

Analysis of new Zambian High School Physics Syllabus and Practical Examinations for Levels of Inquiry and Inquiry Skills

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The purpose of this study was to analyze the new Zambian high school physics syllabus and practical examinations for levels of inquiry and inquiry skills. Several inquiry skills are explicitly emphasized in the introduction, aims, content objectives and assessment sections in the national high school physics syllabus. However, the syllabus is less explicit on levels of inquiry. The syllabus has no suggested inquiry activities and guidelines for inquiry-based teaching. As such, teachers are expected to create inquiry activities for their physics lessons to address the content and inquiry skills outlined in the syllabus. The experiments in the practical examinations were restricted to structured and confirmation/verification inquiry levels. The inquiry skills emphasized in the practical examinations were the same as those outlined in the physics syllabus. Implications for science teaching, learning, and curriculum design have been stated.

Keywords: High School, Inquiry, Physics, Practical Examinations, Syllabus

INTRODUCTION

On the advent of independence in the 1960s, many African nations revamped their school curricula with a view to satisfy the aspirations of their citizens. Zambia, like many African countries, made changes to its high school science curriculum that had been inherited from Britain. Recent changes to the national high school science curriculum were made in 1998 to align it with then current trends in science education. These changes gave birth to the new national high school physics syllabus which was implemented in schools in 2000

(Curriculum Development Center [CDC], 2000). One other major change in the high school physics curriculum was the introduction of practical examinations. The national physics practical examinations are taken by all high school students at the end of grade twelve as a requirement for their school certificate. The physics practical examinations are prepared using the national physics syllabus as a guide. The introduction of the physics practical examinations underscores the importance of developing and assessing scientific inquiry skills among Zambian high school students (Ministry of Education, 1996). To date, the new national physics syllabus and practical examinations have undergone seven cycles of implementation since their introduction in high schools. However, these new curriculum materials have not been evaluated for the four inquiry levels *Confirmation, Structured, Guided and Open* (Tafuya, Sunal & Knecht, 1980) and inquiry skills (Tamir & Luneta, 1981) that are emphasized in science education. This lack of evaluation of the new Zambian

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physics syllabus and practical examinations for inquiry levels and skills was the main justification for this study.

The analysis of the Zambian high school physics syllabus and practical examinations for inquiry levels and inquiry skills is desirable, not only to Zambian science educators but also to science educators elsewhere, who have, or plan to implement a similar physics syllabus and practical examinations at high school level. It was also assumed that the findings would provide important implications for teaching, learning and curriculum design. This study was guided by the following questions: (a) What levels of inquiry are emphasized in the new national high school physics syllabus and practical examinations? (b) What inquiry skills are emphasized in the new physics syllabus and practical examinations?

Definitions and previous research on inquiry

In science education, inquiry has two separate identifiable meanings which are *teaching and learning science by inquiry* (Tamir, 1985) and *science as inquiry* (Eltinge & Roberts, 1993). Teaching and learning science by inquiry involves the means by which students gain knowledge. It includes the development of inquiry skills, such as the abilities to: identify and define a problem, formulate a hypothesis, design an experiment, collect and analyze data, and interpret data and draw meaningful conclusions. On the other hand, science as inquiry extends the image of science beyond that of a collection of facts, to include viewing science as a method by which facts are obtained. Both of these types of inquiry approaches are important in science education. However, this study focused on teaching and learning science by inquiry, because the purpose of the study was to evaluate the high school physics syllabus and practical examinations for levels of inquiry and inquiry skills.

Science educators from around the world have examined science curriculum materials for inquiry levels and skills. For example, in Israel, Tamir and Luneta (1981) analyzed high school science textbooks and found that the activities in the textbooks lacked opportunities for students to investigate and inquire. In another study of curriculum materials used in Israel, Friedler and Tamir (1986) analyzed high school science laboratory manuals and classroom observations and found that most activities were at lower levels of inquiry. Friedler and Tamir further found that rarely were students required to: identify and formulate problems and hypotheses, design experiments, and work according to their own designs. In a Nigerian study, Okebukola (1988) reported that the activities in the revised pupils' textbooks and workbooks I and II of the Integrated Science Project were highly structured and deductive in approach with a high emphasis on low level inquiry skills. In the USA, Pizzini, Shepardson and Abell

