter (Grossman, 1990). Knowledge about the horizontal curricula is demonstrated by teachers' knowledge of the goals and objectives for students in the subject they are teaching (in this case the national or WAEC standards) as well as the articulation of those guide-lines across topics addressed during the school year (Magnusson et al., 1999). Knowledge about what students have learned in previous years and what they are expected to learn in later years is included in teachers' knowledge about the vertical curriculum (Grossman,1990).

For this study, vertical knowledge and horizontal knowledge was considered based on the how teachers used information (from science and non-science topics) of what students have known, are supposed to know (by the WAEC curriculum) and will know in teaching. This means that this knowledge deals more with knowledge that students are supposed to possess.

The Link between OTTS and KSC suggests that teaching orientations of these teachers do take KSC into consideration, even though they do not necessarily take into consideration student difficulties in understanding (the feature of KSU looked at in this study). The small linkages would suggest that even still, KSC is something that is rarely taken into account when teaching SHS genetics. This is a feature also observed by Park and Chen (2012) who note that KSC was "rarely integrated into PCK that affected [teachers'] instructional decisions" in their study.

KSC in this case did not have a link to either KSU, KIS or KAS, perhaps because of the nature of the KSC options. OTTS, KIS, KSU and KAS dealt more with increasing levels of cognitive or levels of student engagement, but vertical curricular knowledge cannot be taught of as higher than horizontal curricular knowledge. As such, the only comment that can be made about the lack of interaction between these components could be due to feature of the instrument itself. Nonetheless, the link between OTTS and KSC would suggest, a working, but small relationship between teacher's knowledge of what students are supposed to know and their approach to teaching. However, this knowledge of what students are supposed to know according to the curriculum did not affect their assessment or instructional strategies. This knowledge of what students are supposed to know was also not related to what students actually know (KSU).

Hypothesis 1: There is no significant difference in the PCK for teaching genetics between non-professional and professional senior high school biology teachers.

Fifty-six (56) of the teachers (37.6%) had were non-professional, that is were not trained teachers (Table 18). However, a larger proportion of teachers, ninety-three (93) in number (61.2%), were professionally trained and had either a diploma in education, a post-graduate diploma in education, a Bachelors in Education, or a Masters in Education (Table 19).

Table 18: Teachers' Training in Education

Training	Frequency	Percent
Non-professional	56	37.6
Professional	93	62.4
Total	149	100

Source: Field data, Wilmot, 2019

Table 19: Teachers' Types of Training in Education

Type of Education Background	Frequency	Percent
No training in Education	56	37.6
Diploma in Education	7	4.7
PGDE	20	13.4
B.Ed	55	36.9
M.Ed	11	7.4
Total	149	100.0

Source: Field data, Wilmot, 2019

In investigating the differences in PCK based on whether a teacher had been professionally trained in education or not, A one-way between-groups multivariate analysis of variance was performed. There were five dependent variables used: OTTS, KIS, KSU, KAS and KSC. The independent variable was "training in education". Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

There was no statistically significant difference between professionally-trained and non-professional teachers in the combined dependent variables, $F (5, 143) = 0.978$, $p = .434$; Wilks' Lambda = .967.

Table 20: One-Way Between-Groups MANOVA of PCK of Teachers by Professional Training in Education

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
education	OTTS	1	.423	1.698	.195	.011
	KSU	1	.030	.086	.769	.001
	KIS	1	.232	.351	.555	.002
	KSC	1	.019	.055	.814	.000
	KAS	1	.384	.701	.404	.005

Source: Field data, Wilmot, 2019

Hypothesis 2: There is no significant difference between senior high school biology teachers' PCK for teaching genetics based on their years of teaching experience

Teachers' teaching experience was described by ranges between under 1 year, 1 to 6 years, 7 to 10 years and more than 10 years. The percentages and frequencies for this variable are presented in Table 21. Most of the teachers (61.1%) had between 1 to 6 years of teaching experience. Very few teachers (4.7%) had more than 10 years of teaching experience.

Table 21: Years of Teaching Experience of Teachers

Years of teaching experience	Frequency	Percent
Under a year	23	15.4
1 to 6 years	91	61.1
7 to 10 years	28	18.8
More than 10 years	7	4.7
Total	149	98.0

Source: Field data, Wilmot, 2019

A one-way between-groups multivariate analysis of variance was performed to investigate differences in PCK based on years of teaching experience. Five dependent variables were used: OTTS, KIS, KSU, KAS and KSC. The independent variable was gender. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

There was no statistically significant difference between teachers based on their years of experience on the combined dependent variables, F (5, 141) = 0.612, p = .866; Wilks' Lambda = .938.

Table 22: One-Way Between-Groups MANOVA of PCK of Teachers by Teaching Experience

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
YEARS	OTTS	3	.154	.611	.609	.012
	KSU	3	.014	.041	.989	.001
	KIS	3	.770	1.172	.323	.024
	KSC	3	.385	1.136	.337	.023
	KAS	3	.226	.408	.747	.008

Source: Field data, Wilmot, 2019

Hypothesis 3: There is no significant difference in the PCK for teaching genetics between male and female SHS biology teachers

From Table 23, it can be seen that out of the total of one hundred and forty-nine (149) teachers, thirty-three (33) of them were females (accounting for 22.1%) and one hundred and sixteen of them were male (accounting for 77.9%).

