



Pre- and in-service physics teachers' content and pedagogical content knowledge: Implications and Challenges

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Abstract: The principal aim of this study is to examine pre-service and in-service Mauritian physics teachers' competencies in solving a particular physics concept: 'Charge' – a concept taught to students (aged 17-18) at the Higher School Certificate level. The data from this study, subjected to Rasch analysis and non-parametric statistical tests, show that the sample teachers displayed difficulties in demonstrating both their content knowledge and pedagogical content knowledge. Further test provided little evidence that teaching experience can adequately differentiate the teachers. Implications for physics teacher education programmes demand that physics and physics methods courses be re-invigorated to address the problem.

Keywords: content knowledge, pedagogical content knowledge, teaching, Rasch analysis

I. Introduction

Physics has always been considered a tough discipline, being abstract and remote from everyday life experiences of learners. The mode of teaching has not changed and the teacher-centered approach is still prevailing in our Mauritian primary as well as secondary schools ([1], [2], & [3]). Learners are mostly memorising facts, principles, laws and even procedures, and are reproducing these in the examinations. Researchers are increasingly showing that quality teacher preparation is key to improvement in students' learning outcomes [4]. Teacher quality depends on a number of factors, two of which appear to be prominent, namely content knowledge (CK) and pedagogical content knowledge (PCK), and curricular knowledge [5]. The present study investigates physics teachers' (pre- and in-service) understanding and problem-solving skills about the concept of 'Charge' (Figure 1), which is taught at the Higher School Certificate level (A-level, students aged 17-18) of the Cambridge International Examinations (CIE). The research questions guiding this research are:

1. What difficulties do teachers have in solving the 'Charge' problem?
2. To what extent does the 'Charge' problem discriminate the problem solving ability of teachers with different years of teaching experience?

This study is significant as it serves to highlight what other studies ([6], [7]) have rung the alarm bell about, and helps bring to the forefront that teachers' misconceptions impact on their students' development of misconceptions of the same concepts. To bring meaning to an abstract physics concept, a teacher has to carefully reflect on his/her content knowledge and use the appropriate curricular and PCK to eventually contextualise the concept into a concrete, consistent and logical flow of ideas [8] for conceptual understanding by learners. However, understanding and the development of cognitive structures by learners will fail if any one of the three types of knowledge is considered in isolation. In Mauritius, a teacher acquires content knowledge at the university (local or abroad) and later acquires curricular and pedagogical content knowledge at the sole local Institute of Education. Learning concepts (content) in isolation from the context (curricular and PCK) could be argued to be the source of misconceptions among physics teachers [9].

II. Methodology

The 'Charge' problem (Figure 1) encapsulates a number of mathematics and physics concepts which demands that the participants display CK and PCK through reasoning, understanding of principles, concepts and laws, and their application in specific context. The teachers were required to solve the 'Charge' problem as a pedagogical problem [10] in a very systematic way, based on the problem solving approach, as illustrated in Table 1.

In a Millikan experiment, a positively charged oil-drop is observed to fall at a uniform speed of $4v$ when the electric field between the plates is zero. On applying an electric field X , the drop rises at a uniform speed of $2v$. On changing the electric field, the drop is observed to fall at a uniform speed of v . If the charge on the drop remains unaltered, what are the magnitude and direction of the final field? (Neglect upthrust from the air.) [CIE, N82/II/18]

Figure 1: 'Charge' problem

A. Problem solving approach

Our response to the ‘Charge’ task is summarized in Table 1 below. We adopted a scientific approach [11], organised into four categories, to the problem solving, as follows: (a) analyse the problem using diagrams, (b) plan and proceed with the problem with reference to the principles and laws, (c) plan and proceed with the problem with reference to conceptual physics, and (d) work out the problem using appropriate mathematical formulae. The teachers were required to solve the problem in a worksheet.

