Design Principles for Simulations in Science Learning

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Abstract: Technology is becoming increasingly important in today’s classroom. Computer animations and simulations are the most commonly used technological tools for educational purposes. Simulations should be used easily by students, if not, students’ attention is focused on the use of simulation rather than on the exploration of scientific concepts. Therefore design principles are very important for students’ use of simulation and understanding of scientific concepts. Design principles are an attempt to capture consensus on design approach to make simulations easier to use and more effective to teach scientific concepts. There are many researches investigating various aspects of simulations. And some of them deal with the design issues in simulations. The purpose of this study is to examine, discuss and summarize the design principles for simulation in science learning covered in literature.

Key-Words: Simulation, design principles, science learning.

1 Introduction
It is indispensable for educational institutes and teachers to take advantage of technology in today’s classroom. Although technology and education are two different terms, using together bring into existence a new term, educational technology. Educational technology makes teaching and learning activities enjoyable. Thanks to the educational technology, students learn with playing, having fun and loving [1]. Computer aided instruction is the method that students can see their performance, control their learning with getting feedbacks, engage the lesson with graphics, sounds, animations and figures [2].

One of the applications of computer aided education is simulations. According to Wikipedia free encyclopedia, simulation is the imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected physical or abstract system. Simulation is used in many contexts, including the modeling of natural systems or human systems in order to gain insight into their functioning. A computer simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. In this study, the term, simulation, will be used in the place of computer simulation. Virtual reality is a similar term. But there is a little difference that it is used generally for the imitation of some imagined thing instead.

Students are generally supposed to visualize the complex processes in science learning. Simulation can provide audio-visual interactive virtual experiences about various environments, objects, phenomenons and processes without going out of class. For example, lightning accompanied by thunder is a complex process including lots of variables such as cloud, temperature, electric charge. A simulated learning environment for lightning can be created for students to understand the process and to interact with the process.

Simulation presents a great opportunity to concrete the abstract things and models. With simulation the learning of the abstract things and models can be simple and intuitive. Besides students learn by doing instead of reading and listening with simulations. This situation also supports the constructivism, a psychological theory of knowledge, which argues that humans generate knowledge and meaning from their experiences instead of acquiring knowledge passively.

Another concept about simulation based learning is motivation. According to Papert, learning is essentially hard; it happens best when one is deeply engaged in hard and challenging activities [3]. Therefore teachers need to motivate students to be engaged in activities [4]. Simulation has a great potential to support learning by motivating learners.

Effectiveness of computer aided instruction is substantially related with the quality of the courseware. While good quality software affects the student’s success positively, bad quality software can cause waste of time and getting undesired behaviors for students [5]. Therefore design principles are very important for
students’ use of simulations and understanding of scientific concepts. Design principles are an attempt to capture consensus on design approach to make simulations easier to use and more effective to teach scientific concepts. There are many researches investigating various aspects of simulations. Some of them deal with the design issues for simulations. The purpose of this study is to examine, discuss and summarize the design principles for simulation in science learning covered in literature.

2 Effectiveness of Simulations

In this part, researches dealing with the effectiveness of simulations are examined.

In the research performed by Finkelstein et al. the effects of substituting a computer simulation for real laboratory equipment was examined. Students who used the simulated equipment outperformed their counterparts both on a conceptual survey of the domain and in the coordinated tasks of assembling a real circuit and describing how it worked [6].

In the research performed by Zacharia and Constantiniou, they compared the effect of experimenting with physical or virtual manipulatives on undergraduate students’ conceptual understanding of heat and temperature. As a result, it was appeared that both modes of experimentation are equally effective in enhancing students’ conceptual understanding. Therefore the nature of experimentation and the learning outcomes do not change substantially when physical manipulatives are substituted by virtual manipulatives [7].

Zacharia and Anderson investigated the effects of interactive computer-based simulations which are presented prior to inquiry-based laboratory experiments on students’ conceptual understanding of mechanics, waves/ optics, and thermal physics. Their results indicated that the use of the simulations improved the students’ ability to make acceptable predictions and explanations of the phenomena in the experiments. The use of simulations also fostered a significant conceptual change in the physics content areas that were studied [8].

Computer simulations and laboratory activities have been traditionally treated as substitute or competing methods in science teaching. The aim of two study performed by Jaakkola and Nurmi [9] and Zacharia [10] was to investigate if it would be more beneficial to combine simulation and laboratory activities than to use them separately in teaching the concepts of simple electricity. The results showed that the simulation–laboratory combination environment led to statistically greater learning gains than the use of either simulation or laboratory activities alone, and it also promoted students’ conceptual understanding most efficiently.

