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Evaluation of computer-based animation and simulation modules designed to enhance learning of physics concepts.

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Abstract

Computer animations and simulations are usually excellent tools for education. Technology is becoming increasingly significant in today's classroom and has been integrated in a variety of ways; however, computer animations and interactive simulations are becoming the most common. This study explored the efficacy of computer simulation and animation modules especially designed for the students learning physics at undergraduate level. Understanding of physics concepts requires a sound knowledge of mathematics and thus, in order to help the students visualize the various mathematical concepts, the use of computers has been attempted and the students are made to interact with series of computer simulation programs to imbibe the difficult concepts related to mathematics. These modules are designed and developed with a special focus on the use of mathematics in understanding the core concepts in physics. A quasi-experimental investigation method, along certain quantum mechanical tools as developed by Physics Education Group, Maryland University, Maryland, has been employed to study the impact of use of computer simulation and animation modules to bring about the effective learning. The Student's conceptualization of mathematics (including misconceptions, if any) are gathered as the inputs, to form a database of the student's models and this database has been used to analyze the effectiveness of the computer simulation modules especially designed to study mathematics needed to comprehend the concepts in physics.

Introduction

Mathematics is considered to be more than a subject and is conceived as a key for solving the problems. One of the main objectives of teaching and learning Mathematics is to prepare students for practical life. Students can develop their knowledge, skills; logical and analytical thinking while learning Mathematics and all these can lead them for enhancing their curiosity and to develop their ability to solve problems in almost all fields of life. Further, the language of physics is mathematics. In order to study physics seriously, one needs to learn mathematics at conceptual level. A complete understanding of the concepts in physics requires fluency in the mathematical language in which these concepts are embedded. However, since the topics in mathematics are taught by the teachers of mathematics under separate mathematics heading, the subject is covered with the emphases on symbolic manipulations with the objectives of enhancing the skills requiring simplifications through well defined procedures. For example, the topics on complex number covered by the mathematics teacher involve such manipulations demanding simplification of assorted and typical problems without understanding the need of complex numbers in physics. As an another example, for learning of Algebra, learners should have a conceptual understanding about the use of the symbols and the context in which it is used. In other words, they should know the situation in which the algebraic statements are made. Foster (2007) highlighted that, "when we memorize rules for moving symbols around on paper we may be learning something but we are not learning Mathematics" . Moreover, the use of symbols without an understanding cannot develop student's relational understanding of Algebra. Foster (2007) also argued that if students are taught abstract ideas without meaning, this might not develop their understanding.

Significance of the study

Student learning in Physics, in general, is a very complex process because of the abstract nature of many scientific concepts and their representation by mathematics. However, mathematics is an indispensable tool in the study of Physics. Mastery of certain mathematical techniques is a prerequisite for the learning of advanced level Physics. To a student of Physics, a course on mathematical methods in physics is absolutely necessary as most of the physics concept necessitate a sound mathematic base. . It becomes sometimes impossible to explain the beauty of the laws/concepts of Physics in a way that students can feel, without their having a deep understanding of mathematics. It should be brought to the notice of the students that mathematics is not just another language but it is a language plus reasoning; it is like a language plus logic.

Particularly in physics, where most phenomena are expressed in the language of mathematics, an in-depth knowledge of certain concepts in mathematics are extremely vital to understanding the phenomena. The students' conceptual understanding of complex numbers, vectors calculus, vector arithmetic etc are relevant in physics contexts. As an example, students enrolled in the traditional differential equations class learn to become proficient in symbolic calculations and show little understanding of the basic concepts involved. The course, in general, exclusively deals with the derivation of formulas for the solutions to different types of differential equations and the students become proficient at the procedural aspect involved in problem solving with a little emphasis on the understanding of basic concepts in the context of Physics. For example, when we formulate the differential equation and find its solution, students don't realize that, ultimately, by solving the differential equation, we arrive at the original function of which the differential equation is formed and this solution (function) gives the account of the behaviour of the system under investigation. It is, therefore, felt necessary to understand difficulties encountered by the students in mastering the required mathematical concepts and then accordingly present the topic in much simpler way, with the help of computer as a learning tool. This research project, therefore, sought to explore student learning in physics in an attempt to develop a more inclusive and broad understanding of the concepts of physics embedded in mathematical forms.

