Abstract

Most students have difficulties in solving physics problems and do not have deep understanding of the underlying concepts in the problem. To overcome this situation, we propose a computer aided learning tool known as Adaptive Learning Environment for Problem Solving (ALEPS) that is based on Polya’s four problem solving stages: 1) understanding; 2) planning; 3) implementing; and 4) checking. The overall system focuses on a cognitive approach to learning, which deals with the mental processes involved in acquiring knowledge. However, the focus of this paper is to demonstrate how students’ understanding of a physics problem can be improved by guiding them towards a better representation of the problem. The aim is to develop a learning tool that can assist students or novices to identify known, unknown, and latent features of the physics problems based on their knowledge and the major concept involved. The tool consists of a problem formatter, a feedback system and a knowledge base.

Keywords: Physics Problem, Problem Representation, Problem Solving, Categorization, Learning

1. Introduction

As we go about performing our daily activities, we develop structures in our minds to interpret experiences. These structures are developed to allow an easy and efficient access to knowledge when required. These processes involved in acquiring skill or knowledge (learning) such as thinking, remembering and problem solving is known as cognition [11]. Docktor et al. (2012) described the process of grouping related entities and continually updating the connections between these concepts when new information is encountered as categorization. It has been established that ease of solving a problem depends on the quality of its representation [1] [2] [3] [4] [5] [6]. Based on the study by Soong et al., one of the major areas of hitches in solving physics problem is the misinterpretation of the question [5]. Chi et al. (1981) highlighted the fact that the major difference between a “Novice” and an “Expert” in solving physics problems is in how the problem has been categorized or represented. Various experiments have shown that “Novice” categorizes physics problems based on the surface content encountered only, while the “Expert” considers not only the surface content but also the underlying principles and concepts [1] [2] [3] [7] [10].

The two types of problems identified by psychologists are well-structured and ill-structured problems. The well-structured are problems that applying certain procedure will lead to a correct answer, while ill-defined problems do not usually have a single correct answer and have an unclear process to arriving at a solution [8] [9]. Physics instructions are designed to help students improve their problem solving expertise [5]. This is why some physics problems are ill-structured, similar to most real-life and professional problems. This work is focused on aiding “Novice” in shifting their mode of categorizing physics problems from a content feature base to a deep structure, through receiving immediate feedback during physics problem categorization via a computer system (expert view). This approach is based on findings by Docktor et al. (2012) which shows that a “short intervention can help students (Novice) to increase their tendency to use principle-based categorizations”.

This paper describes the approach we intend to use in guiding “Novice” physics students to develop a proper physics problem representation, fostering a good understanding of physics problems. Section 2 reviews some work related to our research. Section 3 describes our system and approach. Finally section 4 concludes the paper.

2. Related Works

This research focuses on how a computer system can be used to aid “Novices” in changing their mode of categorizing physics problems. This is based on its effect on problem solving as established in other literatures.
We will discuss in brief how knowledge is acquired, the role of categorization in physics problem solving and tools that have been developed to solve physics problems.

2.1 Cognition and Learning

Cognition is one of the three main types of learning theories, including behaviorism and constructivism. Behaviorism theory defines knowledge acquisition based on an observable and measurable change in behavior. This approach to teaching was used in developing curriculums in schools [11]. Though this approach was able to account for a behavioral change it failed to explain how conceptual change occurred. This is due to the fact that it does not explore the mental processes in the human mind. Constructivism theory tends to describe learning as a construction of knowledge. Unlike the other theories, cognitivism focuses mainly on how knowledge is acquired, processed, stored, retrieved, and activated by the learner during the learning process [11].

This cognitive school of thought is more concerned with the knowledge learners have and how they acquired it, rather than their actions. This approach focuses on helping learners organize and relate information, to make it meaningful to them. The foundation of the cognitive theory is based on Piaget’s theory of cognitive development and Vygotsky’s theory on social cognitivism. Piaget discusses the concept of schemata, while Vygotsky focused on explained learning that later gave birth to the concept of scaffolding [11].