(1991) analyzed activities in commercial junior high school science textbooks and their accompanying supplemental activity guides for inquiry. They found that most of the activities were at the confirmation and structured levels of inquiry. However, there was a statistically significant difference in the frequency of inquiry level of activities among the science textbooks, supplemental activity guides, and disciplines. In another study on curriculum materials used in the USA, Germann, Haskins and Auls (1996) found that high school laboratory manuals only rarely called upon students to use their knowledge and experience to ask questions, solve problems, investigate phenomena, construct answers or make generalizations. In Western

Australia, Staer, Goodrum and Hackling (1998) examined the laboratory activities undertaken by lower secondary school science students in an attempt to determine the openness to inquiry of these activities. They found that most activities were at lower levels of inquiry, despite science teachers being aware of the benefits of using higher levels of inquiry. Many teachers cited time constraints, management problems, and equipment demands as reasons for not using open inquiry activities in their classrooms. In a Caribbean study, Soyibo (1998) analyzed the practical activities prescribed in eight process-oriented integrated science textbooks for pupils of grades 7-9 for the structure and skill level of the tasks. The results suggested that most of the tasks were structured and deductive in approach with an emphasis on low level inquiry skills. Soyibo observed that the continued use of the activities provided in the textbooks in Caribbean schools may not effectively facilitate the development of inquiry skills among students which they would need to carry out open-ended scientific investigations in the future.

This review of previous studies from around the world indicates that many science curricula offered few opportunities for open investigation work and development of high-order scientific inquiry skills that are emphasized in science education reforms (American Association for the Advancement of Science [AAAS], 1993; Ministry of Education, 1996; National Research Council [NRC], 1996). It is also evident from literature that science educators have mainly examined textbooks and laboratory manuals for inquiry levels and inquiry skills. Science syllabi and practical examinations have not been examined for inquiry levels and skills. Yet, in many countries like Zambia, national science syllabuses and examinations are used by teachers as main guides for instruction in their classrooms. The practical examinations are also used as tools for assessing scientific inquiry skills among students. Therefore, this study went beyond previous research studies by examining the national physics syllabus and practical examination papers for inquiry levels and inquiry skills.

Overview of Zambian high school physics education

Zambia has a centralized education system and all high schools follow one national curriculum. High school education starts in grade ten and ends in grade twelve. Students' admissions to high school are based on their performance in the national junior high school examinations, which they take at the end of grade nine. Physics is a compulsory subject and all students are required to take it for three years in high school. The national physics syllabus serves as one of the main resources for physics teaching and learning in high schools. Each physics teacher is given a copy of the national physics syllabus as a guide for the scope and depth of the content to be taught. There are five periods of physics instruction in a week per class and each period is forty-five minutes long. There are three school terms in a year: January to April, May to August, and September to December, and each term is thirteen weeks long. At the end of twelfth grade, students take national examinations which are equivalent to the Ordinary-Level standard in the British education system for certification, admission to post-secondary school education, training, and employment. In physics course, students take three examination papers namely: Paper 1 (40 multiple-choice questions), Paper 2 (8 structured and essay questions) and Paper 3 (4 laboratory-based experiments). This study is focused on the physics syllabus and Paper 3 which is the physics practical examination. The national physics examinations are prepared by experienced high school physics teachers and physics lecturers from a local national university in conjunction with the Examination Council of Zambia. The examiners use the national physics syllabus as the guide for preparing these examinations.

METHODOLOGY

Sample

Data sources were the new national high school physics syllabus and six physics practical examination papers that were written by high school students between 2000 and 2005. The physics syllabus is fifty pages long and has five main sections: introduction, general aims, topics, content, and assessment objectives. There are twelve main topics namely: Measurements, Mechanics, Thermal physics, Light, Sound, Wave motion theory, Magnetism, Static electricity, Current electricity, Electromagnetic induction, Basic electronics, and Atomic physics. Under each topic, there are content objective statements. The numbers of content objective statements vary from topic to topic, and part of the reason for such variation could be due to the amount of

content to be covered. The national high school physics practical examination is a two-hour laboratory-based examination, printed on seven pages. Each physics practical examination paper has four main experiments (questions) on different topics, and has two sections, A and B. Section A has three experiments while section B has one. Therefore, a total of twenty-four experiments in the six practical examinations papers written by students between 2000 and 2005 were examined for levels of inquiry and inquiry skills.

