UNDERSTANDING OF THE CONCEPTS OF MECHANICS AMONG A-LEVEL PHYSICS STUDENTS

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Konsepsi Tentang Mekanik Di Kalangan Pelajar Fizik *A-level*

Abstrak

Tujuan kajian ini ialah untuk mengkaji konsepsi pelajar fizik peringkat A-level tentang mekanik. Kajian ini juga bertujuan untuk menentukan hubungan antara kefahaman konsep dalam mekanik dengan tahap kebolehan penaakulan formal pelajar. Sejumlah 95 pelajar A-level (76 lelaki dan 19 perempuan) dari sebuah universiti tempatan telah terlibat dalam kajian ini. Dua instrumen yang terdiri dari Ujian Pemikiran Mantik (TOLT) dan Inventori Konsep Daya (FCI) telah digunakan untuk tujuan pengumpulan data. TOLT digunakan untuk mengkategorikan tahap kebolehan penaakulan formal pelajar, manakala FCI pula digunakan untuk mengenalpasti tahap kefahaman pelajar tentang konsep mekanik dan juga untuk mengenalpasti salah konsepsi yang kerap didapati dan yang kerap berulang dikalangan pelajar. Keputusan kajian menunjukkan bahawa:

(1) Tahap kefahaman mengikut skor purata pelajar dalam FCI adalah 43.3%. Ini adalah merupakan tahap kefahaman yang rendah memandangkan skor purata 60% merupakan tahap terendah yang perlu bagi kebolehan menyelesaikan masalah fizik.

(2) Pelajar yang mempunyai penaakulan formal tinggi menunjukkan pencapaian lebih baik dalam kefahaman konsep tentang mekanik berbanding dengan pelajar yang mempunyai penaakulan yang sederhana pada tahap signifikan $p < 0.05$.

(3) Sejumlah 19 salah konsepsi yang kerap didapati dikalangan pelajar telah dikenalpasti.

(4) Sejumlah 11 salah konsepsi yang kerap berulang dikalangan pelajar telah juga dikenalpasti.

Implikasi daripada dapatan kajian ini telah juga diperbincangkan dan cadangan untuk kajian lanjut juga disyorkan.

ABSTRACT

This study was designed to provide some quantitative evidence concerning the extent to which misconceptions about force and motion exist among A-level students. It also sought to establish the relationships between students' understanding of concepts in mechanics and their formal reasoning ability.

The subjects of the study consisted of 95 A-level students (76 males and 19 females) from a local university. Two data gathering instruments, Test of Logical Thinking (TOLT) and Force Concept Inventory (FCI) were used. The TOLT was used to categorize the formal reasoning ability of the students, and the FCI was used to assess the students' understanding of the concepts in mechanics and to probe the common and recurring misconceptions. The findings showed that:

(1) The percentage means score for the students' performance on the FCI was 43.3%. This was a fairly low score considering a means score of 60% was a kind of conceptual threshold for problem-solving competence in physics.

(2) The high formal reasoning ability students performed significantly better than the medium formal reasoning ability students in their understanding of concepts in mechanics at the level of significance of $p < 0.05$.

(3) A total of 19 common misconceptions were identified from the students' responses in the FCI.

(4) A total of 11 recurring misconceptions were also identified from the students' responses in the FCI.

Implications arising from the findings were discussed and specific recommendations were also suggested for further studies.

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CHAPTER 1

Introduction

1.0 Background of the Study

Physics teaching relies heavily on the understanding and application of the physical laws and concepts. For student and teacher alike, these laws and concepts act as staging posts in the arduous journey through the syllabus. Comprehending physics, that is learning about physics, means learning to interpret and use the physical laws and concepts. Teaching and learning are intimately interrelated in the educative process. For the learner, an element of personal struggle is often present in the best secured learning or understanding; the struggle needed in thinking out and applying a concept, or in solving a problem, often involves a deeper scrutiny and is more likely to contribute to an enhanced sense of achievement. For the teacher, there is the perpetual challenge to manage and structure the experience of students to ensure the appropriate balance between struggle and accomplishment. If the struggle to understand a concept is too daunting, students' confidence and motivation will decline. If the challenge is too feeble, it will fail to stimulate students, and this will attenuate their levels of motivation.

Piaget's work on staged cognitive development has been influential in the development of both the curriculum and approaches to teaching. Piaget recognised that a learner's thinking develops as a result of their experiences. A key feature of the developmental approach to learning is that it implies that there are limitations imposed by a particular stage on what can be learned by the learner. From this perspective, the importance of matching teaching to learning lies in the recognition of the varying cognitive demands of different learning tasks. Thus, it is necessary to determine whether individuals at different stages in their cognitive development could perform such learning tasks.

