Multiple Choice Questions and Interview as a Combined Tool for Unravelling Students' Cognitive Processes in Physics

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Rationalism which is one of the approaches to epistemology is based on logical reasoning as a method for constructing knowledge. Extensive use of mathematical reasoning forms an integral aspect of rationalism. Learning processes in physics, specifically in the context of physics problem solving, can therefore, be used as a method for validating epistemological beliefs. Ability to solve physics problems is considered as an index of effective physics learning. However, due to the complexity of processes involved in solving of physics problems, there exists a perceived notion of difficulty for learners. The research into the understanding of microstructure of the processes involved in problem solving has the following implications. They help in the generation of strategies for effective problem solving and in validation of epistemological beliefs in the context of physics problem solving. In this paper, we have probed in detail into students' physics problem solving processes and have attempted to associate them with the underlying epistemological beliefs.

Keywords: Epistemy, Physics education research, Problem solving

Introduction

Epistemology – the philosophical theory of knowledge considers how we know, what we know, and establishes just what ought to be defined as knowledge. One view is that justification distinguishes genuine knowledge and there are two main types of justifications: rationalism and empiricism. Rationalism uses formal logic and mathematics to construct human knowledge by 'pure' reasoning. Empiricism takes the impressions of sense-data as the foundation of all knowledge. Different types of knowledge may be recognized: knowledge-how, knowledge - of and knowledge - that. What constitutes as knowledge and what amounts to learning is a matter of considerable debate. However, in the framework of formal education, knowledge is content which is domain specific and learning is its use in the appropriate context.

Physics education research deals with the study of how students understand or fail to understand physics. Physics education researchers who mostly comprise of physicists have utilised their teaching experiences to probe into the teaching and learning of physics. Initial research in this area was meant to improve physics instruction and hence enhance the efficacy of physics teaching /learning (Goldberg & Anderson, 1989; Rosenquist & McDermott, 1987; Trowbridge & McDermott, 1980). The process of learning physics involves use of non intuitive and abstract concepts/ideas. It also involves the use of tools of unfamiliar nature. Learning physics effectively translates to learning specific skill sets to handle these ideas / tools.

Physics education research has also shown that students possess a strong dependence on content that has been explicitly taught and deep compartmentalised learning outcomes (Eylon & Reif, 1984). A main consequence of this is a limited ability to solve physics problems (Chi, Feltovich, & Glaser, 1981; Duch, 1997; Steinberg & Sabella, 1997). Problem solving, in general, involves going to a known state from an unknown state. Solving a problem therefore necessitates the generation of appropriate strategy (Larkin & Reif, 1979; Hardiman, Dufresne, & Mestre, 1989). However, in the context of physics, the strategy for problem solving depends on the nature of the problem. For example, a chug and plug problem requires very little or no strategy at all. A more detailed strategy is needed for solving the end of the chapter problems or context rich problems (Reif, Larkin, & Bracket, 1976). Testing the problem solving skills of a student is a reliable method of testing a student's ability to apply in an altered situation what is learnt by explicit instruction. In other words, successful problem solving ability of the appropriate type can be considered to establish effective physics learning.

In this paper, we present the results of our research conducted at the department of Physics, Bangalore University, Bengaluru. We analyse the response of students to a chosen physics problem and follow it up with a detailed personal interview to probe the microstructure of their problem solving processes. Also, the study throws light on internal representation that mirrors their knowledge structure.

METHODOLOGY

More often than not, students are trained in problem solving by resorting to the practice of solving the end of chapter problems. This seemingly generates a tendency to approach the solution to a physics problem by attempting to identify the 'chapter' the problem belongs to. Better understanding of the difficulty in solving a physics problem can be obtained by careful examination and analysis of steps taken by a student when presented with a physics problem. In order to do so, researchers have collected and analysed the responses of a large number of students to physics problems. The physics problems presented may be in the open ended form or in the multiple choice question (MCQ) format. Another accepted practice is to interview students to obtain a deeper understanding of the microstructures involved in problem solving processes of students.