Analysis frameworks

Levels of inquiry in the new national physics syllabus and practical examinations were determined by using the analysis framework and procedure that was developed by Tafoya, Sunal and Knecht (1980). Pizzini, Shepardson and Abell (1991) also used this framework to examine junior high school science textbooks for inquiry levels. The framework classifies the inquiry level of activities as Confirmation/verification, Structured, Guided, and Open. Confirmation/verification-inquiry level activities require students to verify concepts through a known answer and given procedure that the students follow. Structured-inquiry level activities present students with a problem in which they do not know the results, but they are given a procedure to follow in order to complete the activity. Guided-inquiry level activities provide the student only with a problem to investigate. Students are given a chance to determine the procedure to use and the data to collect. Open-inquiry level activities allow students to formulate hypotheses or problems and the procedure for collecting data for interpretation and drawing conclusions.

The physics syllabus and practical examination papers were further analyzed for inquiry skills using a modified Laboratory Structure and Task Inventory (Tamir & Luneta, 1981). The original Laboratory Structure and Task Inventory have two main sections: (a) Laboratory organization with 14 categories in four sub-sections and (b) Laboratory tasks with 24 inquiry skills statements in four inquiry task sections. This is a valid and reliable framework and several science educators have used it to analyze science textbooks for structure and levels of inquiry (Okebukola, 1988; Soyibo, 1998). We only adopted the second section and modified it by decreasing inquiry tasks statements to 20 in order to meet the needs of this study (See Table 3). The four Inquiry task sections in the framework are: Planning and design [Inquiry task section 1], Performance [Inquiry task section 2], Analysis and interpretations [Inquiry task section 3] and Application [Inquiry task section 4]. Each Inquiry task section has inquiry skills outlined.

Analysis procedures

Since a variable in determining the inquiry levels and inquiry skills is the content of the textual information presented, the sections analyzed in the physics syllabus were introduction, general aims, notes to teachers, and content and assessment objectives. These sections were read and matched with inquiry levels and inquiry skills outlined in the two analysis frameworks. Similarly, the physics practical examination papers were analyzed for levels of inquiry by coding textual information on each experiment such as background information, aims, list of materials, instructions and procedures. Then the codes from each experiment were matched with the characteristics of the four levels of inquiry stated above. A total score was obtained for each level of inquiry and percentages for each year were calculated. The procedure for analyzing inquiry skills emphasized in physics practical examinations involved analyzing the experiments. All parts of the experiments including instructions, aims, questions, procedures, diagrams, figures and tables in the examination papers were coded by placing a check in the appropriate inquiry skill statement in the modified framework. If a statement in the experiment called for more than one inquiry skill, more than one check was made. For each inquiry skill statement the checks were tallied. Then this number was divided by the total number of inquiry skills identified in each paper and expressed as a percentage for each year.

Two physics educators independently coded the physics syllabus and practical examination papers for levels of inquiry and inquiry skills using the procedures described above. An intercoder agreement coefficient was calculated using Cohen's Kappa (Cohen, 1960). This coefficient factors in chance agreement and represents a measure of reliability.

RESULTS

Intercoder agreement

As shown in Table 1 below, the percentage agreement between the two raters for the physics

Table 1. Intercoder agreement coefficients for physics syllabus and examination papers.

<i>Course Material</i>	<i>Percent Agreement</i>	<i>Kappa</i>
Physics Syllabus	89	0.88
2000 (N= 208)	93	0.92
2001 (N= 200)	89	0.88
2002 (N= 123)	88	0.86
2003 (N= 190)	91	0.90
2004 (N= 173)	89	0.88
2005 (N= 184)	85	0.82

Note: This data is from two raters who conducted the coding.
N= Number of codes in each year.

syllabus and practical examination papers analyses ranged from 85% to 93% with a corresponding range of kappa values from 0.82 to 0.92. These statistics suggest a high degree of agreement between the two raters in categorizing the levels of inquiry and inquiry skills in the physics syllabus and practical examination papers. The values above 75% indicate excellent interrater agreement while kappa values below 0.4 indicate a poor coefficient (Chiappetta, Sethna & Fillman, 1991).