Use of technology in education

An abstract nature of mathematics sometimes intimidates the students and as a result the students slowly drift away from learning the mathematics. Thus, it becomes the additional job of the teachers to create and maintain the interest amongst the student so that students take mathematics with ease and eagerness. The use of multimedia learning environments may offer ways to combat this problem of boredom leading to losing interest by the students in mathematics (Mayer, 2001). Also, it is possible to go a step further and attempt the use of computer animation and simulation programs which not only remove the monotony of mathematics teaching but also provide a different environment and the platform for the students to flourish in conceptual part of mathematics. It will provide the learning environments in which information presentation can be accomplished by using the representational formats other than textual, for example, the pictorial design, animation, three dimensional images, dynamic visualizations etc. which may be processed by the different sensory channels (auditory and visual).

New technologies and scientific developments always bring about changes in the functions and nature of many fields and education cannot be an exception to that. The revolutionary developments in media and communication technologies (internet, Information and Communication Technologies (ICT) as the examples) are significant contributing factors when we think of enhancing the quality of education to be rendered to pupils. Effective exploitation of these changes requires adequate attention to understanding the technology so that it can be used in the effective way to facilitate the learning. The enhanced graphic capabilities of today's computers allow for excellent pictorial representation of the information, full animation, realistic three-dimensional images, creation of friendly environment with special attention to interactivity etc. According to Bork (1981), the major advantage the use computers in education offers is the interactivity. The computer allows every student to play an active role in the learning process, in contrast to the passive role of lecture and textbook formats. The student is no longer a spectator, but is an active participant in the learning process. Hence use of computer, multimedia, animation and simulation in teaching-learning process surely helps provided the role of teacher in this new scenario is properly understood and framed accordingly.

Prior knowledge and misconceptions

The most important but least focused area which deserves a special attention is the prior knowledge that students bring in the class. Physics education research group, University of Maryland, seeks to study how students come to understand physics. When teachers provide instruction on concepts in various subjects, they are teaching students who already have some pre-instructional knowledge about the topic. Student knowledge, however, can be erroneous, illogical or misinformed. These erroneous understandings are termed alternative conceptions or misconceptions (or intuitive theories) as these understandings don't fit into the scientific perceptive (J. Clement, 1982). Some researchers in the field of cognitive science believe that students' conceptions are not very systematic at all; rather, they are composed of fragments of knowledge, which are fabricated together to form explanations when the need arises (diSessa A, 1998).

The misconceptions prevailing in the minds of students at the time of discourse can greatly impede learning for most important reasons that the students generally are unaware that the knowledge they have is erroneous. Thus, any new concept based on the prior knowledge which is not correct and also not in line with the current concept under study would definitely be conflicting to bring about the perplexity. Further, these misconceptions are so strong that the normal dialogue with the student is barely sufficient to remove these misconceptions. As a result, new experiences are interpreted through these erroneous understandings, thereby interfering with correct pattern of the new understanding which is sought. This entangles teachers in the very challenging position of needing to bring about significant conceptual change in student knowledge. Generally, ordinary forms of instruction, such as lectures, laboratory work, discovery learning, or simply reading texts, are not very successful at overcoming student misconceptions. For all these reasons, misconceptions can be hard nuts for teachers to crack. However, several instructional strategies have been found to be effective in achieving conceptual change and helping students leave their alternative conceptions behind and learn correct concepts or theories.

Mental model

A mental model is a person's conceptualization, or personal theory, of some domain or environment. In cognitive science research, many theories have been developed to model a conceptual learning process. Mental model is a term used by many researchers in cognitive science & Physics Education Research often with different meaning. The Instructional design theory starts from the basic assumption that learning results in the organizing of memory into structures. The mental models are constructed from procedures provided by schema. Mental model theory can be viewed as an attempt to model and explain human understanding of objects and phenomenon. Mental models are frequently pictorial or image-like structures rather than symbolic and representational. A mental model is a person's conceptualization, or personal theory, of some domain or environment. Mental models serve as both explanatory and predictive tools as we interact in a complex environment. Students create mental models to help themselves understand and solve problems in domains of physics and other subjects too.