In our study, we have adopted a two phase approach. We have obtained and analysed responses to physics problems designed in a MCQ format and followed it up with well structured interviews to probe in detail the students' physics problem solving methodologies. Nearly three hundred students from undergraduate level were presented with a set of physics problems in the MCQ format. Options for each question were designed with clear objectives. The students' responses were analysed. Among these, we have selected a representative problem which required the application of concepts from different domains of physics. The responses to the MCQ test provide us with pointers that have been used in the design of interview protocol. The design of the interview protocol is the critical aspect of this study. The interview protocol is designed with appropriate scaffoldings so as to bring out the microstructure of their knowledge representations. The interview stage involves validation interview as the first step which serves the purpose of identifying whether a question conveys the meaning the interviewer intends to present to the student. Based on these inputs, the questions were reformatted wherever necessary and the scaffoldings were fine-tuned. These processes laid a foundation for the data interviews. Each student was interviewed in a specially set up studio. We have interviewed twelve students using this problem. The interviews were recorded using video camera and electronic writing pad. Scaffoldings were given to ensure progression of solution to the problem. The recordings have been transcribed and analysed.

The details of the interview protocols will be discussed in the context of the physics problem chosen for this study. The students who participated in the study were in the age group of nineteen to twenty one years and are students of an undergraduate program. All the students studied physics as one of their subjects. The problems presented ensured that the students had received formal class room instruction on the relevant topics.

The question presented to the student in the first phase is given below:

Question: Water, from a tap, emerges vertically downwards with an initial speed of 1 ms^{-1}

The cross sectional area of the tap is $10^{-4}m^2$. Assume that the pressure is constant throughout the stream of water and that the flow is steady. Since the equation of continuity holds good, the cross sectional area of the stream 0·15 m below the tap would be

(A) $5x10^{-4} m^2$ (B) $1x10^{-4} m^2$

(C) $5x10^{-5} m^2$ (D) $2x10^{-5} m^2$

The problem selected is expected to bring forth the categorisation tendency not based on sound physical reasoning but rather on weak 'chapter' association. The actual content of the problem (whether mechanics problem or electrostatics problem etc.) is not necessarily critical; however it is the nature of the problem that plays a major role. The above problem is what may be termed as a 'bridge problem'. The solution to such a problem would involve the usage of concepts from different domains – in this case from fluid dynamics and kinematics.

The responses of the students are presented below. The correct answer is (D).

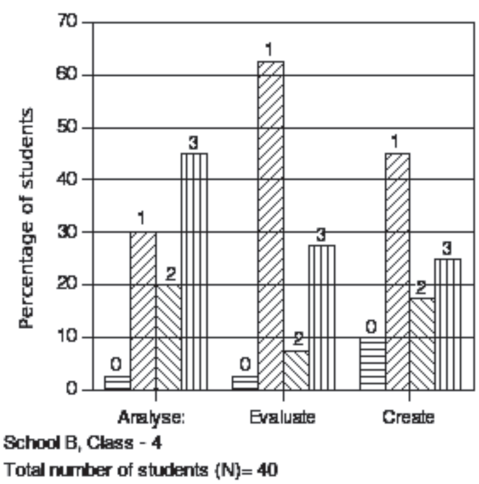

Figure 1: Students' responses

The interview protocol has been designed based on the responses to MCQ test. In the interview, the question was presented initially in the open ended form, as given below.

Water, from a tap, emerges vertically downwards with an initial speed of $1ms^{-1}$. The cross sectional area of the tap is $10^{-4} m^2$. Assume that the flow is steady. The pressure is constant throughout the stream of water. Calculate the cross sectional area of the stream 0·15 m below the tap.

The mind map represented in Figure 2 summarises the interview protocol.

