Computer Simulation in Education: Using Learning Objects to Learn Physics Concepts

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Abstract. Using computer simulation to complement instruction is gaining popularity among educators around the world. Digital repositories (or Digital Libraries) have been developed to store large numbers of interactive digital educational resources that can be delivered on demand online. These digital educational resources, also called Learning Objects, offer a high level of interactivity to their users facilitating learning. A major move of educational institutions in a number of countries, including Australia, is to create a bigger pool of learning objects that can be made available to both teachers and students. Research indicates that the use of learning objects can be effective in teaching and learning in the enabling sciences such as Physics. This paper highlights how the use of learning objects impacts on students’ learning, especially in Physics where students are known to bring with them into the classroom a number of alternative conceptions resulting from their prior knowledge and experiences. Research studies have found that using conventional instruction techniques is not effective in dealing with students’ alternative conceptions, and especially in physics. Learning objects can be an effective tool in transforming students’ alternative conceptions and facilitate scientific understanding, provided they include three pedagogical steps: First, it should be able to introduce new concepts clearly and concisely. Second, it should address students’ alternative conceptions. Finally, it should provide a means in assessing students’ learning (diagnostics). A number of objects are reviewed to explore this pedagogical hierarchy. Diagnostics can be effectively achieved using a computer program called Adaptive Testing and Diagnostics System. The paper concludes with examining considerations for evaluation and improvement of Learning Objects, implementation for practice in the Physics classroom and future directions.

1. INTRODUCTION: DIGITAL TECHNOLOGY AND EDUCATION

Most of us would agree that technology, especially digital technology, has come a long way to where it is now. We have become very dependent on digital technology. We use it on almost anything imaginable – from basic household chores, to communicating, to entertainment. Many call this to be living in the “digital age”. We are ripping so many benefits from using digital technology, especially in the area of communication. The reason for this is obvious: the way we communicate with one another these days is so much more efficient and fast as compared to just a few decades ago. Digital technology has truly increased our global connectedness. As Hodgins (2004) points out:

One of the fundamental characteristics of innovations that have truly changed the world is that of connecting things, especially data and people. Trains, planes and automobiles; television, telecommunications, the Internet and the World Wide Web have each and all fundamentally altered our transaction space as well as the nature and diversity of our interactions. (p. 80)

Another area to which digital technology is applied is in education. Digital technology can easily be seen in classrooms in schools and universities. Typical manifestation of this is the use of desktop and laptop computers and data projectors in classroom and lecture halls, and interactive Smart Boards. More recent addition to this is the use of mobile phones or iPods® in interactive lecture theatres in universities. Not only does digital technology facilitate more efficient data and materials management in the classroom but also is now being used by both teachers and students to help facilitate learning, especially in the sciences. These digital resources used by teachers and students are in the form ranging from simple audio, video, or picture files, to interactive computer programs (or software) that are available as computer software packages in CD- or DVD-ROMs. These days, a more popular mode of delivery of these resources is through the Internet where they can be downloaded or streamed on demand. The immense growth of information and applications available through the Internet provide not only abundance of information for everybody but also provide online learning resources that could be used by students to possibly augment what they are trying to learn in the classroom. This is one of the reasons why the evolution and growth of information and communication technology (ICT) using digital technology is believed to have significant potential to dramatically impact educational practice (Ben et al., 2007). However, it should be noted that not all of the available online resources are “fit for academic consumption”. Users of online resources should be careful in choosing something only from reputable sources such as educational institutions or organizations. This leads to the growing demands for information literacy, that include the ability to search, locate, evaluate, manage, use and present can communicate information and to engage in problem solving, self directed learning, autonomous-targeted learning, and research skills fundamental to learning (Alagumalai, 2003, p. 1257). Thus, these resources...
should allow for multiple learning and educational opportunities.

Recent trends in research on digital technology in education show that educational institutions, such as universities, have focused on developing “educational digital libraries”. These are repositories of high quality educational online resources in recognition of their potential to transform education (Curriculum Corporation, 2002; Recker et al., 2004; Recker et al., 2006). These online resources are often called “learning objects”, which offer users a high level of interactivity to facilitate learning, especially in sciences such as physics. Alagumalai (2000) highlighted the learning opportunities presented by these objects and indicated that the objects themselves could provide tracking and monitoring information that could be used for diagnostics and remediation. Furthermore, Alagumalai & Larkin (2001) demonstrated the use of metadata, derived from carefully designed objects, to assist both learners and teachers to scaffold learning. Learning management systems, and a number of recent developments in tracking learning through assessment utilizes these metadata to optimize and value-add to learning.

Details about learning objects and some examples of learning objects initiatives are provided in the next section. This is followed by a brief discussion of the issues in physics education and how learning objects might impact students’ learning of physics concepts. Some examples of learning objects specifically designed for physics are also provided. The paper closes with the discussion of the future directions of using learning objects in classroom instruction.

2. LEARNING OBJECTS: WHAT ARE THEY?

In education, learning objects are often associated with interactive digital media developed using advanced multimedia authoring computer programs such as Adobe Flash™ and Java™. However, the term learning objects is still ambiguously defined that it creates confusion among educationalists as to what they really are. Wiley (2000) provides a popular, simple but broad definition: any digital resource that can be delivered across the network on demand be it large or small, which can be used to support learning. The IEEE Learning Technology Standards Committee suggests that learning objects can include multimedia content, instructional content, instructional software and software tools, learning objectives, persons, organizations, or events (Friesen, 2004). Moreover, knowledge element, learning resource and online materials (including interactive assignments, cases, models, virtual laboratory experiments, simulations, and other electronic resources for education and training) have also been used to mean learning objects (Vargo et al., 2003). Vargo et al. (2003), also added that a major eLearning provider (called NETg) defines a learning object as a resource consisting of three parts: a learning objective, a learning activity, and a learning assessment.

Polsani (2003) stressed that in addition to the definitions provided above; learning objects should consist of and provide for three functional characteristics. These are:

- Accessibility: learning objects should be tagged with metadata so that they can be stored and referenced in a database.
- Reusability: learning objects should function in different instructional contexts.
- Interoperability: learning objects should be independent of both the delivery media and knowledge management systems.
- Provision of metadata: learning objects should have tags to indicate relevant educational attributes to facilitate categorization and to generate learning markers (Alagumalai & Larkin, 2001).

The broad definitions presented above simply means anything can be a learning object. However, it is also clear that the term learning objects is biased towards interactive electronic digital media delivered through the use of computers and the Internet. For the purposes of this paper, learning objects pertain to the digital online resources (in the form of simulations) that have the potential to enhance learning. Simulations fall under the “interactive” type of learning objects based on elements from the IEEE Learning Object Metadata (LOM) standard (see Table 1, p. 2 of Vargo et al. (2003), for details of types of learning objects based on elements).

Recent learning objects initiatives that invested huge amounts of money include The Learning Federation (TLF) and Cyberinfrastructure for Education and Learning for the Future (CELF). TLF is a joint initiative of the Australian and New Zealand governments that aims to develop online interactive curriculum content designed for Australian and New Zealand schools. This initiative is delivered on behalf of the Australian Education Systems Officials Committee (AESOC) and is project managed by the Curriculum Corporation. In this project systems are being developed and tested to allow input and delivery of high quality curriculum online by a range of approved content developers to a designated set of specifications (more details can be found at www.thelearningfederation.com.au). A recent progress of TLF is the launching of Scootle (www.scootle.edu.au). Scootle provides over 7000 digital learning resources which include thousands of learning objects. Resources in Scootle are developed by TLF. Resources found in TLF and Scootle are essentially the same. The difference (and improvement) lies in the accessibility of the materials and some security features.

Another large-scale and challenging initiative in the United States to train adequate numbers of students for careers in science and technology, or to develop the scientific and technological literacies necessary for full participation in a democratic society, is the
Cyberinfrastructure for Education and Learning for the Future (CELF) (Computing Research Association, 2005). CELF is only part of a huge cyberinfrastructure being developed in the United States with the support of the country’s National Science Foundation (NSF) to cater to the training needs of different sectors such as education and the industry (see www.nsf.org for details). Although it is still in its proposal stage, CELF is envisioned to provide the following attributes (Computing Research Association, 2005, p. 1):

1. Unprecedented access to educational resources, mentors, experts, and online educational activities and virtual environments;
2. Timely, accurate assessment of student learning; and
3. A platform for large-scale research on education and the sciences of learning.

What CELF failed to provide, however, are details of how it would attract more students to become science educators which is what needed worldwide. Details on this issue are expounded further in the next section of this paper.

Learning objects in the form of interactive computer simulations have the potential to transform challenging and “boring” classroom science subjects, particularly physics. The following sections briefly describe issues confronting physics education, and how learning objects are being integrated and used in the physics classroom.