It is possible to collect data using Student's conceptualization of mathematics (including misconceptions, if any) as an input, and processes it further to create instructional package which will include dialogue on the various models of students understanding of the mathematics. The computer simulation package to be developed will thus include the actual visualization of mathematical concepts. While interacting with the computer simulation package, students will be able to change certain parameters and then study mathematical problems with greater understanding.

Physical models

While assessing the students' performance, on the basis of the marks obtained in the examination, we tend to discard the wrong answers completely. However, the wrong answers given by the students, if analysed properly, gives us the large amount of valueable information, on the basis of which we can improve performance of the students. One way to judge and analyse the wrong answers, which sometimes appear in terms of misconceptions, is to consciously develop the Mutiple Choice Single Response (MCSR) conceptual questions based on the topic undertaken for study. The MCSR is to be so developed that it incorporates three states as the student's response, namely correct (or expert) state, misconception state and null state. A student will enter only one state based on his/her previous knowledge.

In order to make the analysis of the responses of the students to the multiple choice questions we define a set of three physical models:

i. **The correct or expert model.** Here a student enters the correct answer to the question.
ii. **The misconception model.** It is likely that a student has certain misconception about the concept underlined in the question. In such a case, the student enters this model. The term misconception is used to mean a knowledge structure that is activated in a wide variety of contexts, which is stable and resistant to change, and is in disagreement with accepted scientific knowledge. Thus, misconceptions are strongly held stable cognitive structures that differ from expert conceptions. Misconceptions fundamentally effect student understanding of science and must be overcome for students to achieve expert understanding. For the instructor, to simply transfer information is inadequate.

Misconceptions must be overcome before expert opinion is framed and accepted by the student.

iii. **Null model.** This model is triggered when the students have irrelevant ideas about the physical concept.

Further, the composition of the questions is made by taking into account the Bloom's Taxonomy as a guideline. The equivalence in terms of difficulty level has been maintained for the questions framed for pre-test and post-test papers. The post-test was administered to the students of control group and experimental group separately at the end of the respective sessions. Using a set of questions so designed to probe a single concept, we can measure the probability for a single student to activate the different common models in response to these questions. We can use these probabilities to represent the student model state. Thus, a student's model state can be represented by a specific configuration of the probabilities for using different common models in a given set of situations related to a particular concept.

Student model state

For a single student, solving a set of problem related to a single physics concept domain, there are usually two different situation .

1. The student can use on the physical model & be consistence in using it in solving all questions. The model can be either the expert model or another physical model (eg. An incorrect student model.)
2. The student can hold different physical models, at the same time and be inconsistent in using them, i.e., the student can use one of the physical models on same question and use another model on another question, even though all questions are related to a single concept domain and the questions are seen as equivalent by experts.

Then, the different situations of student using their models are described with different students' model state. The first case corresponds to a consistent model state and the second case is considered as a mixed model state.

Formation of density matrix

The density matrix of the data to be analysed is found out. In order to find the density matrix following steps can be adopted:

1. Firstly, an individual student model state is obtained from the data (responses entered by a student in 15 questions). From the student model state, a student model response matrix of each student is formed. This matrix is a row matrix.
2. From the student response vector, the student model vector is obtained by taking the square-root of the elements of the normalized mode response vector.
3. Then a single student model density matrix is constructed.
4. From a single student model density matrix, a class density matrix is obtained.

From the density matrix, eigenvalue matrix & the eigenvector matrix are evaluated using MATLAB software. The eigenvector corresponding to largest value of eigenvalue can be used for further analysis. Detailed mathematics analysis of forming the density matrix, eigenvalue, eigen vector decompositions are not dealt with here for the lack of space.

Data collection : In order to achieve an objective of testing the ***interactive computer simulation module on Complex numbers*** for the undergraduate students, a class of S.Y.B.Sc. (Physics, Electronics and Computer science) students from three different colleges are selected. The complex number topic is cover for these students during the first term.

Pre test: In total ***126*** students from three different colleges from Nashik district participated in the pre-tests.

Control group: Out of These 126 students, 58 students are taken for control group through a random selection. To these 58 students detailed notes are given and after these students studied theses note, a post test was held for these students.