Items	Variable	Description	Category
Diagram	Dia1(i) Dia1(ii) Dia1(iii)	Identification of (i) f_a [1] (ii) $4v$ [1] (iii) mg [1]	Diagram
Newton’s Law	New1(i) New1(ii)	$f_{net} = ma$ [1] f_{net} Is a resultant force. [1]	Principles and laws
Conceptual Mathematics	CM1(i) CM1(ii)	v is constant $\Rightarrow \frac{dv}{dt} = 0$ [1] $a = 0$ [1]	Principles and laws
Newton’s Law	New2	$f_{net} = 0$ [1]	Principles and laws
Direction	Dir1	Choosing a particular direction of motion (taking downwards as positive) [1]	Conceptual physics
Newton’s Law	New3	$mg - f_a = 0$ [1]	Principles and laws
Conceptual Mathematics	CM2	$f_a \propto v$ [1] (at low speed)	Principles and laws
Drag Force	Drag1	$f_a = Kv$ [1]	Conceptual physics
Procedural Mathematics	PM1	$mg = 4kv$ [1]	Procedural math
Diagram	Dia2	Identification of f_E [1]	Diagram
Electric Field	EFie	Since oil drop rises, E acts upwards [1]	Conceptual physics
Direction	Dir2	f_a' acts downwards [1]	Conceptual physics
Newton’s law	New4	$f_{net} = 0$ [1]	Principles and laws
Drag force	Drag2	$f_a' = 2kv$ [1]	Conceptual physics
Electric force	EFor	$f_E = Eq = Xq$ [1]	Conceptual physics
Procedural Mathematics	PM2(i) PM2(ii)	(i) $2kv + 4kv - Xq = 0$ [1] (ii) $Xq = 6kv$ [1]	Procedural math
Direction	Dir3	Taking downwards direction +ve [1]	Conceptual physics
Procedural Mathematics	PM3(i) PM3(ii) PM3(iii)	(i) $3kv = Yq$ [1] (ii) $\frac{1}{2} = \frac{Y}{X}$ [1] (iii) $Y = \frac{X}{2}$ [1]	Procedural math

Table 1: Description of solution steps, scored earned (in []) and categories of the ‘Charge’ problem. The items and variables are used in Rasch Analysis.

B. Participants

A purposive sample of 31 secondary school physics trainee teachers enrolled in a Post Graduate Certificate of Education (PGCE) across three different cohorts participated in this study. The three cohorts enabled the grouping of the teachers as follows: (a) pre-service ($n = 7$), (b) in-service – novice ($n = 14$), and (c) in-service – with experience ($n = 10$). The seven pre-service teachers are full-time PGCE trainees and have no teaching experience. The twenty-four remaining are part-time PGCE trainees whereby fourteen are novice teachers having less than one year of teaching experience while, the remaining 10, have at least 3 years’ experience.

C. Analysis Procedure

Ministep 3.81.0 was used for Rasch Analysis and SPSS (Version 22) was used for statistical analysis. Rasch analysis was used to estimate measurements of the level of difficulty the teachers encountered in performing the problem-solving activities and addressed the following: (a) What difficulties do the teachers have in solving the ‘Charge’ problem? (b) To what extent does the ‘Charge’ problem discriminate the problem solving ability of teachers with different years of teaching experience? We examined the map of persons and items to compare the range and position of the item measure and the person measure distribution. The problem solving ability of each teacher in solving the task is referred to as the person measure and the problem solving skill required to perform each item (e.g., diagrammatic representation, application of Newton’s law, etc.) within the task is called the item measure. SPSS was used to perform Kruskal-Wallis tests and post hoc procedures to explore the effect of teaching experience on the problem-solving task.

III. Results

A. What difficulties do the teachers have in solving the ‘Charge’ problem?

Table 2 shows the number of participants (out of $N = 31$) who scored from 0 to 5 marks in the four categories of the problem solving approach to the task. For the category 'Diagram', the modal score is 1 and was obtained by 17 teachers out of 31. Similarly, the modal score for 'Conceptual physics' is 1 while the remaining two categories reported a mode of 0.

Score	Diagram	Principles and laws	Conceptual Physics	Procedural Mathematics
0	3	22	2	30
1	17	5	14	0
2	6	2	8	1
3	3	1	5	0
4	2	1	0	0
≥ 5	0	0	2	0

Table 2: Scores obtained by the participants in the four categorical task design.