There is disquieting evidence that many students never achieve a real understanding of physics. To a large extent this is due to the fact that for most students, the knowledge of physics which they derive from everyday experience conflicts with the scientific knowledge taught in class, and that this conflict is seldom resolved in their minds. The prevalence of these unresolved conflicts in school physics had long ago been established through the work of Viennot (1979) in France and of Driver and Gilbert (1983) in Britain. Its extension into universities has been established in the United States of America (see e.g. Hestenes, 1987)

In a constructivist view of learning, it is important to identify individual learners' starting points in planning teaching strategies that match students' learning. The key features of this view of learning include recognising that the understanding derived from and meanings attached to learning experiences are personal to the learner and these are shaped both by the context and their prior experiences. In teaching, an essential part of the process is to probe learners' current understanding. This is required so that appropriate teaching strategies can be devised to further develop that understanding (Driver & Bell, 1986).

Ausubel (1978) describes two extremes in the learning processes. At one end is rote learning, where students attempt to learn by placing information in memory by repetition and in isolation from any other learned material. The other extreme is meaningful learning, in which new information is attached to existing learning, making it richer, more interconnected and accessible through many cross references. However, many students fail to see physics as a subject of interconnections with its own rich picture.

Theories of learning overwhelmingly commend teaching that recognises the needs of individual learners. At A-level, students' needs increase still further to include the development of strategies, skills, attitudes and values for the application of ideas to solve problems, evaluate observations and data, and for communication.

Each student entering a first course in physics possesses a system of beliefs and intuitions about physical phenomena derived from extensive personal experience. This system functions as a common sense theory of the physical world which the student uses to interpret his experience, including what he uses and hears in the physics course. Surely it must be a major determinant of what the student learns in the course. Well established findings of research have indicated that student beliefs about physics are loosely organised, incoherent, ill defined and context dependent. From their own extensive analysis of test data and student interviews, Halloun and Hestenes (1995) have concluded that:

(1) Student concepts are often vague and undifferentiated and they are incompatible with Newtonian concepts in most respects.

(2) Student belief systems are incoherent and can best be described as bundles of loosely related and sometimes inconsistent concepts.

Over the last decade, physics education research has established that these beliefs play a dominant role in introductory physics. Instruction that does not take them into account is almost totally ineffective, at least for the majority of students. Naturally, we all want deeper insight into the cognitive structure of student beliefs.

Yet conventional physics instruction fails almost completely to take this into account. This instructional failure is largely responsible for the legendary incomprehensibility of introductory physics (Haloun & Hestenes, 1985).

Because a good understanding of concepts appears to be a prerequisite for expert problem-solving, much effort has gone into identifying fundamental concepts and the difficulties that students have with them. Knowing more about students' preconceptions in science has become increasingly recognised as essential, and a lot of important research has been carried out in this field (Mc Dermott, 1984). McDermott and other physics education researchers have documented that even after studying physics, students have an understanding of fundamental concepts that is usually weak.

According to the constructivist perspective, humans are seen as subjects who actively construct understanding from experiences using their already existing conceptual frameworks (Wubbels, 1992). A constructivist way of teaching assumes the existence of learnt conceptual schemata and the active application of these when responding to and making sense of the new situations of learning. Applied to science education, the constructivist view supports teachers who are concerned with the investigation of students' ideas and who develop ways, which incorporate these viewpoints into a learning-teaching dialogue.

A constructivist view of learning may lead us to consider the content of a science curriculum in a developmental way. At first, pupils do not necessarily construct a complete understanding of a new concept. Ideally, the teaching strategy should extend pupils' understanding of mechanics from its human centred beginning to a more general notion gradually approaching what is taught at school.

More than in other areas of college-level science, reformers in physics are asking not only what ought to be the content or sequence of physics courses, but what do we want our students to know and what do we want our students to be able to do when they complete our courses?

For many years, the physics community has been uncertain about how college students – even good students – reason about the material in introductory physics. One line of research has pursued alternate conceptions (so-called misconceptions), which researchers believe will go far to account for students' inability to qualitatively understand physical processes (McDermott, 1984).

Much of the interest in misconceptions derives from instructor's experience with the persistence of naïve conceptions that students bring with them to introductory physics. These misconceptions were always present, but until recently were presumed to be temporary since it was thought that a brief exposure to dynamics, for example, would suffice to replace naïve notions about motion with the Newtonian view. Long ago, Arnold Arons (1983), professor emeritus of physics at the University of Washington, commented that many students who complete the first-year programme in physics remain "Aristotelian" in their views of motion. But it was not until 1985 when David Hestenes and Ibrahim Abou Halloun provided a convincing experimental demonstration of the "failure of conventional [college-level] instruction in physics to overcome students' naïve misconceptions about motion"(Halloun & Hestenes, 1985) that the physics community as a whole took note. Their research on common sense beliefs about motion has lead to the following general conclusions:

(1) Common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics courses.

(2) Common sense beliefs are very stable, and conventional physics instruction does little to change them.

Hestenes et al. (1992) designed a test, acronymic as the FCI (The Force Concept Inventory), to measure students' qualitative understanding of the physical principles underlying Newtonian mechanics. They gave it to 1000 students about to enrol in introductory physics, then to those who have successfully completed the course. The results showed only a "very small gain of about 20% in understanding" and, even more significant, that this "small gain" was independent of the instructor.

Much of the research into misconceptions and many of the alternate pedagogies being developed are intended to address such results. The main purpose of this study was to investigate and document students' conceptions of mechanics using the Force Concept Inventory. In addition, the relationship between the students' performance on the Inventory and their formal reasoning ability was also studied. The FCI was used in this study to assess the knowledge state of beginning A-level physics students, including physics related mathematical knowledge as well as beliefs about physical phenomena. The FCI was also used to identify and classify specific students' conceptions and misconceptions of mechanics and to identify the extent of the persistence of their recurrent misconceptions.

1.1 An Overview of A-level Physics Education in Malaysia

Students pursue A-level courses for a variety of different reasons; the traditional preparation for a university course is an important purpose for A-level study in Malaysia.

The A-level physics programme is a preparatory programme for higher degree-level course in physics, engineering, medicine, chemical engineering and other related programmes. Students undertaking the course are expected to have an appropriate qualification in Ordinary level Physics and Mathematics. This programme offers opportunities to students to explore spiritual, moral and cultural dimensions as well as to gain scientific knowledge and understanding of physics topics (A-level physics syllabus, March 2000). Students may experience a sense of amazement as they understand the extent to which physical principles may explain the natural world and the nature of the Universe.

Aims of the Specification

The aims of the A-level physics specifications (A-level syllabus, March 2000) are to encourage students to:

(1) Develop essential knowledge and understanding in physics and, where appropriate, the applications of physics, and the skills needed for the use of this in new and changing situations.

(2) Develop an understanding of the link between theory and experiment.

(3) Appreciate how physics has developed and is used in present day society.

(4) Show the importance of physics as a human endeavour which interacts with social, philosophical, economic and industrial matters.

(5) Sustain and develop their enjoyment of, and interest in, physics.

(6) Recognise the quantitative nature of physics and understand how mathematical expressions relate to physical principles.

(7) Bring together knowledge of ways in which different areas of physics relate to each other.

(8) Study how scientific models develop.

The A-level physics syllabus contains six major units (see Table 1). The topic of mechanics is taught in the first unit and it covers all the major Newtonian concepts.

Table 1

A-level Physics Units

Unit	Topics
1. Mechanics and radioactivity	Rectilinear motion Forces and moments Dynamics Mechanical energy Radioactive decay and the nuclear atom.
2 Electricity and thermal physics.	
3. Astrophysics, solid materials, nuclear and particle physics, medical physics.	
4. Waves and our Universe.	
5. Fields and forces.	
6. Synthesis.	

1.2 Research Questions

It is hypothesized that only a very small proportion of students embarking on physics courses have any rational understanding of the concept of force. Documented studies on A-level students' misconceptions done locally are still lacking. Thus this study was carried out to assess local A-level students' misconceptions about motion and to achieve the objectives, the following research questions were put forward:

1. What are the students' level of understanding on the Force Concept Inventory (FCI)?
2. Are there any significant differences in the level of understanding of mechanics between students of different formal reasoning abilities?
3. What are the students' common misconceptions in the dimensions of:
   (a) Kinematics,
   (b) First Law,
   (c) Second Law,
   (d) Third Law,
   (e) Principle of Superposition and
   (f) Kinds of Force?
4. What are the students' recurring misconceptions in the above areas?

The outcome of the study is to be used as a basis for post-instruction evaluation intended at helping instructors see where their instruction can be improved as well as proposing more effective methods of instruction and ways of overcoming the seriously persistent misconceptions of mechanics at the college level.

1.3 Definition of Terms

Throughout this study, certain terminology has been used. Their definitions for this particular study are as follows:

(1) Understanding

This is defined as the ability to select the correct or best responses from those given in multiple-choice test items.

(2) Concepts

They are defined as a summary of essential characteristics of a group of ideas and/or facts that epitomize important common features or factors from a large number of ideas (Pella, 1966). This definition includes concepts learnt as principles or laws in physical sciences.

(3) Misconceptions

Misconceptions are defined as knowledge spontaneously derived from extensive personal experience that is incompatible with established scientific theory (Lawson & Thompson, 1988). The misconceptions are considered the wrong conceptions held by the students in contrast with correct scientific conceptions.

(4) Formal Reasoning Ability

It is defined as the capability of dealing with formal reasoning operations, such as proportional reasoning, control of variables, correlational reasoning, probabilistic reasoning and combinatorial reasoning (Lawson, 1985). In this study the formal reasoning ability is measured by the subject's total score on the Test of Logical Thinking (TOLT), an instrument developed by Tobin and Capie (1981).

(5) Recurring Misconceptions

Recurring misconceptions in mechanics are students' misconceptions identified from their responses in more than one of the FCI items. It should be noted that these recurring misconceptions refer to the misconceptions that appear in the different items and not referring to the same students having the misconceptions.

(6) Common Misconceptions