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A framework for identifying performance indicators of effective science process skills teaching in Botswana senior secondary physics

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ABSTRACT: This study sought to construct a framework that can be used to identify specific pedagogical descriptors for facilitating science process skills development in the teaching of Botswana senior secondary physics. A framework comprising six categories of pedagogical features derived from the literature was advanced and this framework was used to identify an initial set of statements addressing the development of the various science process skills. These statements were compiled into a questionnaire with Likert sub-scales, one measuring the perceptions of physics teachers about the extent to which the statements are essential (*essential sub-scale*), and the other measuring the perceptions of physics teachers about the extent to which the statements are practical (*practicality sub-scale*) on a scale ranging from *strongly agree* (scored 5) to *strongly disagree* (scored 1). A preliminary study in this regard was conducted with 17 physics teachers from four senior secondary schools in Botswana. The most important finding was that the participant physics teachers agreed that the theoretically-derived statements in the questionnaire are essential for science process skills development in senior secondary school physics in Botswana.

INTRODUCTION

The increased emphasis on science process skills development in Botswana senior secondary science curricula poses a challenge for science teachers. In addition to teaching science content, teachers are expected to help learners acquire an understanding of the processes of science and develop the necessary skills for doing science. Curriculum statements recommend that teachers should adopt instructional strategies that would facilitate the meaningful learning of science by engaging learners in authentic activities that reflect how scientific knowledge is developed [1]. To this end, learner-centred approaches to teaching are encouraged (eg inquiry, practical work, project work, etc) that involve *laying emphasis on science process skills, problem-solving skills, and the acquisition of hands-on experience which should increase the participation and performance of all groups* [1].

Teachers' knowledge with regard to implementing these demanding reforms is thus crucial. Teachers require an in-depth understanding of both the substantive and syntactic aspects of science and how best to represent it to their students. In other words, science teachers should have a rich knowledge base of teaching science – including knowledge and beliefs about subject matter, pedagogy and learners [2]. Such a knowledge base is essential for enhancing teachers' beliefs about their abilities to represent science to their learners in a manner that is prescribed by curriculum statements and advocated by current science education research. These beliefs – often called capability or self-efficacy beliefs – are believed to have a significant influence on teachers' subsequent behaviour in the classroom.

However, a number of studies in Botswana have reported that science teaching in Botswana has traditionally been dominated by transmission-type teaching approaches with very little emphasis on facilitating learners' acquisition of the inquiry skills necessary for generating scientific knowledge. Inadequate knowledge on the teachers' part is arguably one of the factors that hinder the implementation of the inquiry-oriented reforms recommended for the senior secondary science curriculum in Botswana. This is especially the case because the teachers themselves may have never experienced learning science through approaches that emphasise the processes of science. In this article, an attempt is made to make a contribution towards enhancing physics teachers' knowledge of facilitating process skills development in senior secondary physics.

BACKGROUND AND RATIONALE

This article is part of a study that is contextualised in the teaching of physics in senior secondary physics in Botswana. The education system in Botswana is currently driven by the recommendations of the Report of the National Commission on Education (RNCE) of 1993 and its associated Government White Paper, the Revised National Policy on Education (RNPE) of 1994. One of the recommendations adopted in the RNPE was the *localisation* of the senior secondary school curriculum, which, until then, was following the Cambridge O Level School Certificate (COSC) curriculum [2]. This resulted in the inception of the Botswana General Certificate of Education (BGCSE) – adapted from the International General Certificate of Education (IGCSE). Among the first BGCSE curriculum subjects to be implemented in 1998 was the physics syllabus (together with chemistry and biology). The new physics syllabus, as with the other science syllabi, strongly emphasised *learner-centredness*, in line with the recommendations of the RNCE of 1993.

The RNCE also recommended the recognition of *school-based continuous assessment* in the final certification of the learners at the senior secondary level. For the science component of the BGCSE curriculum, the Examination Research and Testing

Division (ERTD) of the Ministry of Education (MoE) responded by proposing the adaptation of an IGCSE model of *coursework assessment* to replace timed practical examinations that were used in the COSC curriculum. Coursework assessment is based on the assessment of science processes and skills. The BGCSE coursework scheme of assessment in the sciences is categorised into four skill areas as follows:

- *Skill C1*: Using and organising techniques, apparatus and materials;
- *Skill C2*: Observing, measuring and recording;
- *Skill C3*: Interpreting and evaluating experimental observations and data;
- *Skill C4*: Planning, carrying out and evaluating investigations.

The four skill areas comprise both cognitive and manipulative skills and abilities in which learners are expected to show competence (eg observing, classifying, hypothesising, controlling variables, interpreting, inferring, experimenting, etc) and it is the responsibility of the science teachers to facilitate the learners' acquisition of these skills and abilities. Thus the introduction of coursework assessment is expected to increase the emphasis of teaching science processes and skills in the BGCSE science curriculum in addition to content coverage. This emphasis is further articulated in the rationale of the BGCSE science curriculum, which maintains that:

> *Science is an experimental discipline and its method of inquiry allows learners to appreciate the practical impact of science on their lives and society as a whole. The Science programme will equip learners with skills that will be of long term value and encourage them to participate in lifelong learning. In the process the learners will exercise their creativity and develop skills such as critical thinking, innovativeness, communication, analysis, observation, recording, drawing conclusions, making judgements, etc.* [1].