It should be pointed out that 30 out of the 31 participants failed to proceed to the 'Procedural mathematics' level while 22 out of 31 failed to identify the principles and laws relevant to the task. Clearly, the items related to these two categories proved difficult for the participants. This is concurred by the strong item measure reliability

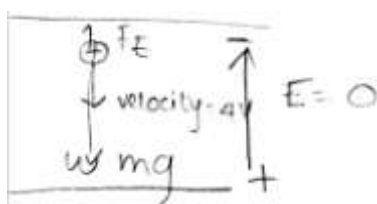


Figure 2a: Content Knowledge (faulty)

3) upthrust or drag force $\rightarrow$ opposes motion
($6 \sin \theta v$)

According to the question, the 3rd force i.e upthrust is neglected, which leaves us with only weight and electric force.

Figure 2b: PCK (faulty)

of 0.70 reported from the Rasch analysis.

Figures 2(a) and 2(b) illustrate the faulty content and pedagogical content knowledge displayed by two of the teachers. In Figure 2(a), though the electric field is zero, the diagram contains the electric force as well as the direction of the field from the positive to the negative signs. In Figure 2(b), in the explanation provided by the second teacher, upthrust is referred to as being a drag force, and in his/her thinking (PCK), drag force is also neglected and this assumption already hinders progress in further logical reasoning. This situation makes apparent the teacher's weak PCK in order to explain the subject matter to make the content accessible to students.

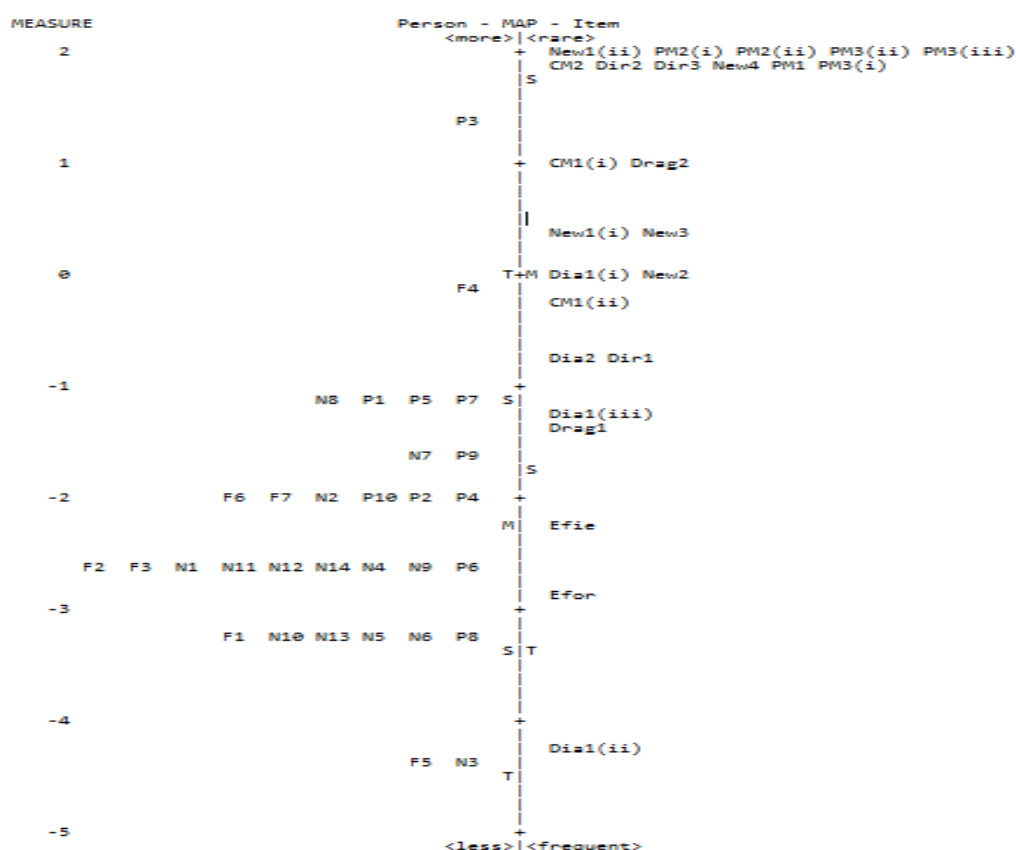


Figure 3: Person-Item map for 'Charge' problem

[F's represent the full-time pre-service trainees, N's are the novice trainee teachers and P's are the part-time experienced trainee teachers.]