Experimental group: Out of the remaining 58 students selected for the experimental group, 56 students actually turned up to work on the computer. All these students individually worked on the interactive computer simulation module on Complex numbers for about one and half hours. These students showed enormous interest in the interactive computer simulation module on Complex numbers. After few days these students are again asked to assemble and the post test was conducted for these students.

Composition of the Question Paper:

As stated earlier, the Pre test mainly consist of 4 open ended questions, 12 question on classification 6 true or false question 9 questions on valid and invalid physical situations and the remaining 15 questions are multiple choice single response questions. Each multiple choice single response question has five choices Out of 5 choices, one is the correct answer & remaining 4 are distracters The distracter contains misconception and null models in varied proportions. The correct choice is represented by Expert model. The distracters main consists of the Misconception model & Null model.

Further the questions are framed by taking into account the Bloom's Taxonomy as a guide so that the same difficulty level is maintained for pre-test and post-test questions. The entire question paper is set as per the break up given in table 1.

KNOWLEDGE	**:**	**40 %**
COMPREHENSION	**:**	**10 % (40-49) pass**
APPLICATION	**:**	**10 % (50-59) IInd class**
ANALYSIS	**:**	**15 % (60-74) Ist class**
SYNTHESIS	**:**	**25 % (75-100) Distinction**

Table 1 : Formation of question paper

Result and Conclusions

One way to bring about the meaning full learning is by the way of reducing the established misconceptions residing in the minds of the students. This study observed students from three different colleges undergoing instructions through interactive computer animation and simulation modules performing well because of their considerable diminishing of misconception model. The most of the students fell into the category of misconception model before going through interactive computer simulation module and after going through the modules, students show considerably high progress and thus, this shows that if a interactive computer simulation module is designed by taking deliberate effort, the learning becomes effective. In addition, the interaction of digital learning materials allows students to learn through intuitive and trail-and-error methods and to repeatedly attempt to establish concept and models contained within course content. Therefore students are likely to obtain greater learning achievement.

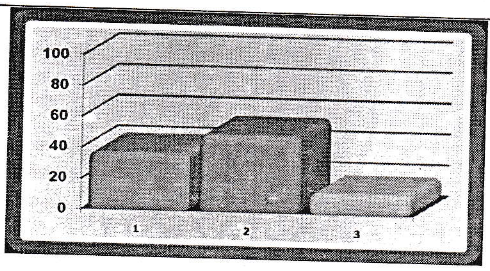
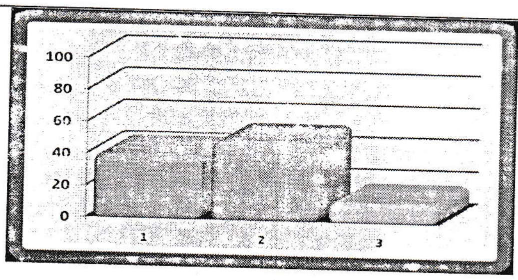
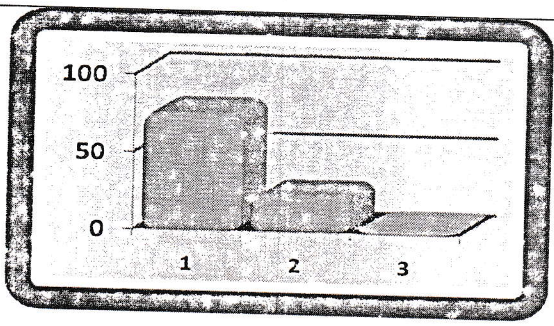
Tests administered	1 = Expert model, 2= Misconception model, 3 = Null model
Pre test of all 126 S.Y.B.Sc.. Students.	
Post test of 58 S.Y.B.Sc.. Students (Control Group).	
Post test of 56 S.Y.B.Sc.. Students (Experimental Group).	

Table 2 : Analysis of students' data

From the Table 2 we observe that, the primary model state of the control group (CG) undergoing the traditional class indicates a mixed model state, which shows that most students in the class are still inconsistent in using their models. On the other hand, the model state of the experimental group (EG), which is exposed to the computer simulation module, indicates that most students use the correct model rather consistently. Thus, in nutshell, it can be stated with affirmation that the computer animation/simulation modules developed by investigator is more effective, particularly, in helping low achievers who tend to work with low pace than the others in the same class.

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