Inquiry levels and inquiry skills in the physics syllabus

Inquiry is explicitly emphasized in the introduction and aims sections in the high school physics syllabus as shown below:

This syllabus aims at stimulating pupils' curiosity and sense of enquiry which will in turn not only provide suitable basis for further study of the subject but also provide pupils with sufficient knowledge and understanding to make them become useful and confident citizens. The essence of such an enquiry is related to problem solving and reflecting on scientific enterprise. During this course pupils should acquire practical abilities associated with investigation of certain phenomena and principles in physics. Pupils should develop scientific attitudes such as open mindedness and willingness to recognize alternative points of view (CDC, 2000. p. vii).

Several inquiry skills and some inquiry levels are outlined in the introduction, aims, notes to teachers and content objectives sections in the high school physics syllabus as shown below:

During the course students should know how to: follow instructions [Structured & confirmation Inquiry levels & Inquiry task section 2]; use techniques, apparatus and materials; observe, measure and record [Inquiry task section 2- Performance]; plan investigations [Inquiry task section 1- Planning and Design; Open Inquiry]; interpret and evaluate observations and results [Inquiry task section 3- Analysis and Interpretation]; evaluate methods and suggest possible improvements [Inquiry task section 4- Application; Guided Inquiry] (CDC, 2000. p. xii).

The assessment section also states that the physics practical examinations will focus on assessing students' knowledge, understanding and application of:

...scientific apparatus and instruments and their safe operation [Inquiry task section 2- Performance]; translating information from one form to another manipulate numerical data, plotting results graphically, identify patterns and

draw inferences from information' give reasonable explanations for patterns and relationships, [Inquiry task section 3- Analysis & Interpretation], make predictions and hypotheses, and experimental methods evaluation and possible improvements [Inquiry task sections 1 & 4, Guided Inquiry] (CDC, 2000. p. viii & xi).

Although the physics syllabus outlines several inquiry skills and some levels of inquiry, it has no suggested inquiry activities and guidelines for implementing inquiry-based science teaching. As such, teachers are expected to create inquiry activities for their physics lessons to address the content and inquiry skills outlined in the syllabus.

Inquiry Levels in the physics practical examinations

The analysis revealed that across the six year period the experiments in the practical examinations were at structured inquiry level (50% to 100%) and confirmation/verification inquiry level (0.0% to 51%). One example of a structured inquiry activity was question 1 in the 2002 examination paper in which students were asked to determine the density of a piece of rock. The procedure provided involved Archimedes' principle and moments of force. Students measured distances of a standard mass and rock away from the pivot after the beam balanced (Y_1) and after (Y_2) submerging a rock in water. Then, students calculated the density of a rock using a given formula $(1-Y_1/Y_2)^{-1}$. An example of a confirmation activity was question 2 in the 2004 examination paper in which students were asked to verify that the distance of an object in front of a mirror is equal to a distance of its image behind the mirror. Table 2 also shows that in 2001 and 2002 all the experiments in the practical examinations were at structured inquiry level. In 2003 and 2005 structured and confirmation inquiry levels had equal representation (50%).

Only two (0.08%) experiments in the physics examination papers analyzed had two levels of inquiry though the levels were not equally represented in each

experiment. For example, in the year 2004 question 4 had structured inquiry and confirmation/verification inquiry levels. The aim of the investigation was to study the relationship between the length and period of pendulum and determine the value of gravitational acceleration, g . The second part of this statement was a confirmation/verification activity because most students already knew, from their previous work in the course, that g on earth is 9.8 m/s^2 .

Inquiry skills emphasized in the examinations

Each experiment started with the aim, instructions and list of materials. Some questions also had diagrams showing how the apparatus should be assembled or used. Safety precautions were also stated for experiments on heat and electricity. In most cases, standard data and formulae were provided by the examiners. Students were further instructed that an account of the method of carrying out the experiments was not required; instead, they were asked to perform all four experiments in the examination papers following the procedure provided and write a report for each investigation. For each three experiment in section A, students were only allowed to work with the apparatus for a maximum of twenty minutes.

For the question in section B, students were allowed to work with the apparatus for a maximum of one hour. Additional materials such as graph papers, electronic calculators, scrap papers, and answer booklets were provided. Table 3 below shows the percentage of inquiry skills distribution in the physics practical examinations.

Table 3 shows some consistency across the six years on inquiry tasks students were asked to perform in the practical examinations. The most emphasized were Performance (Inquiry task section 2) and Analysis and Interpretation (Inquiry task section 3). In Inquiry task section 2 (82.1% to 93.2%) students were mostly asked to, in decreasing order, take measurements or make observations, manipulate apparatus, record results, and draw and label diagrams following the instructions provided. The inquiry skills emphasized in Analysis and

Table 2. Percentage of inquiry levels in physics practical examinations.

Year	Inquiry levels			
	Confirmation/ verification	Structured Inquiry	Guided Inquiry	Open Inquiry
2000	28.8	71.3	0.0	0.0
2001	0.0	100	0.0	0.0
2002	0.0	100	0.0	0.0
2003	50.0	50.0	0.0	0.0
2004	31.3	68.8	0.0	0.0
2005	50.0	50.0	0.0	0.0

Interpretation (6.2% to 14.0%) were, in decreasing order, performing calculations and determining quantitative relationships, stating conclusions, stating precautions, transforming data and graphing data. In Inquiry task section 4 (Application) (0.0% to 1.1%), students were mainly asked to use their graphs to make predictions using given data. Students were neither asked to apply the experimental techniques they learned to a new problem nor to determine the accuracy of their experimental data. However, in some experiments students were asked to state and describe underlying assumptions, precautions or limitations of the experiments. In Inquiry task section 1 (Planning and design) (0.5% to 4.3%) the only task students were asked to perform, in some investigations, was to design tables in which to record their observations and measurements.

CONCLUSIONS AND DISCUSSION

The results show that the new national high school physics syllabus is more explicit on inquiry skills than on levels of inquiry. The physics syllabus also has no suggested inquiry activities and detailed guidelines on how to implement inquiry-based science teaching. Although this arrangement give teachers opportunities to create their own inquiry lessons, it may not be helpful to those who have limited training in inquiry-based science teaching.

The findings also show unbalanced coverage of inquiry levels and inquiry skills in the national physics practical examinations. The inquiry levels in the physics practical examinations were restricted to structured and confirmation inquiry levels, with the former dominating. To a large extent the findings in this study are similar to

Table 3. Percentage distribution of inquiry tasks and skills in physics practical examination papers.

Inquiry task & skills	Year					
	2000 N=208	2001 N=200	2002 N=123	2003 N=190	2004 N=173	2005 N=184
1.0 PLANNING & DESIGN						
1.1 Formulates a question, defines a problem	0.0	0.0	0.0	0.0	0.0	0.0
1.2 Predicts experimental results	0.0	0.0	0.0	0.0	0.0	0.0
1.3 Formulates hypothesis to be tested	0.0	0.0	0.0	0.0	0.0	0.0
1.4 Designs observations/measurements protocols (Tables)	2.8	3.5	1.6	0.5	3.5	4.3
1.5 Designs experiment	0.0	0.0	0.0	0.0	0.0	0.0
<i>Subtotal</i>	2.8	3.5	1.6	0.5	3.5	4.3
2.0 PERFORMANCE						
2.1 Manipulates apparatus	28.9	27.0	25.2	21.6	21.4	23.4
2.2 Measures/observes	33.2	35.5	35.0	55.3	31.8	35.3
2.3 Draws/labels diagrams	13.5	1.5	3.3	0.5	5.8	7.1
2.4 Records results	11.1	23.5	21.1	15.8	23.1	17.4
<i>Subtotal</i>	86.7	87.5	84.6	93.2	82.1	83.2
3.0 ANALYSIS & INTERPRETATION						
3.1(a) Transform results into standard form	1.0	0.5	0.8	0.0	0.6	1.1
3.1(b) Graphs data	0.5	0.5	0.8	0.5	0.0	0.5
3.2(a) Determines qualitative relationship	0.5	0.5	0.8	0.0	0.0	0.5
3.2(b) Calculates/determines quantitative relationship	3.9	5.5	7.3	4.7	11.6	7.1
3.3 Determines accuracy of experimental data	0.0	0	0.0	0.0	0.0	0.0
3.4 States limitations/assumptions/precautions	0.5	0.5	1.6	0.5	0.6	1.1
3.5 States conclusion/proposes a generalization	2.4	1.0	0.8	0.5	1.2	0.5
3.6 Explains relationships	1.0	0.0	0.8	0.0	0.0	0.5
<i>Subtotal</i>	9.8	8.5	12.9	6.2	14.0	11.3
4.0 APPLICATION						
4.1 Predicts on basis of obtained results	0.5	0.0	0.0	0.0	0.6	0.0
4.2 Predicts beyond the data/uses given data	0.5	0.5	0.8	0.0	0.0	1.1
4.3 Applies technique to new problem	0.0	0.0	0.0	0.0	0.0	0.0
<i>Subtotal</i>	1.0	0.5	0.8	0.0	0.0	1.1

N= Number of codes identified in each examination paper for each year.

those reported in previous studies that examined science textbooks and laboratory manuals (Tamir & Luneta, 1981; Staver & Bay, 1987; Pizzin, Shepardson, & Abell, 1991) and laboratory manuals (Friedler & Tamir, 1986; Germann, Haskins & Auls, 1996; Staer, Goodrum & Hackling, 1998). However, there is some consistency in the coverage of inquiry skills in the syllabus and practical examinations. Both documents mostly emphasize lower inquiry levels and skills. A desirable situation would be where all the four levels of inquiry are covered in the practical examinations for students to demonstrate a wide range of investigative skills. However, some advantages of using activities at confirmation and structured inquiry levels are: students who have just started “doing science” gain procedural knowledge and manipulative skills (Woolnough & Allsop, 1985) which they can later apply in guided and open-ended activities; students can complete the investigations within the allowed time for the examination; it is much easier for the examiners to score students’ reports, especially that standard marking keys (rubrics) are used. However, confirmation and structured inquiry levels mainly stimulate students’ thinking about the procedure and results of the experiments. The analyses of the inquiry skills in the examinations provided further evidence that students were mainly asked to manipulate apparatus, carry out observations and measurements, record results, interpret results and draw conclusions. This finding implies that during the examinations students commonly worked as technicians following explicit instructions outlined in the examination papers. The lack of inquiry tasks on planning and designing in the practical examinations also suggests that students were not given many opportunities to identify or formulate problems or hypothesize and test them based upon their understanding of the concepts involved. Science instruction organized exclusively around confirmation and structured levels of inquiry emphasizes a teaching approach that portrays scientific knowledge as fact, which can only be found if one scientific method is followed (Eltinge & Roberts, 1993; Tamir, 1985). Such instructional approaches also portray an image of science as authoritarian, with correct answers coming only from an outside source (Staver & Bay, 1987).

These findings also show that the practical examinations were focused on the inquiry skills prescribed in the national physics syllabus, making it very easy for students and teachers to identify those that are frequently tested. As such, during the lessons some teachers are likely to restrict students to develop inquiry skills that are only tested in the practical examinations.

In order to provide opportunities to high school students to develop and demonstrate higher-order inquiry skills, the physics syllabus should be explicit on inquiry levels and the practical examinations should

cover all four levels of inquiry. While the extent to which open inquiry experiments should be used in physics practical examinations may be questioned considering the limited time for the examinations, it should be an integral component of instruction during the course. On the other hand, when the various demands of open inquiry tasks are taken into consideration, it seems unrealistic to expect students to perform many open-ended activities in two hours of the physics practical examination. However, the responsibility to include guided and open inquiry activities in physics practical examinations rests with the high school physics curriculum planners, examiners, and teachers. One other implication of this study is that the findings provide information about some strengths and weaknesses of the physics syllabus and practical examinations that Zambian science educators or other science educators elsewhere can use in planning for teaching to compensate for deficiencies in their curriculum.

It is recommended that future research should focus on analyzing other Zambian high school physics curriculum materials such as textbooks, teacher made tests and laboratory activities for inquiry levels and inquiry skills and the compare them to those identified in this study. Physics classroom instruction observations should also be undertaken to find out the extent to which the levels of inquiry and inquiry skills are addressed during the lessons.

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