The challenge for science teachers is to plan for learning environments that would give learners opportunities to learn physics content through such methods as *inquiry, demonstration, practical work, project work, case study, field trips, discussions, computer guided learning, etc* [1]. However, curriculum documents do not provide comprehensive descriptors that would guide teachers in their efforts to implement these proposed teaching approaches. Furthermore, very little research has been undertaken to establish the capacity of science teachers in Botswana – including physics teachers – with respect to their knowledge and skills of implementing the recommended reforms. Most studies focused on science teachers' general perceptions about the new science curriculum reforms. Instead, this study focuses specifically on process skills development, which seems to be one of the major goals of the BGCSE science curriculum.

PURPOSE

The main purpose of this research was to construct a framework that would guide in identifying performance indicators of science process skills teaching in BGCSE physics. The purpose of these indicators was to provide specific descriptors that physics teachers can use as reference for facilitating science process skills development in their teaching. This study has the following objectives:

- To identify broad categories of pedagogical features that are essential for facilitating science process skills development in BGCSE physics;
- To identify specific pedagogical descriptors for facilitating science process skills development and performance under each of these categories.

SIGNIFICANCE

The significance of this study lies in its overall goal of assisting physics teachers in Botswana in facilitating science process skills development of their learners. The acquisition of science process skills by learners is important because, equipped with these skills, learners will be able to engage in scientific activities in a more authentic way and thus meaningful learning is more likely to be achieved. These skills are also especially important for those learners aspiring for science-based tertiary education and future careers like engineering where the skills are required for solving scientific and technical problems [3]. Therefore, it is fitting that attention is paid to teachers' competences in facilitating process skills with the aim of providing support to teachers.

THEORETICAL UNDERPINNINGS

A review of the literature reveals that science processes and skills can be developed by engaging learners in authentic learning activities [4]. These are activities that should provide learners with opportunities to formulate scientific problems and design investigations for solving these problems. This requires teachers to adopt inquiry-based approaches to science teaching and learning. Inquiry teaching and learning is well documented by the National Research Council (NRC) in the USA. For example, the NRC suggested five essential features of inquiry [5]. The learner:

- Engages in scientifically oriented questions;
- Gives priority to evidence in responding to questions;
- Formulates explanations from evidence;
- Connects explanations to scientific knowledge;
- Communicates and justifies explanations [5].

The NRC further elaborated on a typology of school laboratory experiences, which include the following:

- Posing a research question;
- Using laboratory tools and procedures – handling materials safely and making measurements;
- Formulating hypotheses;
- Designing investigations;
- Making observations, gathering and analysing data;
- Building or revising models;
- Evaluating, testing or verifying explanatory models (including known scientific theories and models) [6].

It has been observed that *these essential features introduce important aspects of science to students while simultaneously assisting them in developing knowledge in regard to specific science concepts* [7]. Thus, science teachers should have the necessary knowledge and skills for planning and executing learning experiences that will expose learners to inquiry experiences, thereby allowing them to apply both cognitive and manipulative processes in solving scientific problems. Contemporary research suggests that teachers derive their knowledge for teaching from a set of knowledge bases such as subject-matter knowledge, pedagogical knowledge, context knowledge, knowledge of learners, etc. These combine to form what is known as Pedagogical Content Knowledge (PCK), which has been widely acknowledged as the essential component of teacher knowledge that influence teachers' actions in the classroom [8]. Shulman defined PCK as:

> *… that special amalgam of content and pedagogy that is uniquely the providence of teachers … It represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction* [9].

Van Driel, Verloop and de Vos observed that

> *… the key elements of Shulman's conception of PCK are knowledge of representations of subject matter on the one hand and understanding of specific learning difficulties and student conceptions on the other* [8].

This implies that teachers should have an understanding of how to represent subject matter in a manner appropriate for the nature of the subject they are teaching and take into consideration the cognitive levels and abilities of their learners.

As discussed earlier, in the case of teaching science process skills, science teachers should have the necessary knowledge for inquiry-based teaching and learning, and how to represent inquiry activities to their learners. Keys and Bryan argued that:

> *… it seems intuitive that teachers who use an inquiry approach must have rich and deeply developed understandings of science content, student learning, the nature of science, and ways to engage students in investigative practices* [4].

To this end, researchers have sought to assist teachers in their efforts to implement inquiry approaches. One comprehensive framework for inquiry teaching was advanced by Davis and Krajcik, who developed nine design heuristics for *educative curriculum materials* [10]. While these design heuristics were developed for guiding the design of *curriculum materials that are intended to promote teacher learning in addition to student learning*, they were adapted in this study to guide in identifying pedagogical descriptors of teaching science process skills in Botswana senior secondary physics.

Table 1 gives a brief summary of these design heuristics. However, only the heuristics that are relevant to this study were used, particularly those under the category of *design heuristics for PCK for scientific inquiry* because they address issues that are related to science process skills development.