Table 23: Teacher Gender Frequencies

Gender	Frequency	Percent
Male	116	77.9
Female	33	22.1
Total	149	100

Source: Field data, Wilmot, 2019

To answer this hypothesis, a one-way between-groups multivariate analysis of variance was performed to investigate sex differences in PCK. The dependent variables used were, OTTS, KIS, KSU, KAS and KSC. The independent variable was gender. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

There was no statistically significant difference between males and females on the combined dependent variables, F (5, 143) = 0.646, p = .665; Wilks' Lambda = .978.

Table 24: One-Way Between-Groups MANOVA of PCK of Teachers by Gender

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
Gender	OTTS	1	.370	1.485	.225	.010
	KSU	1	.141	.404	.526	.003
	KIS	1	.246	.371	.543	.003
	KSC	1	.561	1.660	.200	.011
	KAS	1	.102	.185	.667	.001

Source: Field data, Wilmot, 2019

PCK was the same across different demographics of Teachers

The PCK of teachers was not significantly different based on gender, years of teaching experience or professional training in education. Because there was no composite 'PCK score' but rather measurements of individual components, this conclusion is made only based on where teachers align in the different components of PCK. Specifically, the orientations, assessment knowledge, knowledge of student understanding, knowledge of science curricular and the use of instructional strategies of genetics teachers was not statistically different.

This research found no significant difference in the PCK of teachers based on their gender. Many researchers agree that teacher gender has no effect on their quality (Carrington, Tymms, & Merrell, 2008; Holmlund & Sund, 2008). However, some suggest gender may impact the quality of teaching. In fact, Lam, Tse, Lam and Loh (2010) found that both boys and girls in grade 4 learnt better when taught by women. If there was a gap in the PCK for teaching SHS genetics based on gender, future teacher training programs could be targeted towards bridging that gap. However, no such gap was identified.

Teaching experience had no effect on the PCK for teaching genetics of Ghanaian SHS biology teachers. Teaching experience, measured as prior teaching experience has also been found to make little difference in the lesson plans of biology teachers entering alternative training programs by Friedrichsen, Abell, Pareja, Brown, Lankford and Volkmann (2008). Likewise, Patra and Guha (2017) also reported no significant difference in PCK with respect to variations in teachers' experience. One reason for this is, if PCK can be thought of as the amalgamation of pedagogical knowledge and content knowledge, perhaps the successful integration of this is a skill that has to be specifically taught. In fact, Yang, Liu and Gardella (2018) have found, for example, that teacher attendance in professional learning communities and interdisciplinary science research related positively to teachers' scores on a pedagogical content knowledge test. This research data suggests that teachers do not just learn this skill of integrating pedagogy and content as they gain more teaching experience.

Even with regards to training in education, there is empirical evidence that CK (Content Knowledge), as well as PCK, improve during both phases of initial teacher training (e.g., Blömeke, Kaiser & Lehmann, 2008; Schmelzing, Driel, Jüttner, Brandenbusch, Sandman & Neuhaus, 2013). However, Fritsch et al. (2015) reported little to no observed change in the PCK of German and Australian trainee teachers respectively as a result of University based practical training in teaching. This research also found that professional training in education made no impact on Ghanaian SHS biology teachers' PCK for teaching genetics. This may be because the way teachers align in their methods of teaching etc, for this relatively new and rapidly expanding field of genetics may be entirely cultural and may transcend the usual modifiers to PCK quality such as training in education and years of teaching experience. As such what may be needed is a national or cultural shift in teacher training to address this particular field.

Hypothesis 4: There is no significant difference in the PCK of SHS biology teachers teaching genetics in category A, B or C schools.

The "category" of schools looked at here were the categories of schools according to GES school selection register (A, B & C), shown in Table 25,

Table 25: School Categories

Type of School	Frequency	Percent
CAT A	64	43.0
CAT B	49	32.9
CAT C	36	24.2
Total	149	100.0

Source: Field data, Wilmot, 2019

PCK Across Different School Categories

A one-way between-groups multivariate analysis of variance was performed to investigate differences in PCK based on school category. Five dependent variables were used: OTTS, KIS, KSU, KAS and KSC. The independent variable was gender. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

There was no statistically significant difference between school category on the combined dependent variables, F (5, 142) = 1.080, p = .373; Wilks' Lambda = .894.

Table 26: One-Way Between-Groups MANOVA of PCK of Teachers by School Category

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
School category	OTTS	3	.012	.047	.986	.001
	KSU	3	.526	1.525	.211	.031
	KIS	3	.414	.623	.601	.013
	KSC	3	.233	.681	.565	.014
	KAS	3	1.253	2.357	.074	.046

Source: Field data, Wilmot, 2019

There was no significant difference in PCK of teachers across the different categories of schools

There was no significant difference in the PCK of teachers based on school category. Public (government owned) SHS's are rated on a scale of A to C, but the criteria for the designation of a school as A or C is unclear.

With regards the category of schools, some classifications of schools, such as private versus public schools have been found to produce different results. In fact, private schools have been shown to perform better than public schools in student performance (Coleman, Hoffer & Kilgore, 1982; Jimenez, Lockheed & Paqueo, 1991) and worse than public schools in teacher burnout (Ferreira & Martinez, 2012). The latter means that teachers in private schools are more engaged and less prone to burnout unlike their public-school counterparts. In terms of resources available for learning, research has also been split. Yi et al. (2018) for example find that when students from schools with poor reading resources were supplied with a library, student reading habits and the degree to which students like reading were improved. Conversely, Li et al. (2016) found no significant benefits of attending model vocational education training schools (with higher levels resources) to attending non-model schools (with lower levels of resources).

This data also suggests that there is no difference in the genetics PCK components of teachers based on the category of schools. Posting of teachers to these different categories seems random and as a result does not reveal any major biases or favouritism towards a particular category of schools. It is unclear what goes into the categorisation of these schools. However, a major implication of this result means that there is no difference between the genetics PCK of teachers across the different categories of schools.

Hypothesis 5: There is no significant difference in the PCK of SHS biology teachers teaching genetics in all female, all male and mixed schools

The teachers obtained for the study are shown according to the genders of their schools, that is, either all-male, all-female, mixed (co-educational) in Table 27.

Table 27: School Gender

Type of School	Frequency	Percent
Single Sex Male	37	24.8
Single Sex Female	38	25.5
Mixed	74	49.7
Total	149	100.0

Source: Field data, Wilmot, 2019

PCK Across Different School Genders

A one-way between-groups multivariate analysis of variance was performed to investigate sex differences in PCK. Five dependent variables were used: OTTS, KIS, KSU, KAS and KSC. The independent variable was gender. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

There was no statistically significant difference between schools on the combined dependent variables, F (5, 143) = 0.567, p = .840; Wilks' Lambda = .961 based on the school gender.

Table 28: One-Way Between-Groups MANOVA of PCK of Genetics Teachers by School Gender

Source	Dependent Variable	df	Mean Square	F	Sig.	Partial Eta Squared
School gender	OTTS	2	.000	.002	.998	.000
	KSU	2	.317	.910	.405	.012
	KIS	2	.867	1.320	.270	.018
	KSC	2	.069	.201	.818	.003
	KAS	2	.261	.475	.623	.006

Source: Field data, Wilmot, 2019

There was no significant difference in PCK of teachers across the different genders of schools

There was no significant difference in the PCK of teachers based on school gender. Ghanaian senior high schools are either single sexed (male or female) or mixed (co-ed) gendered boarding or "day schools". Public (government owned) SHS's are rated on a scale of A to C, but the criteria for the designation of a school as A or C is unclear.

Looking at USA colleges and universities, some research has suggested no benefit of single sex schools over co-ed schools. Astin (1993) for example, found that whether a college was co-ed, single-sex female, or predominantly male had no meaningful effect on a variety of areas including standardized measures of general knowledge, communication skills or professional knowledge. In the same research however having a greater proportion of women administrators or faculty was found to have a positive effect on women's education. Bradley (2009) also supported this by suggesting that single-sex education may be an effective instructional strategy for facilitating math and reading improvement particularly for female students.

In Ghana, there is a perception that single gendered schools have some benefits in terms of quality of mixed schools. This research suggests that there is no difference in the genetics PCK of biology SHS teachers, with respect to the gender of the schools. This quality was measured in the form of the genetics PCK of teachers to ascertain whether there was such an imbalance. Based on school gender, there was no such imbalance in the PCK of teachers. Any imbalance observed would, among other things suggest an institutional bias in the posting of teachers to certain.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Magnusson et. al. (1999) proposed that PCK includes five components which were particularly important for science teachers. The components of PCK, according to Magnusson and his colleagues, were,

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

These components provided the framework upon which a series of 43 (forty-three) questions were designed to assess the way teachers across 43 (forty-three) SHS in Ghana aligned under these five components. The word aligned here is important because this research was not so much interested in measuring the amount of knowledge that teachers possessed in these five components but rather the nature of their PCK. As such, this research does not seek to make claims about high or low scores of PCK or PCK components. The options provided under the questions were neither right nor wrong but were simply options available to the teacher in the context of "Genetics" and teaching at the SHS level.

Biology teachers teaching in SHS, 149 in total, were chosen to explore the impact of teaching experience, training in education, gender, the types of schools (single-sex or mixed) and the category of schools on the nature of their PCK. In addition to this, the interrelationships between the different

PCK components were also examined to see where Ghanaian SHS biology teachers aligned with regard to their PCK for teaching genetics.

Genetics becomes an area of focus because of its numerous applications across different fields, including archaeology and human history, medicine, prenatal diagnosis, reproductive technology, genetically modified organisms (GMO), criminal investigation, cloning and health (e.g., vaccine development and gene therapy). The field of genetics represents a potential lifeline to the development hopes of a country like Ghana. However, trends cited by the chief examiners' reports from 2011 to 2015 reveal that students struggle with genetics concepts.

The options provided under the questions in the instrument were neither wrong nor right. Data from this study was thus quantitative in nature. Data was obtained both from participants' responses to the demographic survey questions, and participants' responses to the content items on the instruments.

To assess whether the questionnaire questions 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.

Differences in PCK across different demographics of teachers and schools was assessed using MANOVA. However, because there was no composite PCK score, differences were calculated based on the average scores of the five individual components.

This research only focused on in-service biology teachers at the SHS level in Ghana. Also, the domain of knowledge used as the focus of the study was genetics. This means that all the items or questions on the instrument used for data collection were genetics related questions. Furthermore, the study was limited to senior high schools in only three administrative regions of Ghana (Western, Central and Ashanti). In these three regions, 149 teachers in from 43 schools were targeted. These regions were selected randomly and are composed of densely populated schools with teachers coming from almost all over the various public universities across the nation teaching there.

This research was limited by the number of participating teachers. This in a way could place a limitation on the outcome of the study in that if a larger number of teachers are involved it might yield different results.

Key findings

1. The five-component model of PCK was confirmed by CFA. This meant that teachers had indeed answered the questions according to the five-component model of PCK. Because the questionnaire items were set according to Magnusson’s framework, what this finding reveals, is that these components of PCK hypothesized by Magnusson et al. (1999) are in fact distinct separate components which can be individually studied based on Magnusson’s framework.
2. This research revealed that the PCK of Ghanaian biology teachers, who favoured the use of vertical curriculum (forward and backwards) for teaching genetics, is teacher-centred in its orientations, instructional strategies and does not favour student-centred methods of assessment. Teachers also identified that their students struggle with higher cognitive tasks such as the application of genetics knowledge.
3. There was a significant correlation between the five components of PCK.

a. Orientations to Teaching Science did not play a central role in the connections between other components. It had no connections with student understanding nor assessment. This is probably because the orientation of most teachers was mostly teacher centred and as a result did not fully take into consideration the problems that students have with understanding genetics (KSU) or how to assess this difficulty in understanding.

b. Instruction was central and had a strong connection with teaching orientations but weak connections to assessment and knowledge of student understanding. This meant that instructional strategies teachers were indeed based on their orientations but were however only weakly correlated with student understanding and the way students were assessed.

c. Assessment was not connected to students' understanding. As explained above this meant that teachers' methods of assessment did not take into consideration the problems that teachers themselves identified students to have.

d. Knowledge of Science Curricula had a small role to play in PCK interconnections. It was only weakly connected to teaching orientations. The link suggests a working, but small relationship between teacher's knowledge of what students is supposed to know and their approach to teaching. However, this knowledge of what students are supposed to know according to the curriculum did not affect their assessment or instructional strategies. It also was not related to what students actually know (KSU)

4. PCK was the same across different demographics of Teachers. Specifically, the gender of the teachers. their professional training, years of experience and the category or gender of their schools did not affect their PCK components and hence their PCK.

Conclusions

While some research has looked at how the development of one component influences a teacher's whole PCK and practice (e.g., Kamen, 1996; Matese, 2005) this research was interested in understanding the correlation between the five components or blocks of knowledge hypothesized by Magnusson et al (1999) as well as the teacher or school factors thought to affect these components. It is important to note that this research did not present questions entirely representative of "every" feature of their blocks of knowledge. Rather, the questions presented, being formulated based on the descriptions given by Magnusson et al. (1999), and confirmed by CFA, could be said to have "some" characters or features of the knowledge block they represented. PCK then could be said to comprise of these components and the way they interact with each other. As such, comparisons of PCK were only made component by component and the study of the correlations between the components only sought to describe interlinkages that existed between them.

Just as Park and Chen (2012) identified linkages and cross linkages between all the different components of PCK, this current research also identified linkages and cross linkages between the different components of PCK. A new conceptual framework which includes the interlinkages between the other components can thus be created. This new framework, built off the original framework of Magnusson, also contains linkages suggested by work done by Park and Chen (2012)

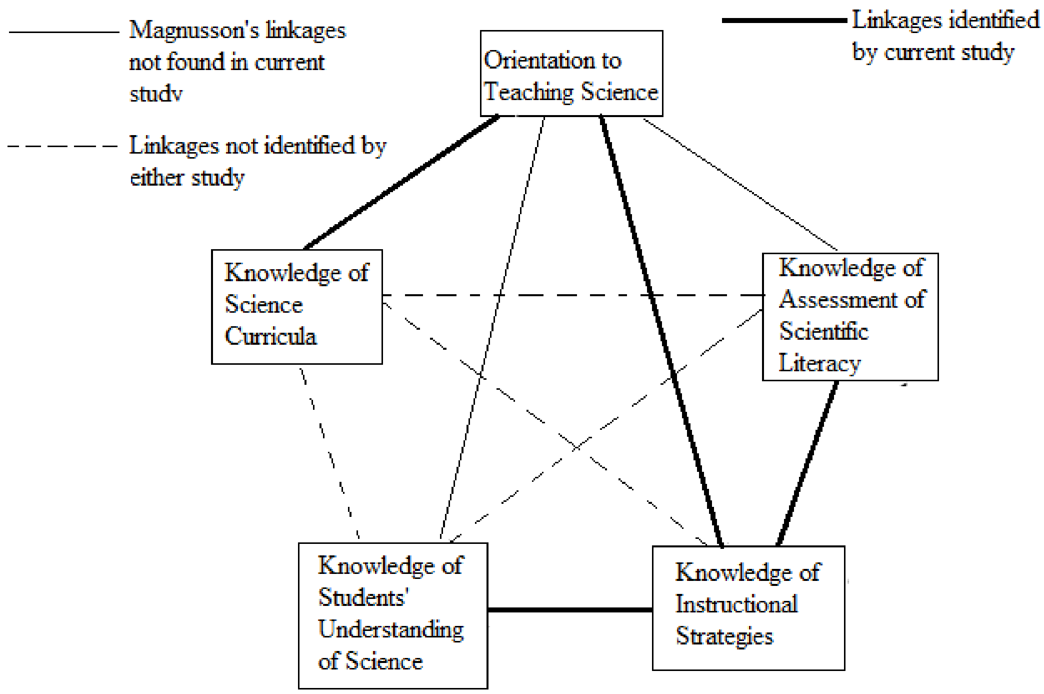

Figure 5: Conceptual framework of the linkages between PCK components. Source: Current study, Wilmot, 2021

Orientations to teaching science was found to be predominantly teacher centred and thus inconsistent with current moves towards reform teaching. Reformed teaching advocates that that classes be "taught via the kinds of constructivist, inquiry-based methods advocated by professional organizations and researchers" (MacIsaac & Falconer, 2002). Reform signals a paradigm shift from the traditional teacher-centred lecture-driven class to a student-centred, activity-based learning environment that typically includes multiple opportunities for collaboration among students.

As Park and Chen (2012) noted, teachers with “strong didactic orientation toward teaching science” in effect isolated their instructional strategies from interacting or catering to student understanding or assessment of that understanding. Likewise, as a result of the teacher centred teaching approach of teachers teaching genetics observed in this study, which is more concerned with imparting ideas or information, data suggests that genetics teachers employ assessment methods and instructional strategies which poorly cater to the problems with higher cognitive tasks that the teachers claim students have difficulty in (KSU). This is evident in the observed significant, but weak correlations found between teachers' KIS ⇔ KSU and KIS ⇔ KAS, as well as the non-existent link between neither OTTS nor KAS and KSU.

On the other hand, teachers' while aware of the requirements made by curriculum for what students are supposed to know did not factor this into their everyday teaching. KSC made weak correlations with OTTS and no correlations with any other components of PCK

The nature of the PCK components was found to be the same for teachers regardless of school type, teaching experience, gender or training in education. This has a number of implications.

Specifically, this research identified no significant difference in the PCK for teaching genetics between senior high school biology teachers with background training in education and those of their counterparts without background training in education. This perhaps has more to do with the nature of teacher education in Ghana. 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.

There was also no significant difference in the PCK for teaching genetics between high school biology teachers based on gender. This is by all means not saying there is no disparity in the ratio of male to female teachers. But it does at least say that the nature of genetics PCK of teachers is the same for male and female teachers.

There was also no significant difference between senior high school biology teachers' PCK for teaching genetics based on the years of teaching experience. This is consistent with past research which suggests that teaching experience, makes little difference in the lesson plans of biology teachers (Friedrichsen et al., 2008) nor in the PCK of teachers (Patra & Guha, 2017). One reason for this is, if PCK can be thought of as the amalgamation of pedagogical knowledge and content knowledge, perhaps the successful integration of this is a skill that has to be specifically taught.

With regards to school type, it is apparent that the Ministry of Education in Ghana is rather unbiased in posting biology teachers, regardless of their genetics PCK. Since data is not collected, either in the form of standardized exams or some sort other form of data collection, on the PCK demographics of all teachers in Ghana, postings of teachers cannot possibly take into account their PCK. This was true for both the categories of schools and whether the school was single-sex or mixed.

The overall picture painted of the genetics PCK of Ghanaian SHS teachers is that it is generally teacher centred in its teaching orientations and therefore does not fully take into consideration connections between instruction, assessment and difficulties in student understanding. The implications of this nature of genetics PCK are many. With regards to students' inability to understand genetics concepts such as the monohybrid test cross, transcription of DNA into mRNA (WAEC, 2014), terms like co-dominance, sex-linked characters, genetic engineering (WAEC, 2012) and translation (WAEC, 2011), this research suggests that the teaching orientation of teachers, being teacher centred, is not able to address this student difficulty. Since orientations determine the type of instruction, teacher-centred orientations in this case are creating instructions and methods of assessment that are not well equipped to meet students at their level of understanding. Higher cognition tasks, like that which deal with understanding, applying and analysing genetics concepts, which teachers themselves identified as problem areas for students are not being catered for by the instruction methods and student understanding.

The implications of this nature of Ghanaian SHS teachers' genetics PCK are that unless an intervention is made, students may still struggle with genetics concepts under "biology of heredity". Even if students' performances improve without an amendment in the teaching approach of teachers, students will pass the WASSCE examinations but still demonstrate a lack of understanding of genetics concepts. In moving away from the traditional teacher-centred, lecture-driven classes to student-centred, activity-based learning environments that typically include multiple opportunities for collaboration among students, the genetics PCK of Ghanaian SHS teaching has a lot of ground to make up.

Recommendations

Recommendations for policy and practice

Based on the findings of this research the following recommendations have been made for educational policy and practice in the genetics PCK of teachers

1. It is recommended that professional training be organized for genetics teachers at the SHS level to help them see the importance of the individual components of PCK.
2. It is recommended that professional training be organized for genetics teachers to move them towards more student-centred methods of instruction and assessment.
3. It is recommended that professional training programs be given to genetics teachers at the SHS level with the goal of helping them successfully integrate the five types of knowledge under PCK.
4. It is recommended, since there is no difference in PCK of teachers based on teaching experience, professional training or gender, that any such professional training of teachers be targeted at all teachers that teach genetics at the SHS level.

Suggestions for Further Research

1. Further research needs to be conducted to view PCK component interaction in practice in order to identify examples of poor and good interaction of the components.
2. Also, further research should be conducted to link the PCK of teachers to the performance of their students in the classroom and in standardized examinations

3. Further research can also be conducted to understand the impact of teacher-centred and student-centred teaching orientations on student understanding in genetics.

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APPENDICES

APPENDIX A: In-Service Teachers' Instrument

Part I : Background Questionnaire

1. Gender
   - ☐ Male
   - ☐ Female
2. Which school type do you teach currently?
   - ☐ Single sex male
   - ☐ Single sex female
   - ☐ Co-educational
3. What is your highest professional qualification?
   - ☐ Diploma in Education
   - ☐ Postgraduate diploma/certificate in education
   - ☐ B.Ed
   - ☐ M.Ed
   - ☐ MPhil
   - ☐ PhD
   - ☐ Other (specify)____

4. What is your highest academic qualification?
   - ☐ Diploma in Education
   - ☐ BSc
   - ☐ B.Ed
   - ☐ MPhil
   - ☐ M.Ed
   - ☐ PhD
   - ☐ Other (specify)____
5. What is/was your major in college/university?
   - ☐ Natural Sciences (Biology, Agriculture, etc)
   - ☐ Physical Sciences
   - ☐ Other (specify) ____________________
6. If you have a master's degree, in what area was it?
   - ☐ MPhil/MSc Science
   - ☐ Science Education
   - ☐ Other (specify) _____________________
   - ☐ I do not have a master's degree
7. In your tertiary/post-secondary education, which of the following *types* of courses have you taken before?

   Check all that apply.

Biology Courses

- ☐ Animal Biology.
- ☐ Biochemistry,
- ☐ Molecular Biology
- ☐ Biophysics.
- ☐ Bioinformatics.
- ☐ Plant Biology
- ☐ Cellular Biology and Anatomy.
- ☐ Evolutionary Biology and Ecology.
- ☐ Genetic Sciences.
- ☐ Immunology
- ☐ Microbiological Sciences

Science Education Courses

- ☐ Psychological Basis of Teaching & Learning Science
- ☐ Methods of Teaching Biology
- ☐ Assessment in Science Education
- ☐ Development of Science Teaching Materials

8. Which of the following biology courses have you taught in the last five years? Check all that apply.
   - ☐ Biology in SSS 1
   - ☐ Biology in SSS 2
   - ☐ Biology in SSS 3
   - ☐ Other (please specify) ____________________
9. Which area are you currently teaching?
   - ☐ Urban area
   - ☐ Rural area
   - ☐ Other (please specify)
10. Which category of students do you teach?
    - ☐ Science
    - ☐ Agricultural Science
    - ☐ Home Economics
    - ☐ Other (please specify)
11. For how many years have you taught biology at the SHS level?
    - ☐ 0-1 year
    - ☐ 1-3 years
    - ☐ 4-6 years
    - ☐ 7-10 years
    - ☐ More than 10 years

Part II: Assessment Questions

Instructions

This instrument contains 43 multiple-choice questions about knowledge for teaching genetics.

In this booklet all the questions are ALL multiple choice questions. There are no right or wrong answers.

1. You are introducing SHS students to Mendel's law of segregation, and have two models of chromosomes available to you. How would you approach this lesson?

   A) I would explain the law and demonstrate the law by separating the chromosomes myself.
   B) I'd state and explain the law and students will pull apart the chromosomes to demonstrate it.
   C) I will ask students questions to guide them propose the law by pulling apart the chromosomes.
   D) Students will explore by playing with the chromosome models and discussing their findings amongst themselves.

2. Mr. Gyampo is beginning a unit on continuous and discontinuous variations. After giving examples, he asks students to classify orange colour. How would you appraise his lesson?

   A) He did well but I think he should've classified the orange colours himself so students can understand.
   B) This is a good lesson because he explains and has the students do an activity later.
   C) He should have had the students first sort the various variations themselves and followed with a lecture on the topic, correcting any mistakes.
   D) He should have allowed the students to explore freely with the variations and discussed amongst themselves.

3. In trying to get your students to be able to recognize and describe different types of dominance, for which you have examples, how would you approach the lesson?

   A) I'd teach the types of dominance and classify them using the examples.
   B) I'd teach the types and let the students have an activity to sort the examples into types.
   C) I'd guide the students to sort the examples into types.
   D) I would allow students explore by themselves and sort the examples into types.

4. In introducing your students to the test cross, how you would teach this lesson?

   A) Explain and perform the test cross.
   B) Explain the test cross and guide the students to perform the test cross.
   C) Have the students perform the cross themselves, whilst guiding them with questions.

D) Have the students perform the cross in groups after a guided reading assignment.

5. How would you introduce the dihybrid cross to your students to teach them about how two genes group independently of each other?

A) It would be a demonstration with me explicitly pointing out what students need to know
B) It would be a follow-up student activity after I explain what students need to know.
C) Students would attempt the test-cross first, followed by teacher-led discussion.
D) It would be a stand-alone activity for students to explore and discuss on their own how they think genes assort independently.

6. At the end of the unit, Biology of heredity, the best way to teach how genetics is applied in agriculture is to_______

A) Show examples of crops and livestock and how they were obtained through DNA modification.
B) Explain types of genetic modification and have the students examine examples agriculture.
C) Provide examples in agriculture and ask the students how genetics was specifically applied in each of those cases.
D) Organize group presentations where talk about the role of genetics in the agriculture.

7. How would you use a 5-minute narrated animation of replication, to teach your students?

A) Explain and list all of the major steps of replication followed by the animation.
B) Explain replication and play the animation followed by a pop quiz.
C) Play the animation but pause at each major step of replication for students to ask their own questions.
D) Play the entire animation and have the students explain to each other what they saw in the animation.

8. You are organizing a field trip to the school garden for students to learn about genetic variations. How would you go about it?

A) Explain the types of genetic variations as you point out examples in nature.
B) Explain the types of genetic variations and ask students to point out examples.

C) Have students point to features choice as you classify the type of variation they point to.

D) Have students point to features and compare to those observed by other students.

9. Teachers teaching complex topics like “mutations” should in your opinion.

A) Explain the process in detail with enough examples to their students

B) Explain the process in detail and assign the students the task of providing examples.

C) Assign groups of students to types of mutations to present to the class.

D) Assign groups of students to read on “mutations” and present to the class.

10. Whenever you introduce fresh SHS students to genetics, your main approach is to _____

A) Explain key foundational concepts and experiments to students with detailed examples

B) Explain key foundational concepts and experiments to students then ask students to provide examples

C) Assign specific reading assignments to students before the unit begins

D) Ask students to write down and present to the class what they know about genes.

For questions 11 to 19, identify/select common problems or difficulties students have in the scenarios provided.

11. With regards to Mendel’s laws of segregation and independent assortment, what do most students struggle to with?

A) Defining the laws of segregation and independent assortment

B) Differentiating between the laws of segregation and independent assortment

C) Identifying examples of independent assortment of genes and segregation of alleles in nature.

D) Inferring at what stage in cell division independent assortment and segregation happen

Use the following example to answer question 12

A student asks the question “If a couple has a “one-in-four” risk of having a child with sickle cell anaemia and their firstborn has the disease, will the next three children have a reduced risk”

12. In your opinion, which of the following is the understanding or ability that the student lacks in this case? (requirement +) (test cross, alleles, probability)

    A) The ability to listen to instruction
    B) The ability to define an allele
    C) The ability to interpret the results of a punnett square
    D) The ability to apply mathematical probability.

13. Which of the following, in your opinion do your most of students struggle with concerning the concept of a phenotype?

    A) Defining a phenotype
    B) Describing a phenotype in their own words
    C) Identifying examples of phenotypes in nature.
    D) Understand the relationship between a phenotype and a genotype

14. Which of the following statements do students mostly assume INCORRECTLY about genes? (ability -) (Genes and inheritance)

    A) A gene is a small piece of DNA
    B) All genes are transferred to our offspring.
    C) Genes can be used to predict how a child will look like
    D) Students assume genes are found only in the nucleus.

15. In teaching on Meiosis, which of the following do students mostly struggle to do?

    A) Define Meiosis
    B) Illustrate the steps of meiosis
    C) Apply the concept of meiosis to understanding "haploid" and "diploid" cells.
    D) Infer on the role of meiosis in sexual reproduction.

16. Which of the following implications of meiosis do students mostly find difficult to grasp?

    A) The end products of meiosis
    B) The difference between meiosis and mitosis.
    C) The benefits of meiosis
    D) The implications of meiosis in gamete formation, sexual reproduction and fertilization.

17. With regards to ABO blood typing, as it relates to recessive and dominant genes, most students after SHS 3 CANNOT demonstrate?

A) A proper definition of what a genotype is.
B) An ability to classify blood type alleles as dominant or recessive
C) The phenotypic implication of blood type genotypes.
D) Understand immune interactions between the different blood types.

18. In your experience, concerning dominant alleles, most students are NOT able to understand/explain…..

A) An allele
B) Dominant and recessive alleles
C) Complete dominance
D) Co-dominance

19. Genes that are carried by either sex chromosome are said to be sex linked. You overhear a student in a group discussion tell another student that height comes from mothers. Which of the following is the student FAILING to grasp?

A) That height cannot come from the mother
B) That fertilization involves 50% of genes from either parent.
C) That height is a continuous variation.
D) That height is a highly polygenic trait.

For questions 20 to 28 indicate how you would most likely approach teaching in the scenarios provided (choose one).

20. In introducing students to the concept of a gene,

A) I will use the example of the colours of maize to teach students about alleles.
B) I will use the example of the concept of legal inheritance from the social studies perspective.
C) I will use their JHS knowledge on biological heredity and provide examples of characters inherited from parents.
D) I will provide examples of applications of genetics knowledge.

21. When teaching students about the relationship between a gene and an allele,

A) I compare it to the relationship between chemical elements and their isotopes.
B) I will compare it to the relationship between the concept of country and the many different types countries that exist..
C) I will talk about biological characters inherited from parents and the different shapes and sizes of that character that exist.
D) I will give an example of a specific gene and a particular allele of that gene, for example, blood antigens.

22. When teaching students about ethical issues with genetics technology

A) I will use their knowledge of laboratory ethics in physics.
B) I will define what "ethics" mean from a social science perspective.
C) I organize a class discussion about ethics after we treat the applications of genetics technology
D) I will introduce students to the on-going debate about stem cell research

23. When correcting students' misconceptions and fears about DNA, GMOs and genetics

A) I will let them know that everything is a chemical, even water, and entreat them to not be afraid of "chemicals" like DNA.
B) will use religious anecdotes to encourage them to seek the right information.
C) I organize a class discussion about misconceptions after we treat the applications of genetics technology.
D) I point out examples in applied genetics that challenge student misconceptions.

24. When teaching students to make use of knowledge across different disciplines to understand genetics

A) I will highlight the types of chemical bonds in DNA
B) I will show students how genetics can provide solutions to some of society's sanitation problems
C) By encouraging students to use their basic understanding of probability to make sense of punnet squares.

D) By linking topics in genetics with future lessons to be tackled in chemistry and/or physics.

25. When building on students' knowledge to help them understand genetics…

A) I make use of their knowledge of science topics like chemical bonds, organic compounds, etc.
B) I make use of their knowledge of popular movies and literature
C) I make use of their knowledge of basic reproduction
D) I make use of their basic knowledge of some careers in genetics.

26. When teaching students about complex topics in genetics.

A) I link the complex topic to others in science that students are treating at that time.
B) I link the complex topic to other ideas from literature or popular culture
C) I link the topic to a simpler one that students have treated in the past
D) I rely on my in-depth knowledge advanced genetics.

27. When teaching students about recombinant DNA technology

A) I will talk about its application in treating diseases
B) I will talk about its application in solving environmental problems
C) I will build on earlier lessons in genetics.
D) I will present complex problems and ask students how recombinant DNA technology would be useful in those scenarios.

28. When trying to capture student interest in genetics

A) I build on their knowledge in other science disciplines like physics and chemistry.
B) I use fitting examples from literature and film
C) I mostly start by talking about reproduction
D) I talk to them about the many different exciting careers in genetics.

For each of the questions below, indicate what method of assessment (choose one) best fits what you would use to assess students.

29. Their ability to understand key experiments in genetics.
    A) Paper and pencil-based tests
    B) Written take-home assignments
    C) Presentations by students
    D) Observe student performance on simulations of lab procedure

30. Their ability to incorporate their understanding of genetics concepts into solving everyday problems
    A) Paper and pencil-based tests
    B) Written take-home assignments
    C) Presentations by students
    D) Observe student performance on simulations of lab procedure

31. Their ability to engage in meaningful dialogue about social and economic implications of genetics research
    A) Paper and pencil-based tests
    B) Written take-home assignments
    C) Presentations by students
    D) Observe student performance on simulations of lab procedure

32. Their ability to understand genetic processes.
    A) Paper and pencil-based tests
    B) Written take-home assignments
    C) Presentations by students
    D) Observe student performance on simulations of lab procedure

33. Their ability to recall terms and definition of key genetics concepts
    A) Paper and pencil-based tests
    B) Written take-home assignments
    C) Presentations by students
    D) Observe student performance on simulations of lab procedure

34. Their ability to apply their understanding themes that cut across multiple disciplines
    A) Paper and pencil-based tests
    B) Written take-home assignments
    C) Presentations by students
    D) Observe student performance on simulations of lab procedure

35. Their ability to solve WASSCE exams questions
A) Paper and pencil-based tests
B) Written take-home assignments
C) Presentations by students
D) Observe student performance on simulations of lab procedure

36. Their ability to explain genetics terms in their own language

A) Paper and pencil-based tests
B) Written take-home assignments
C) Presentations by students
D) Observe student performance on simulations of lab procedure

Please indicate which instructional method you most often use when teaching the following sections under "biology of heredity".

37. Heredity variation
A) A well-organized lecture
B) Class assignments
C) Classroom discussions amongst students
D) Lab experiment

38. Mendel's experiments
A) A well-organized lecture
B) Class assignments
C) Classroom discussions amongst students
D) Lab experiment

39. Mendel's laws and traits
A) A well-organized lecture
B) Class assignments
C) Classroom discussions amongst students
D) Lab experiment

40. Chromosomes: The basis of heredity
A) A well-organized lecture
B) Class assignments
C) Classroom discussions amongst students
D) Lab experiment

41. Process of transmission of hereditary characters from parents to offspring
A) A well-organized lecture
B) Class assignments
C) Classroom discussions amongst students
D) Lab experiment

42. Probability in genetics
   A) A well-organized lecture
   B) Class assignments
   C) Classroom discussions amongst students
   D) Lab experiment

43. Application of the principles of heredity medicine and agriculture
   A) A well-organized lecture
   B) Class assignments
   C) Classroom discussions amongst students
   D) Lab experiment

APPENDIX B: Introductory Letter to Senior High Schools

UNIVERSITY OF CAPE COAST
COLLEGE OF EDUCATION STUDIES
FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION
DEPARTMENT OF SCIENCE EDUCATION

Tel: 03320 96801/96951
Email: dse@ucc.edu.gh
Website: www.ucc.edu.gh

University Post Office
Cape Coast
Ghana

Your Ref:
Our Ref: DSE/S.3/V.1/015

30th October, 2018.

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

LETTER OF INTRODUCTION

We write on behalf of **Dennis Wilmot**, a Ph.D. (Science Education) student with registration number **ED/SED/16/0001** who has been assigned to collect some data at your School.

Mr. Wilmot is conducting a research on the topic: **"ASSESSING BIOLOGY TEACHERS' PCK FOR TEACHING GENETICS AT THE SENIOR HIGH SCHOOL LEVEL ACROSS THREE SELECTED REGIONS IN GHANA".**

We therefore write to introduce and request that you grant him the needed assistance.

Counting on your usual cooperation.

Thank you.

Yours faithfully,

DEPARTMENT OF SCIENCE EDUCATION
FACULTY OF SCIENCE & TECHNOLOGY EDUCATION
UNIVERSITY OF CAPE COAST
CAPE COAST

Prof. Christian Anthony-Krueger
SUPERVISOR