3. PHYSICS EDUCATION AND THE USE OF LEARNING OBJECTS

3.1 Issues in Physics Education

Many students have known physics, from high school to university levels, as a challenging and abstract subject. Some students see Physics as boring and irrelevant, especially considering its mathematics component that ranges from the most basic to the most advanced. Perhaps this is the reason why students view physics learning and understanding physics as merely memorizing a good chunk of formulas and just receiving and storing information (Toh & Alagumalai, 1994; Alagumalai & Toh, 1997; Langley & Eylon, 2006), and, therefore irrelevant. Researchers find this “feeling of irrelevance” as one of the reasons why students, especially those in high school, are veering away from studying physics (see, e.g., Labudde et al., 2000; Reid & Skryabina, 2002; Rodriguez and Zozakiewicz, 2004). Students moving away from studying physics raised a lot of concern from the science education community because of its implications in the society. This can become an even bigger concern if groups within a school cohort, for example girls, have an aversion towards physics (Toh & Alagumalai, 1994; Alagumalai & Toh, 1997).

The decline in the number of students participating in physics has been the focus of physics education researchers since the 1960s. Researchers argue that this decline will have significant negative economic impact since physics is at the heart of the technology that drives the economy (National Research Council, 2001). It is clear that the negative impact would be caused by shortages of staff and personnel in workplaces in need of someone who has qualifications in Physics, especially in science departments in schools and physics departments in universities. Particularly in the education sector of our society, we cannot afford to lose qualified science educators especially now that scientific literacy among people is heavily promoted. Therefore, it is important to keep the number of students choosing to study physics at a reasonably high and stable level.

A number of factors have been examined by science education researchers as to what might contribute to this decline in the participation of students in physics. Broadly, one of these factors is the effect of school. School effects cover a number of factors including teachers and their teaching and intervention strategies; the school’s learning environment, and curriculum. A plethora of research has been carried out to examine these school factors and their impact on the attitudes of students towards physics (see, e.g., Mazur, 1997; Zollman, 1997; Reid & Skryabina, 2002; Lorenzo et al., 2006). A “popular” school factor examined by science education researchers for many years was on teachers and their teaching strategies. Science teaching strategies has been linked to students’ declining interest and enrolments in physics (Palmer, 2008). Research reports indicate that science was typically taught in a traditional way: teacher-directed, students copying notes from the board, and students were never allowed to choose their own topic to investigate (see, e.g., Palmer, 2008). A proposed strategy uses inquiry-based teaching and learning of science where students get to investigate ideas and explanations about the real world (Rennie et al., 2001). However, a number of issues such as student safety and equipment costs could limit the potential of this strategy. This is where the use of digital technology becomes appealing, especially that digital resources for educational purposes abound these days.

3.2 Using Learning Objects to Enhance Learning in Physics

An area in which researchers are taking more interest in recent years is on the use of the digital form of information and communication technologies used in classroom education. Jargons such as “e-learning” or “online learning”, “virtual labs”, and “cyber-education” have recently been touted as popular terms used to signify gaining popularity of the application of the digital technology in education, particularly the Internet. According to Ben et al. (2007), a rapid growth in schools and institutions integrating the use of information technology in their planning, development and delivery of their curriculum in one way or another has been observed in recent years. This is because of
the consensus among educational researchers that the use of digital technology offer great potential in facilitating student learning. In addition, the integration of technology in school curricula can play a vital role in promoting public understanding of science. As Cajas (1999) asserts:

Technology, as curricular content, can play a connecting role between academic knowledge and students’ everyday lives, given the nature of pragmatic models on which technology is usually based. The introduction of this knowledge in general education has important implications for the ideal of public understanding of science. (p. 770)

Modern and progressive science curricula and media that will make a difference in the lives of all students are important at the beginning of the third millennium (Toh and Goh, 2003, p. 1254. In physics classrooms, educational simulations, in the form of web-based learning using learning objects are gaining popularity because of their usability, availability and accessibility. Examples of learning objects in the form of digital simulation used in the physics classrooms are the Interactive Physics by Design Simulation Technologies (www.design-simulation.com) and the various educational simulation softwares developed by Physics Curriculum & Instruction (www.physicscurriculum.com). Physics Curriculum & Instruction softwares come in a variety of titles ranging from the most fundamental physical science concepts to the most modern and advanced. These are pay softwares. However, learning objects for learning physics concepts are also available online for free. They have less features compared to the paid ones but can be as effective, especially that they use a research-based approach that supports student engagement with and understanding of scientific concepts. Good examples include physics simulations that can be found in the PhET Interactive Simulations website (http://phet.colorado.edu) developed by the University of Colorado at Boulder. Different screenshots are shown in Figure 1.

