A Brief Review on Adaptive Learning Applied for Teaching Physics

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Abstract: Web-based learning or E-learning is becoming more and more popular. Moreover, the need for effective learning environments is increasing by the day. The aim of using e-learning is to enable students to not only access learning materials outside the classroom but also to present the students with the needed help and assistance. However, most e-learning systems lack personalization and offer the exact content to all students when in fact, learners each have their cognitive style and prior knowledge that is different from any other student. This is the reason behind implementing adaptive learning in online platforms and why it is considered an essential step and is incredibly important. The purpose of this paper is to provide a literature review of previous work related to the use of various adaptive learning environments for teaching physics.

1 INTRODUCTION

To put it simply, an e-learning system is essentially a virtual classroom, where teachers put forward the course materials students need in the form of text, tutorials, simulations, etc. The materials in an e-learning platform are the same and are meant to be used by all students. Except students have distinct cognitive styles and different prior knowledge, this is the very reason behind why these e-learning platforms were not as effective as they were supposed to be.

This sparked interest in adaptive learning, which has been the subject of several research papers over the years, many of which looked at different aspects of adaptive learning systems for learning in general and learning physics in particular.

Adaptive feedback is without a doubt one of the crucial aspects studied. The web pages of the ALE (Adaptive Learning Environment) (Psycharis, 2007) were adapted to FI (Field Independent) learners and FD (Field Dependent) learners, being the two types of students' cognitive styles.

Some papers explored the text content on itself in the form of adaptive scaffolds (Chen, 2014), both types hard and soft:

- Soft scaffolds: During the learning process, soft scaffolds refer to complex, situation-specific help offered by an instructor or peer,
- Hard scaffolds: While the learner is dynamically engaged with a challenge, hard scaffolds are used to provide learner support at various difficult stages.

While other papers (DeVore et al, 2017) (Marshman et al, 2018) focused on the learning tutorials, which are in the form of quantitative problems that are broken down into sub-problems to help students deepen their understandings of physics principles.

Some research has been conducted on the multiple challenges' students face with self-paced learning that relates to different factors: internal characteristics, external characteristics, student characteristics, and the learning tool characteristics, which are detected using the SELF (Strategies for Engaged Learning Framework) (Marshman et al, 2018), and that inevitably affect the students' learning process.

Another topic of discussion was the connection between physics and mathematics (Nishioka et al, 2018) (Kudo et al, 2018). It was noticed that plenty of students who face difficulties usually do not have a good understanding of how mathematics is applied to physics.

Furthermore, when taking an MC (Multiple Choice) test, students may choose correct or incorrect answers with the wrong intentions. This was the reason behind the development of the CMR

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(Coupled-Multiple Response) test (Rios et al, 2020) that has a reasoning element, in addition to the usual MC test, which helps in identifying which and where interventions are needed for students when using the adaptive learning technology.

The purpose of this paper is to provide a literature review of previous work related to the use of e-learning and various ALEs (Adaptive Learning Environments) for teaching physics which will be presented in sections 2 and 3. The conclusion of this paper is followed by a discussion of future work in section 4.

2 GENERIC E-LEARNING APPROACHES APPLIED TO PHYSICS

Learning can be pretty challenging at various levels of education: middle school, high school, and college. Additionally, for the sake of assisting students in this process, text, graphics, images, videos, and simulations were introduced to the conventional teaching methods, hence the start of the e-learning era.

• Basic e-learning approaches: Learning technologies were established to facilitate the learning process for students and the teaching process for teachers, which were able, through web-based learning platforms, to give out assignments to students without having to be face to face. In the case of (Fayanto et al, 2019), the learning technology MOODLE (Modular Object-Oriented Dynamic Learning Environment) was adopted by high school seniors for physics learning. The platform allows students to access course material outside of the classroom and enables teachers to give out quizzes, assignments, etc. On top of that, it offers simulations to demonstrate some applications and encourages students to visualize physical phenomena better. An additional feature that is provided by this learning technology (Moodle) is the simplicity of communication, not only between students and their teacher but also between the students utilizing chats and forums.

• Game-based learning (GBL): Various video games are used for learning for the reason that GBL explores novel learning techniques and is considered one of the ICT tools (Information and Communication Technology). One of the most popular games among middle schoolers is Angry Birds (AB). It is a well-known physics-based puzzle game in which the aim is to destroy all of the pigs in a 2D level location by using a large number of birds. To go to the next level, each level has a collection of tasks/goals that illustrate a range of topics. Moreover, it was noticed that students play the AB game for long periods that vary from 6 hours to 8 hours a day. Furthermore, to use the wasted time productively, (Department of Computer Science, Shah Abdul Latif University, Khairpur, Sindh, Pakistan & Umrani, 2020) used the AB interface as a tool to teach basic physics principles. This technique was feasible since students have access to mobile devices; this way not only do they get to play their favorite game, but they also learn along the way.