B. To what extent does the 'Charge' problem discriminate the problem solving ability of teachers with different years of teaching experience?

The person-item map (Figure 3) indicates a tendency of the experienced teachers to perform better at the given task as compared to the novice teachers who are mostly stacked towards the lower end of the map. To assess whether the difference is statistically significant, a Kruskal-Wallis test was conducted to evaluate differences in the test score among the three categories of teachers (pre-service, novice and experienced). The non-parametric approach, based on rank of values, negates the effects of the outliers [12]. In this case the outliers represent unusual scores of some teachers (e.g., teacher P3 who earned a score of 14) and are legitimate cases, representative of the whole population [13]. The test was significant ($\chi^2(df = 2, N = 31) = 6.607, p - value = 0.037 < 0.05$), indicating differences in the test scores among the three groups of teachers. Follow-up tests were conducted to evaluate pairwise differences among the three groups, using the Bonferroni approach ($p - value = 0.05/3 = 0.017$). The results of these tests indicated a significant difference (Mann-Whitney, $U = 27.500, p - value = 0.011 < 0.017$) between the novice teachers and the experienced ones. However, no evidence was found for any significant difference between the pre-service and the novice groups of teachers (Mann-Whitney, $U = 41.500, p - value = 0.562 > 0.017$) and between the pre-service and experienced groups of teachers (Mann-Whitney, $U = 19.500, p - value = 0.123 > 0.017$). This may simply be due to the smaller sub-sample of pre-service teachers ($n = 7$) in the study. Additionally, it should be noted that the person measure reliability (from the Rasch analysis) is 0.43, thereby indicating that the various items in the task weakly differentiated among the teachers. The person-item map (Figure 3) establishes that except for teacher P3 (who scored 14 marks), the measures of the remaining teachers were negative.

IV. Discussion

In this study, we attempted to investigate the content and pedagogical content knowledge of in-service (experienced and novice) and pre-service physics teachers on the concept of 'Charge' while they were engaged in a problem-solving task. This concept has been chosen intentionally as the problem contains a series of physics and mathematics sub-concepts and to solve it demands that the teachers hold good knowledge and understanding of the sub-concepts. The 'Charge' problem entailed four stages in its problem-solving, in particular, (1) diagram, (2) principles and laws, (3) conceptual physics and (4) procedural mathematics. The relatively easy items were identification of electric field, electric force and velocity of charge ($4v$). The most

difficult items, on the other hand, were (1) application of Newton's second laws, (2) situating the direction of the drag force and (3) procedural mathematics.

From the statistical analysis, we found evidence that the teaching experience of the experienced in-service teachers has to some extent enabled them to proceed towards the solution in a reasoned manner. However, the average score obtained and the measure of Person's ability from the Rasch analysis demonstrate limited knowledge and understanding of the 'Charge' concept. From the worksheets, we observed that much of the problem-solving was related to the 'plug-and-chug' method and the 'memory-based approach' which is much in line with what was observed by Zewdie [11]. Moreover, our analysis revealed that there is no significant difference between in-service novice and pre-service teachers. Their works contained mostly mathematical formulae related to the concept of 'Charge' and useful explanations which would have helped in identifying their logical thinking were largely missing. This implies a need to consolidate content and pedagogical content knowledge thereby requiring teachers being involved in continuous professional development courses on a regular basis [14].

V. Conclusion

An investigation using the 'Charge' problem has enabled us, within the scope of this study, to highlight shortcomings in content and pedagogical content knowledge of in-service (novice and experienced) and pre-service physics teachers. The two research questions were meant to determine, on the one hand, what difficulties the teachers have in solving the 'Charge' problem, and, on the other, to find out to what extent the 'Charge' problem discriminates the problem solving ability of teachers with different years of teaching experience. Analyses from the Rasch model and non-parametric statistics reveal that the items related to the 'Charge' problem was difficult for the majority of the teachers. Even though the task weakly discriminated among the teachers, a tendency for the experienced teachers to score more was noted. Most of the participants' workings showed attempts to recall factual knowledge and to select formulae related to the concept of 'Charge'. Written guidelines to the task provided by the participants hardly demonstrated didactical reconstruction of solution processes accessible to students.

VI. References

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