4. IMPACT OF LEARNING OBJECTS ON STUDENT LEARNING IN PHYSICS

It has been demonstrated in various research studies that traditional classroom instruction failed to improve student learning by failing to address students’ alternative conceptions in physics. These alternative conceptions (or misconceptions) about certain physical phenomena that students’ bring with them in the classroom are the result of their previous experiences (Ben et al., 2007). Using educational electronic simulations (either web-based or software-based) in the form of learning objects as complementary or alternative to other teaching tools could aid in transforming these alternative conceptions into scientific thinking (Jimoyiannis & Komis, 2001).

Learning is not about how much information can be stored and recalled, but how appropriate information can be retrieved quickly and utilized optimally and efficiently. Effective learning objects should enable the user to monitor effectively the cognitive and metacognitive processes of the learners, and most importantly make provisions for effective feedback during learnable moments (Alagumalai, 2003, p.1263). The metadata generated could identify concepts that may have been misunderstood or assimilated into the learner’s mental model. For example, in the projectile simulation, learner’s inputs could be gathered at timed intervals to examine whether there are gaps in understanding the underlying physics of trajectories. Similarly, the nexus between conceptual physics and the fundamental underlying mathematics can be illustrated in these objects. Users could extend their learning through presented problems, and the progress of understanding charted for gaps (Alagumalai, 2004).

However, the quality of teaching and learning in web-based learning has often been scrutinized by educationalists (Alagumalai, 2000). In the example above, it is implicit that the electronic or online resources must be developed very carefully to effectively facilitate learning and not cause students to develop any more alternative conceptions.
Furthermore, simulations, and practically all types of learning objects, should include the following three pedagogical steps to effectively provide means to facilitate learning. First, it should be able to introduce new concepts clearly and concisely. Second, it should address students’ alternative conceptions. And finally, it should provide a means in assessing students’ learning (diagnostics).

5. LEARNING OBJECTS AND THE ADAPTIVE TESTING SYSTEM

Alagumalai (2003, pp.1264-1264) highlighted that emerging information and communications technologies, including the utilization of learning objects, is NOT about en-mass education, but is about adaptive individualized support to learning and discovery. A number of applications developed by Alagumalai (1999 – 2006) that highlight adaptive testing have been extended to present learners with virtual facilitators by their side, negotiating and sustaining learning over time. Adaptive learning systems present dynamic simulations that allow high levels of interactions and reactivity. Reactivity, as operationalised by Alagumalai (2003, p.1264), refers to the proactive strategizing and activation of cognition, metacognition, and affects and attitudes. Thus, the learner’s use of the learning object at various stages and levels, can be sequenced and presented with each successful learning episodes, reflecting the processes utilized by adaptive testing algorithms.

Adaptive testing systems, unlike the traditional linear test systems that present all test items in one exposure through a pre-determined ordered sequence, present individual test items matched to the user’s level of performance or competence. A user is presented with an average-difficulty item or an item at a chosen difficulty level. Success at this initial item will be matched with being presented with a slightly more difficult item. However, if the user is unsuccessful at the initial item, a relatively easier item is presented. This process of matching success with a more difficult item and subsequent failure with an easier question continues till there is a plateau in the performance ‘curve’. The final ability of the student is the point where the difficulty of the plateau continues across a selected number of items.

This adaptive process works equally well in sequencing learning (Alagumalai, 2002, 2003; Morrison & Lowther, 2005). Newby et al., (2000) iterate that learning is effective when teaching is customized to the learner, and that current and emerging learning technologies have capabilities to empower learners. It is also acknowledged that certain certain conceptual understandings can have powerful transformative effect (Meyer and Land, 2006), and learning objects embedded in adaptive learning systems will provide insights into why certain students ‘get stuck’ and find difficulty in negotiating particular conceptual transitions, let alone understanding basic concepts.