However, moving from the usual classroom to a virtual one and allowing self-paced learning was not enough. There was always the problem of having the exact content delivered to all students; in other words, a one size fits all platform. This was when research moved the focus to the adaptive aspect of learning to personalize the instructional material for each student individually.

3 ADAPTIVE LEARNING APPLIED TO PHYSICS

Along with adaptive learning, numerous challenges have emerged which affected students' motivation, confidence level, etc…, that undoubtedly influenced students' learning process, especially for physics learning.

• Students' cognitive styles: E-learning environments lack customization, so identical content is offered to all the students. Nevertheless, the web pages of the ALE (Adaptive Learning Environment) (Psycharis, 2007) program were developed to help students in learning physics and were adapted to two types of students' cognitive styles: FI (Field Independent) and FD (Field Dependent). This way, FI learners were presented with physics concepts from specific to general, as they tend to have an analytical approach and are more autonomous when it comes to the development of their cognitive skills. However, information from general to specific was provided to FD students who usually need more assistance in their learning process and approach their environment from the global scope. Additionally, the ALE focused mainly on Problem-Based Learning (PBL), which used real-world problems to help students develop their problem-solving skills.

• Students' proficiency: The adaptive learning platform WPO (Wiley Plus ORION) (Basitere & Ivala, 2017) is one of the online-based feedback systems used for learning physics. When using the platform, learners start by taking a diagnostic test to evaluate their proficiency level on the physics lessons taught in the classroom. And according to learners' level of performance, the online system adapts the difficulty level of the diagnostic test questions. The data generated from the diagnostic test is provided to the students and broken into three categories: low performance, medium performance, and high performance. The teachers can also use this data to grant necessary assistance and support to the students, give Web-Based Proficiency Homework (WBPH), and assignments that are graded automatically to strengthen their level of proficiency.

• The text content: Physics subjects such as velocity and acceleration appear simple to teach when in fact, they are complicated topics. While students are familiar with the terminologies, the concepts behind them are often difficult to teach due to misconceptions and dependence on existing knowledge. (Chen, 2014) addresses the process of designing adaptive scaffolds that take into account cognitive aspects of learning, such as students' current level of proficiency and their prerequisite ZPD's (Zone of Proximal Development). In addition, Brophy's ZMPD (Zone of Motivational Proximal Development) suggests that the adaptive scaffolding e-learning system should also pay attention to learners' motivational needs that can be empowered through scaffolding. This study further proves that one size does not fit all.

• Self-paced learning challenges: Both articles (DeVore et al, 2017) and (Marshman et al, 2018) discuss the challenges that students face with physics self-paced learning. Three e-learning tutorials on introductory mechanics were used in the (DeVore et al, 2017) investigation. Each tutorial contained a quantitative problem that was broken down into a series of sub-problems to help students develop their problem-solving skills and improve their self-reliance. However, the self-paced learning tutorials remain challenging for students. This is why the SELF (Strategies for Engaged Learning Framework) (Marshman et al, 2018) was put in place to detect what are precisely the factors, be them internal and external factors, that influence the learning process and how they can be taken into consideration and implemented in the development of the self-paced learning tutorials, as well as using quantitative problems that are divided into sub-problems to further improve the efficacy of learning for students and enhance their understandings of physics principles.

• Adaptive feedback: Feedback is essential during physics problem-solving in an adaptive learning environment, where the three main knowledge components are usually treated in isolation. In (Bimba et al, 2018), these three components are portrayed in the form of models, using the OAR model (object, attribute, and relations): the pedagogical model that represents the technique and knowledge of teaching, domain model which constitutes the facts, rules, equations, feedback, and student model containing information about students learning style and their understanding of the domain. The relationships between these components are hard to illustrate using existing methods that can only represent the relationship between a pair of concepts. (Bimba et al, 2018) proposes a concept operator that can represent the relationships between multiple criteria and therefore represents the relationships between the three knowledge components.

• Learning management systems (LMS): Instructional methods (e.g., advice from a teacher or specific instructions) that are useful for novices in a given field may lose their efficacy or even be detrimental when applied to experts. This phenomenon which is often referred to as the Expertise Reversal Effect demonstrates how crucial it is to tailor the learning process to the needs of the learners, which in the case of (Imhof et al, 2018) are college students. Moreover, depending on the students' prior knowledge and their online activity, meaning the number of tasks solved daily, the LMS Moodle used for the physics module, otherwise known as the problem module in the 2015/16 and 2016/17 semesters of the Swiss Distance University of Applied Sciences (FFHS), implemented an adaptive task set combined with a simple recommender system that gives feedback to students according to the tasks they chose, either detailed step-by-step tasks or non-detailed tasks. The former ones performed well with low to medium prior knowledge students. The latter ones were sort of effective with high prior knowledge students even though they had less learning progress compared to other students.