2.2 Role of Categorization in Physics Problem-Solving

The duty of the problem solver is to locate the operator that will cause a transition from the current state to the desired state. Chi et al. (1982) supported by Larkin 1985 and Schneider 1987 as cited by Curtis & Lawson (2002) asserted that to be successful in solving problems a student needs to have access to a well-developed and extensive knowledge base. Bereiter and Scardamalia (1986) also investigated how novices with limited access to knowledge base become experts. They discovered that with the use of some strategies this transformation is accomplished. Hence, there exist two major influences on problem-solving, schematic knowledge and strategy use [14].

George Polya (1887 – 1985) claimed that problem solving abilities is not something humans are born with, but a skill that can be acquired. He discovered a strategy for problem solving using four principles: “Understand the problem, devise a plan, carry out the plan then look back (reflect)” [15].

Investigations on physics problem categorization has proven that “Expert” problem solvers who are able to categorize problems based on principles and concepts are better problem solvers than “Novice” who depend on surface features. The existence of these conceptual schemas is regarded as the vital difference between “Expert” and “Novice” problem solvers. Research has shown that “Novice” perception of categorizing physics problems can be shifted from surface based to concept based categorization. This can be achieved by using interventions, whereby “Novices” can be provided with elaborate feedback in the form of explanations [1].

2.3 Computer-Based Physics Problem Solvers

For the past five decades, computer programs like ISAAC [16], BEATRIX [13], OLEA [17], ANDES [12] etc. have been developed to solve physics problems. These projects were developed with different aims, for instance the BEATRIX program which was based on ISAAC a previous work, is aimed at solving the problem of co-reference (“recognizing when two descriptions contain references to the same object or set of objects so that information is associated with the correct object in the internal model”) and how picture can be parsed in same way as text. BEATRIX takes in physics problem statements in English and its associated figure and produces a model of the problem which contains the physical objects mentioned in the problem, their properties, their interaction with each other, and the forces they exert on one another. This is accomplished with the help of a knowledge base having information on the pictures and the real world objects they signify, an English vocabulary, and rules for parsing English. The problem model produced by BEATRIX did not take into consideration the underlying principle and concept in the problem [13].

Unlike BEATRIX and most tutoring systems which are concerned with producing only the answer to a question, ANDER derived from OLEA, is a coached, intelligent tutor which fosters learning in physics by providing an environment for students to solve problem which consist of several steps such as defining variables, drawing vectors and coordinates and writing equations, providing immediate feedback on steps taken in-order to guide the student on the right path to the solution. The system’s environment consists of an action interpreter,
assessor, interface, help system, and student model. It also has an authoring environment which consists of the given problem conditions and a physics knowledge base (problem solver). This differs from BEATRIX which parses physics problem statement and allows the author to define a problem statement, its correct answer, some wrong answer and hints. ANDES present a formal representation of the problem so that the solution can be derived by ANDES. If ANDES produced incorrect derivations, missing derivations or misleading hints, the author can revise the knowledge base. This approach is cumbersome in the sense that a fulltime knowledge engineer is needed to be employed to revise the knowledge base when there are inconsistencies in the derivation made by ANDES. Also the instructor (teacher) needs to translate the problem statement to a formal definition [12]

Most physics tutoring systems such as BEATRIX and ANDES are not aimed at teaching any form of problem solving strategy [12] [13]. ANDES does not provide an explicit way of learning physics concepts and principles; instead it provides principle based hints to foster implicit learning of the principles [12].

3. Physics Problem Representation

3.1 Overview

The overall system focuses on a cognitive approach to learning, which deals with the mental processes involved in acquiring knowledge particularly knowledge about how to solve problems. There are four main modules in the system, each representing Polya’s problem solving stages namely understanding, planning, implementing and checking. All the modules are still under development.

We propose a computer aided system which will provide immediate feedback to students, assisting them in categorizing physics problems based on the concepts involved. This is due to the finding of Docktor (2012) on the effect of feedback in altering the perception of a “Novice” problem solver to that of an “Expert” view. In order to achieve this, the module will consist of a problem formatter, a feedback system and a knowledge base. The problem formatter will parse physics problem statements written in English using an augmented transition network grammar. The parser will identify objects, known, unknown, and latent variables along with the major and minor principles involved in the physics problem statement. A semantic network representing this problem features and their interactions will be developed with the assistance of the knowledge base. The knowledge base will consist of concepts in the problem domain, principle definitions, the principle application methods, definitions of variables and objects alongside some inference rules. The knowledge base will provide the information required to properly categorize the problem and give hints in the identification process. The feedback system will provide three types of hints in sequence based on the student’s request. These hints include; a pointing hint (aims student attention to error position), teaching hint (states knowledge applicable), and a bottom-out hint (exactly what to do giving reasons for the action).

The problem representation component will be developed with the help of an instructor who defines the physics problem statement. Once the problem statement is defined, the system tries to represent the problem by identifying the necessary features and how they interact and this result will be presented to the instructor who will make minor correction if needed through an input text box. This approach will increase the accuracy of the problem representation and reduce the cumbersome task of transforming the problem statement by the instructor.

3.2 Sample Physic Problem Representation

Currently this research focuses on physics problems in introductory mechanics (Kinematics and Dynamics) of the Malaysian secondary school curriculum. A typical problem representation in a Physics textbook [18] is shown in Figure 1. As a first step in improving students’ understanding of the problem, they are required to identify the known variables, unknown variables, objects and the associated physics topic or domain in the problem statement.
A carton is acted on by two forces of 30 N and 40 N which are at right angles to each other as shown in figure below. Determine the resultant force acting on the carton.

![Carton diagram with forces](image)

**Figure 1.** Sample Physics Problem Statement.

From the sample problem statement in figure 1, the student is expected to identify the following:

- **Known Variable(s):** vertical force, horizontal force
- **Unknown Variable(s):** resultant force
- **Object(s):** carton
- **Domain involved:** forces in equilibrium

During this process of identification, the system will provide help in the form of hints to the student when requested. The hints are aimed at fostering constructive learning. As a result of this identification process, the final output will be a more precise physics problem representation based on the problem domain.

The variables and physics domain eventually identified in the understanding stage will serve as inputs to the second problem solving stage which is the planning stage. In the planning stage, a sketch of the problem solution will be done by student based on the identified variables. Using knowledge obtained from the sketch, the latent variables and principle involved are then identified. Next, the relevant formulas are identified based on the principle involved. In the implementation stage, relevant equations are derived and the solution is produced. Finally, in the checking stage, the objects identified are used to simulate the solution produced.

4. **Conclusion**

The tool proposed utilizes a cognitive approach to learning. Its output is a physics problem representation based on the domain. Researchers have established the fact that categorization of a problem is an important aspect of problem solving. Various experiments carried out have shown that the major difference between a “Novice” and an “Expert” in the physics domain is how they represent problems. This tool is aimed at assisting in shifting the perception of “Novice” in categorizing physics problems from surface based to concept based categorization, thus enabling them to have an expert view of physics problem representation. This is achieved by using a problem formatter, knowledge base, and a feedback system. The problem formatter parses the physics problem statements written in English using augmented transition network grammar. The knowledge base stores concepts, principle definitions, the principle application methods, definitions of variables, and objects alongside some inference rules. The feedback system provides an intervention to guide students through the problem understanding process based on the student’s request.

5. **References**


Problem Representation for Understanding Physics Problems
Bimba, A., Idris, N, Mahmud, R., Abdullah, R., Abdul-Rahman, S-S., Bong, C. H