Hence, designers of learning objects could make accessible through metadata the nature of the knowledge students will encounter in them using the objects, and what ability level is expected of the students in negotiating learning through the objects. For example, in the energy object, it is expected of the user to understand kinetic energy, gravitational potential energy and elastic potential energy, and their sum provides the overall energy. Students could be posed adaptively short ‘dip-stick’ questions to gauge their understanding of all ‘parts’ of the concept of energy before presenting the relational aspect of energy. As Mayer and Land (2006, p.xv) highlight, if knowledge is to have a transformative effect it probably should be troublesome, or at least troubling, but that does not mean it should be stressful or should provoke the kinds of anxiety, self-doubt and frustration that can lead students to give up. The interactivity of learning objects allows for this scaffolding of learning, and is superior to static texts and images presented in traditional textbooks (Alagumalai, 2004). Intelligent systems, and in particular adaptive learning and testing systems, provide the optimal interface for learning objects for both the delivery of instructions and for enhancing learning.

6. FUTURE DIRECTIONS

It is believed that systematic integration of information and communication technology in schools, universities and other learning institutions is the way forward (e.g., Burdett, 2003). More specifically, learning objects, in the form of simulations, are becoming more ‘visible’ in terms of their integration to the teaching and learning processes, especially in the physical sciences. However, many academics still resist or reject the use of ICT (Anderson et al., 1998, in Burdett, 2003) because of concerns of uncertainty of its worth as an alternative to traditional teaching methods. Still, the promise that a learning object provides to the teaching and learning processes should not be underestimated recognizing the suitability of this technology varies in different teaching contexts.

Traditionally, teachers reviewed and selected print materials for their students. Print information was scrutinized for misconcepts, appropriateness of layout and accuracy of graphics, figures, content and information. Although learning objects could overcome the limitations of print media, similar rigour in evaluation in the selection of learning objects and digital material, as had been exercised in textbook reviews, has to be exercised by teachers. This implies a thorough understanding of the content/knowledge within the objects, instructional design and human-computer interactions (Alagumalai, 2003, p. 1266).

In a modern society, everybody is aware that technology advances very quickly. Current trends show the potentials of hybridization; technologies converge to form new technologies and products, and so do concepts, communities, and professions (Hodgins,
Learning objects will be no exception. Not so long from now, we will be witnessing the emergence of a “new breed” of learning objects – more powerful and more interactive. However, the authors of this paper firmly believe that learning objects should always include the three pedagogical steps mentioned in the previous section for them to be effective and useable to enhance learning. In addition, for web-based (or electronic) learning objects to appeal to those who resist or reject the use of it, Burdett (2003) suggests taking note of three key issues:

• Firstly, user friendly technology must be assured, particularly for late adopters who are skeptical and less likely to tolerate system failure…Teachers and learners can ill afford to waste time sorting out technical problems and suffer frustrations and reduced confidence that detract from effective learning.
• Secondly, there should be adequate workload allowances for academics incorporating ICT in course design and delivery. Web-based teaching and learning is novel and still largely experimental. The adjustment of traditional pedagogies and the growth of technical expertise require time, time for preparation and evaluation, reflection and the acquisition of new skills.
• Thirdly, professional development and support must be timely and individualized. If delivered in a one-size-fits-all strategy that fails to acknowledge differences between academics, then activities aimed at progressing ICT adoption will miss their mark and continue to be resisted. Since students are the ultimate end-users of educational technology, it must be noted, however, that technology-based education is useless no matter how good it is if students are not motivated and responsible enough for their learning. Alagumalai (2000) pointed out:

…web-based (or technology-based) delivery requires motivated and responsible students who are ready and prepared to receive instructions for the purpose of learning. To be successful in web-based learning environment, students have to be independent learners.

The use of learning objects, and educational technology in general, in the teaching and learning processes opens up important research issues. If the innovative use of learning objects in teaching and learning continues to be a promising integration in education, especially in the hard sciences, then hurdles to its adoption and successful and consistent use must be addressed and supportive practices introduced.

Thus, innovations in these technologies, both objects and adaptive learning systems, need to examine the inputs and education of teachers. Pre-service teacher education and professional learning of teachers need to examine carefully how these important learning tools could complement their delivery of instructions. Moreover, emerging developments in these technologies present educators with an opportunity to shape and direct learning through a Community of Practice (Fleer & Jane, 2004). The time for object developers to have insights into instructional design and pedagogy, and for educators to appreciate the complexities associated with constructing and developing objects and learning systems needs stronger emphasis. We are at a time where learning can be highly self-directed; however, it must be acknowledged that efficient learning could occur if and only if that learning concepts and knowledge in physics is better understood before allowing processes to either promote learning or de-rail and de-motivate prospective champions of physics.

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