In Russia, the Moodle course developed by the Elabuga Institute of Kazan (Volga region) Federal University (Shurygin & Krasnova, 2016) not only makes the teaching material available outside of the classroom but also indispensable in regards to the self-education and the self-development of students. The system also helps in monitoring students' online presence and provides real-time assistance through private messages with the teacher or through forums. Furthermore, within e-learning applications, especially blended learning (Krasnova & Shurygin, 2020), the LMS Moodle is an incredible tool that can be used in the design of refresher courses for teachers in general and physics teachers in particular.

• Remedial instruction system: Designed for senior high school physics instruction, the remedial instruction system's (Lin et al, 2009) learning material is presented in the form of units for different concepts, which are introduced to the learners one at a time so that they are not overburdened with information. The duration of each unit varies between 1 to 3 minutes and includes audio, graphics, text, and video. The learning material is also available anytime and anywhere. The remedial instruction system consists of a comprehensive tracking mechanism for documenting the participants' entire learning experience to gain a greater understanding of their learning process. In addition, when users log out, the system asks them to complete a real-time survey about whether the learning session helped them understand the subject, whether there were any unanswered questions, and so on. The efficacy of learning can be measured through the survey, and the results can be used to plan individualized remedial training to improve learning effectiveness. Both the framework's tracking mechanism and the survey were used to give an insight into the concepts students faced difficulties with and where they needed more help.

• The connection between mathematics and physics: Usually, e-learning websites must have an adequate hyperlink structure, which allows quick access to information and reference to documents spread around the internet using a search engine and a collection of keywords. Based on this approach, the Japanese Kanazawa Institute of Technology, in short KIT, developed different technologies for Mathematical Navigation KITMN and Physics Navigation KITPN in 2004 and 2016, respectively (Nishioka et al, 2018). Moreover, to enhance the learning performance of high schoolers, university students, and even engineers, KIT grants an effective learning environment of physics by providing the connection between mathematical and physical knowledge, as well as visualizing equations by using simulations. The concept behind these technologies was that one webpage should have one topic for optimal searchability; this way, visitors can browse the webpages from basic knowledge to advanced knowledge and thus deepen their understanding of physics and grasp its connection with mathematics. These frameworks were also evaluated (Kudo et al, 2018) based on access logs obtained from visitors who had consulted a KIT environment webpage at least once to draw out the browsing paths of visitors who were curious about the webpage's content. Furthermore, a cluster analysis was used to determine which topics were of interest to the website visitors based on the number of visits and the length of those visits.

• The evaluation process: MC (Multiple Choice) tests have questions with one correct answer and multiple incorrect distractors. However, CMR (Coupled-Multiple Response) test items have two parts: the usual MC part and a reasoning element which renders the students with the option of giving a justification for their answer. Some students may choose the correct answers for the wrong reasons; however, others may choose the wrong answer with the correct reasoning. (Rios et al, 2020) examines the reasoning patterns of students when taking an MC test that led them to choose incorrect, partially correct, and correct answers. The reasoning element of the CMR test items was proven very helpful in identifying which and where interventions are needed in the adaptive learning technology for learning physics.

4 CONCLUSIONS

E-learning tools are a great way to help students engage in self-paced learning outside the classroom. These tools enable them to access learning material anytime and anywhere. Students can also be given assignments online.

However, self-paced learning has its drawbacks as students can face a lack of motivation, their productivity can be affected by internal and external characteristics, which are easily identified using the SELF framework. Speaking of students, there are two types of learners: FI (field-independent), FD (field dependent), and two types of adaptive scaffolds, which play an essential part in the adaptive learning environment. Both hard scaffolds and soft scaffolds provide learners with the needed support at the different stages of problem-solving depending, of course, on their learning styles and their prior knowledge. Students may also struggle with the material that can be too complex for them to understand independently or due to their academic shortcomings in mathematics as they do not understand its connection with physics.

Moreover, one of the essential parts of the adaptive learning environments mentioned previously is adaptive feedback, which goes hand in hand with recommender systems, as a means to help students in their learning process to deepen their understanding of physics principles.

Future work will focus mainly on the use of recommender systems to develop an adaptive learning environment for teaching physics to high school students in Morocco.

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