Based on the theoretical background discussed above, a framework for identifying indicators of science process skills teaching was developed as shown in Table 2. The pedagogical features were derived from a synthesis of literature on inquiry-based teaching with a specific focus on process skills development. The inclusion of the *knowledge bases* column indicates that teachers will require a set of knowledge bases for teaching in the process of facilitating process skills development, while *fundamental influences* reflects the influence of contextual factors that may impede (or support) teachers' performance in this regard.

Table 1: Design heuristics for educative curriculum materials (after [10]).

I. Design Heuristics for PCK for Science Topics
Design Heuristic 1: Supporting teachers in engaging students with topic-specific phenomena
Design Heuristic 2: Supporting teachers in using scientific instructional representations
Design Heuristic 3: Supporting teachers in anticipating, understanding and dealing with students' ideas about science
II. Design Heuristics for PCK for Scientific Inquiry
Design Heuristic 4: Supporting teachers with engaging students in questions
Design Heuristic 5: Supporting teachers in engaging students with collecting and analysing data
Design Heuristic 6: Supporting teachers in engaging students in designing investigations
Design Heuristic 7: Supporting teachers in engaging students in making explanations based on evidence
Design Heuristic 8: Supporting teachers in promoting scientific communication
III. Design Heuristic for Subject Matter Knowledge
Design Heuristic 9: Supporting teachers in the development of subject matter knowledge

Table 2: Categories of pedagogical features of facilitating science process skills development (adapted from [11]).

Knowledge Bases	Pedagogical Features	Fundamental Influences
Subject matter knowledge Curriculum knowledge General pedagogical knowledge Knowledge of learners Context knowledge	Communicating the rationale for science process skills Creating effective learning environments Fostering scientific attitudes Facilitating investigative/inquiry activities Promoting techniques for handling scientific data and phenomena Diagnosing and evaluating learning	Context: • Specific class-room context • Policy demands • Constraints Teacher beliefs: • Views of the nature of science • Views on the teaching and learning of science • Self-efficacy beliefs

The framework was then used to compile a preliminary set of descriptive statements under each of the six categories of pedagogical features. In total, 34 statements were generated and these statements were also derived with reference to literature on inquiry-based science teaching and learning, and are available on request.

PRELIMINARY STUDY

A pilot study was conducted with 17 physics teachers from four senior secondary schools in Botswana and the purpose was to solicit the teachers' judgements with regard to the extent to which they considered the statements to be essential and practical in the context of science process skills development in Botswana senior secondary physics. The statements were compiled into a questionnaire with two Likert sub-scales; one measuring the perceptions of physics teachers about the extent to which the statements are essential (*essential sub-scale*), and the other measuring the perceptions of physics teachers about the extent to which the statements are practical (*practicality sub-scale*) on a scale ranging from *strongly agree* (scored 5) to *strongly disagree* (scored 1).

For the 13 valid responses obtained from the physics teachers on the 34 questionnaire items, some of the main findings of the preliminary study were as follows:

- The average mean score for the *essential sub-scale* (4.19 out of 5) was relatively higher than the average mean of the *practicality scale* (3.64 out of 5);
- Of the six categories of pedagogical features, *Fostering scientific attitudes* received the highest average mean score for both the *essential sub-scale* (4.58 out of 5) and the *practicality sub-scale* (4.19 out of 5). Of the three statements under this category, one item received the highest mean score for both the *essential subscale* (4.75 out of 5) and the *practicality sub-scale* (4.67 out of 5), ie *Encouraging learners to observe safety precautions at all times when conducting scientific investigations*;
- Of the six categories of pedagogical features, the category receiving the lowest average mean score for the *essential sub-scale* was *Assessing and evaluating learning* (3.87 out of 5), which comprised five statements;
- The category receiving the lowest average mean score for the *practicality sub-scale* was *Facilitating investigative/ inquiry activities* (3.87 out of 5). Of the eight statements under this category, the following statements received the lowest ratings (2.75 out of 5):

  - *Encouraging learners to design their own investigations and explore various methods of conducting a particular scientific investigation*;
  - *Engaging learners in investigative activities for which the outcome is not apparently obvious to the learners.*

To justify the low ratings for the category of *Facilitating investigative/inquiry activities*, one teacher commented that this category:

> *… dictates that a teacher works with smaller groups of students which in most schools will not work. Class sizes have been increased from 35 to 40 … This makes it … impracticable.*

CONCLUSION

The preliminary study has already provided some insights into the possible perceptions of physics teachers regarding the development of science process skills in Botswana senior secondary physics. While generally acknowledging that the pedagogical features in this study are essential for science process skills development, the responses of the pilot sample of physics teachers also indicated that there are difficulties in putting these pedagogical features into practice.

This study (currently under expansion) also provided some indications for future modifications. For example, some physics teachers commented in informal conversations that many of the statements do not give any indication to suggest that they are specific to physics teaching and, therefore, any science teacher (chemistry and biology included) could respond to the questionnaire. Thus, current developments of the statements for a further 160 physics teachers are taking this into account.

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