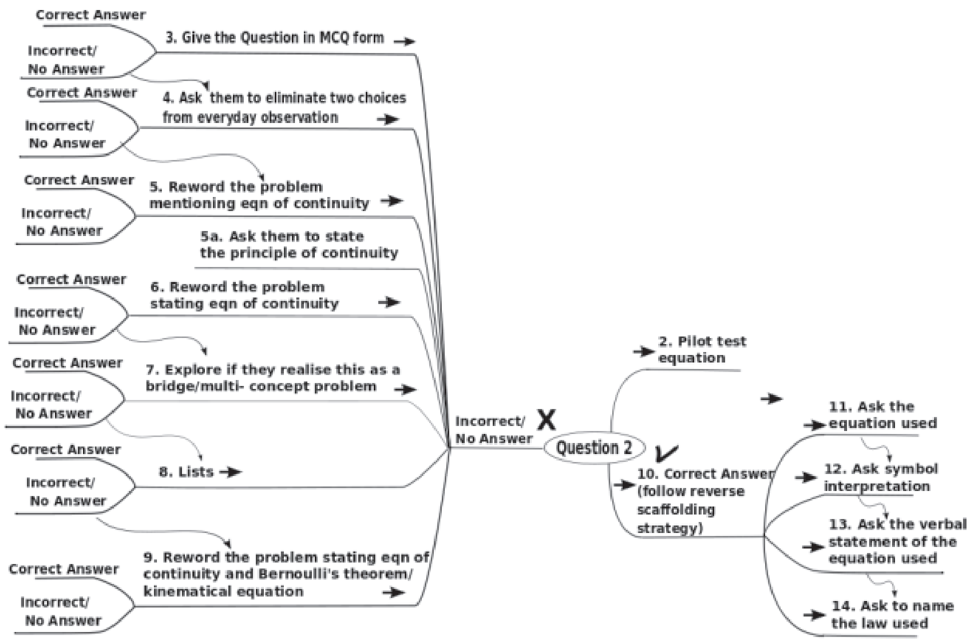

Figure 2: Mind map of the interview protocol

The important considerations for the design of the interview protocol are as follows:

— A question in MCQ format encourages a random selection of answer, which may or may not involve scientific reasoning. To discourage random choice, we presented the problem as an open ended problem. The question was slightly altered from the one used in the MCQ test with the intention of not suggesting the physical principle to be used, which otherwise could work as a scaffolding for the solution.

— The problem was then presented in the MCQ format. The MCQ format was expected to generate the thought process which would initialise the process for the solution.

— The scaffolding which pointed to the possibility of an elimination of options based on everyday observation was presented next.

— The solution to this 'bridge problem' requires the use of concepts/ideas that are learnt in different 'chapters'. We hypothesise that students exhibit a strong compartmentalised mode of learning and therefore, tend to look for approaches for problem solution based on 'chapter' association. Therefore, the next scaffolding presented was the name of one of the physical laws to be used i.e., the principle of continuity.

— Students who could not use the above scaffolding were presented with the statement of the principle of continuity.

— We conjuncture that students show a dominant tendency to search for the appropriate equation rather than the relevant physical principle. Therefore, the relevant equation was presented as the next scaffolding.

— Since this is a bridge problem, the next scaffolding presented the other physical idea necessary for the solution. There are two alternative routes to this part of the solution. We, therefore, presented the kinematical equations and Bernoulli's theorem and prompted students to choose.

— The above steps were presented to the students who could not proceed with the solution.

— The students who were successful in solving were presented with the scaffolding in the reverse order e.g., a student who solved the problem successfully was asked to write the relevant equation. Upon doing so, they were asked to identify the physical principle used in the solution and the interview progressed in the similar reverse order.

Results and Discussions

One of the primary objectives of research in the field of physics education is to identify and analyse students' learning difficulties. The outcome of the research findings is intended to enhance the effectiveness of instruction and have implications in curricular design (Shaffer & McDermott, 1992). A very interesting consequence of such a research is that it brings out the nature of student beliefs and the internal representations they hold that can be unravelled depending on the detailing that goes in to the design of interview protocol. Research in physics education has exposed the limitation of the conventional content transfer mode of learning (Hammer, 1994a; Redish, Saul, & Steinberg, 1998). This passive learning creates a knowledge base in learners which is predominantly fact based, authority driven and is formal in nature. These are the underpinnings on which learners generate their epistemological beliefs. These beliefs are often unexposed in the existing formal instruction and evaluation practices, but get exposed when posed with a problem situation. A shift to a firm knowledge base involves processes which generate personally constructed internal representations. This shift is mandatory for problem solving and the lack of which evidently limits the problem solving competency. Our research has examined these aspects by the detailed interview and its analysis. Some of these issues that influence their problem solving processes that are evident from the transcription of the interview are discussed below.

— Of the eleven students interviewed, only two students did solve the problem successfully in the open ended form. The inability of the remaining students to solve the problem supports the common observation that a large number of students exhibit compartmentalised learning. Their knowledge base appears to be fragmented which can possibly be the cause of major block in majority of the students' problem solving ability. The effect is seen in a pronounced way while solving this problem as this is a bridge problem. What is more interesting is that their 'knowledge in pieces' state has a robust hold on their epistemological beliefs–which is evident by their inability to progress even when the question was presented in MCQ format.

— In order to probe how students connect everyday observations to the physics they learn, the students were presented with the scaffolding asking them to recollect the water flow from a tap. Of the nine students, who were presented with this scaffolding, four students stated that the cross sectional area remained constant, two students responded that the cross sectional area increases and only three students answered that it decreases. The inability of students to draw conclusions based on everyday observations appear to be an issue predominantly arising out of inconsistencies in their beliefs about physics in classroom and the physics of world around us (Reif & Larkin, 1991; Hammer, 1994b). The interview analysis reveals that students resort to the use formal physics ideas rather than invoking of associations with the physical world. The epistemological belief that physics is merely a collection of concepts and equations seems to be prominently deep rooted in students' mind.

— As the problem involves the physics of fluid flow, the relevant fluid dynamics principle i.e., the principle of continuity was presented to the students. Even after presenting the scaffolding suggesting the name of the physical principle to be used, i.e., principle of continuity, students, however, could not state the principle of continuity. The principle of continuity in the form of the representative equation, *not in the form of statement of the principle*, was stated by only four students. The equation of continuity, which arises as a consequence of mass conservation, shows up as for a fluid in steady flow. The comfort level of students in equation hunting mode of problem solving than use of relevant physical principle is an aspect of learning which can be traced to the instructional and evaluation practices that encourage dominant rote learning. This comfort level with rote learning is not a choice of the learner but rather a habit that has evolved as result of a student knowing 'what works'.

— When presented with the two alternative routes i.e., kinematical equations or Bernoulli's theorem, for the progress of the solution, the students chose kinematical equations readily. The choice, probably, is driven by the familiarity with the kinematical equations and by the lower degree of abstractness associated with the concerned physical quantities in kinematics.

— The fact that it is a bridge problem required thinking utilising multi domain connectivity. The compartmentalised mode of learning seems to limit connecting solution to the equation of continuity, kinematical equation / Bernoulli's' theorem. When presented with all the physical principles that need to be used, namely, the principle of continuity, kinematical ideas and Bernoulli's theorem, only three students could present the corresponding equations. The tendency and ability of students to recall equations readily than identify and use physical principles, has been a strongly recurring phenomenon during our interviews.

— The lack of mathematical manipulation skills in an altered and unfamiliar context needed for understanding physics and for problem solving is also exhibited during these interviews. This is a reflection of the students' perception that use of mathematics in physics learning is more an 'inconvenience' than a tool for quantification of ideas.

Conclusions

Problem solving in general and physics problem solving in particular have evoked the research interests among a large group of researchers. The efforts in these directions have been mainly towards the methodology of strategy formulation. Though physics education research primarily deals with the domain specific understanding of the 'understanding', the study throws up issues of relevance to cognitive science researchers at a deeper level. Our research brings forth a technique for a deeper and a detailed analysis of their knowledge structure using scaffoldings which were designed with clear objectives and presented based on their complexity – weakest first. The result reinstates the importance of process over content. A systematic and deeper understanding of the processes involved in problem solving can also be an effective tool for understanding the epistemological beliefs students hold in the context of physics learning.

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