3 Design Principles for Simulations

Success of a simulation mostly depends on its quality. In this part, design principles for simulations are examined according to the literature.

Because it is important how people acquire and construct knowledge and skills, designers should design simulations by considering the individual differences and cognitive structures of learners who will use simulations. Besides designers should design the simulation environment which does not distract but ease learning. According to Kurubacak, audio visual tools don’t provide effective learning and teaching experiences alone [11]. The important thing is that the audio visual tools in a multimedia application should be use according to certain principles. These principles enable students to comprehend multimedia instructional messages effectively. In literature, there are various researches dealing with the design issues of simulation and multimedia. Because simulation is a multimedia eventually, design principles for multimedia can be applicable to simulation design. Therefore the subject of design principles for multimedia are mentioned here briefly.

Clark and Mayer [12] introduced basic multimedia design principles according to their experimental researches. These principles are multimedia principle, contiguity principle, coherence principle, modality principle, redundancy principle, personalization principle, practice principle, worked example principle, and learner control principle.

These principles are actually based on cognitive theory. According to cognitive theory, there are several key ideas that explain learning:

- Human memory has two channels for processing information: visual and auditory.
- Human memory has a limited capacity for processing information.
- Learning occurs by active processing in the memory system.
- New knowledge and skills must be retrieved from long term memory for transfer to the jobs.

Multimedia principle: e-learning courses should include both words (text printed on screen or narration) and graphics (drawings, charts, graphs, maps, photos, animations, video and so on) rather than words alone. Simulations are mostly graphical because of its nature. In addition, concepts, objects and processes, which students are supposed to interact with, are visualized and concretized in simulations.

Contiguity principle: corresponding graphics and printed words should be placed near each other on the screen (that is, contiguous in space). Besides students learn better when words (narration) and graphics are
presented at the same time instead of one after another (that is, contiguous in time). This principle should be taken into account in simulation design.

Coherence principle: extraneous sounds (background music or environmental sounds), pictures and words should be avoided. Because this extraneous information can interfere learning in three ways: distraction (guiding learners’ limited attention towards irrelevant material), disruption (preventing the learner from building appropriate links among pieces of relevant material) and seduction (priming inappropriate existing knowledge). Unnecessary things should not be used in simulation too.

Modality principle: words should be put in spoken form rather than printed form whenever the graphics or animation is the focus of the words and both are presented simultaneously. Therefore it is useful to limit the text use as far as possible according to this principle in simulations.

Redundancy principle: e-learning courses, that contain redundant on-screen text presented at the same time as on-screen graphics, should be avoided. Besides e-learning courses, that contain redundant on-screen text presented at the same time as narration, should be avoided. Briefly same information should not be repeated in different forms in multimedia presentations.

Personalization principle: spoken or printed text should be conversational rather than formal. Narration use can be needed in some parts of simulations. It can be appropriate to use conversational style for narrations in simulations. Personalized speech is also an important component in animated pedagogical agents developed as onscreen tutors in educational programs. Pedagogical agents are onscreen characters who help guide the learning process during an e-learning episode. Pedagogical agent can be a cartoon character. It is wrong to use a real picture or animation as a pedagogical agent because of the details in them which can distract learner’s limited attention towards irrelevant details. Pedagogical agents can be used in simulations effectively and they can guide and lead learners.

Practice principle: more practice questions should be interspersed throughout the lesson. Learners should be trained to provide their own questions when they are studying from receptive materials.

Worked example principle: practice problems should be replaced with worked examples. A worked example is a step by step demonstration of how to perform a job-realistic task or solve a job-realistic problem. Therefore learners can learn how an expert solves a problem logically and can use a similar step by step technique to solve his/her own problems.

Learner control principle: learner control for learners should be included when learner has high prior knowledge or high meta-cognitive skills. Important instructional event should be the default navigation option. Advisements can also be added to learner control.

Principles developed by Clark and Mayer [12] are obviously applicable to simulation design process, because simulation is a kind of multimedia.

Adam et al. wrote two articles which try to find out the design principles for simulations according to the researches they performed [13; 14]. These articles are “A study of educational simulations Part I – Engagement and Learning” and “A study of educational simulations Part II – Interface Design”. In these researches, simulation use of students was investigated in a large scale with more than 200 interviews of 89 different students covering 52 simulations developed for PhET project (phet.colorado.edu) for over three years. According to these researches, various design principles for simulations was found out and tested. These design principles for simulation are described briefly in the following:

- Simulations can be highly engaging and educationally effective, but only if the student’s interaction with the simulation is directed by the student’s own questioning.
- The desired curiosity is encouraged by relating to the real world and using suitable animation and interactivity.
- Clear goals are important for motivation.
- Students notice animated features first, but when only observing and not interacting, students do not ask questions or make new connections.
- Interaction is a valuable parameter. Students engage in exploration and sense-making only after they begin to interact with the simulation.
- Student control over simulation should be limited carefully. It is useful to allow only relevant parameters to be adjusted by students.
- Disabling controls for non-physical reasons can lead students to incorrect ideas because students attribute meaning to the ability to manipulate controls. Therefore hiding controls is useful rather than disabling or graying out them.
- Little puzzles and clues can encourage students to explore the simulation.
- When students encounter small features that they do not understand, they will explore how interacting with that feature changes the simulation until they can create a working definition of the feature.
- Legends and control labels help students build connections, and then when they interact with the simulation, they learn a working definition of the term on the label.
- Simulations that have multiple views of the same item, such as beam view and photon view,
facilitate further understanding and connections about the idea.

- Exploration is not always productive. Elements that distract students’ exploration in irrelevant directions must be avoided.
- When the simulations are fun, students enjoy playing with them. But every feature adds to a student’s cognitive load and so needs to have educational purposes.
- When simulations look boring or intimidating, students are not drawn to playing or they are afraid they will break them.
- Features can be so much fun to play with that students are distracted from learning. There is a fine line between a fun simulation that stimulates learning and fun features of a simulation that distract the student from learning.
- For engaged exploration to occur, students must believe the simulation.
- Students’ level of skepticism is related to their level in school.
- Students who do not believe they already know the relevant ideas, are more likely to explore a simulation and use it to learn. Students who think they should understand the topic of a simulation often use it much less effectively and learn much less from it (performance mode).
- When in engaged exploration, students are actively working to make sense of the information.
- Adding interesting but unnecessary material to simulations can harm the learning (coherence principles).
- Users’ interpretation and use of simulations depends heavily on their prior experiences (Consistency).
- There are three different levels of usability in simulations: non-intuitive (difficult to use even with instruction), semi-intuitive (easy to use after instruction and demonstration), and intuitive (easy to use with no instruction). If simulation controls are difficult to master, students’ attention is focused on the use of the simulation rather than on the exploration of scientific concepts.
- Click and drag is the most natural motion for students. Students try to move anything that looks useful.
- Students are familiar with the functionality of radio buttons and sliders.
- Students turn things on with a checkbox but seldom turn things off.

- Users, who used similar simulations before, have little difficulty immediately interacting with a new simulation.
- Experienced users “know” what something should look like. If the appearance does not match their expectations, it makes it considerably harder for them to figure out what it is.
- To encourage exploration, simulations should start up with very little or no animation.
- Cartoon-like features are an effective way to emphasize important features while avoiding misleading literal interpretations.
- Students look at all visual cues equally, if they do not understand a concept. It is important to emphasize items that are pedagogically important and eliminate all potential distractions. Color is an important visual cue.
- When an object is represented differently from simulation to simulation, students perceive it as two different objects.
- Students only read text that is attached to a control. Abbreviations are not understood by most students. Text strings of one to three words work best.
- The play area must be distinct from the control panel in look and functionality. Objects in the play area are grabble and animated.
- When too many tools are in the play area, the control panel is overlooked. Text is a distraction in the play area.
- Students notice large, bright tabs. When tabs are small and professional looking, they go unnoticed.
- In a good simulation, explanation is not necessary to stimulate learning.
- When the most important object in the play area is not obviously grabbable, a wiggle-me is useful for telling the user where to start. The wiggle-me should draw attention to itself; however, it should not distract the user from the rest of the simulation.

According to Couture, many characteristics of the simulation environment resulting from the application of the realism principle contributed to its verisimilitude and (or) its credibility [15].

According to Rieber et al., it is useful for adults to interact and learn from an interactive computer-based simulation supplemented with brief multimedia explanations of the content. These brief multimedia explanations should be placed into the simulations according to the cognitive load theory [16].
4 Conclusion
In this study, various researches dealing with the simulation use and design issues in science learning were examined. Simulation design issues especially related to the science course are considered.

According to the literature, simulations can take an important role in science learning. Simulations enable students to perform and monitor real science experiments virtually on computer screen. Simulations are useful especially for the experiments which are expensive, dangerous and hard to perform in laboratory environment. Besides simulations can also be used effectively for performing normal science laboratory experiments virtually, because the success level of students who use simulation is the same or even higher than the success level of students who use real science laboratory equipments [6; 7].

One of the most important features of a simulation that affect its effectiveness as a learning tool is its quality. It is appeared that there are some principles that affect the quality of a simulation. It is very important to design and develop a simulation according to the principles revealed in previous researches to make sure of its quality.

References: