Chapter 12
Progress since 1978

Introduction

The work of Arnold B. Arons, Robert Karplus and Jean Piaget, which forms the basis for the first eleven chapters of this book, was the foundation for the development of research in the physics education community. Arons and Karplus were prominent research physicists who turned their professional attention to problems in science education. Their work led to the acceptance of research in physics education by several university physics departments where PhDs in research in physics education became acceptable. This is in contrast to several other disciplines where the study of how to learn a particular subject was largely ignored by the content professionals and left to researchers in colleges of education to examine. The reverse tends to be true in physics, the wide array of results from physics education research done in physics departments is largely ignored by educational research professionals in colleges of education.

The strong interest of Arons and Karplus in the intellectual development of students led to detailed studies of students' misconceptions as well as attempts to measure students' conceptual learning. The attempts to put these ideas into practice in science classrooms lead to a variety of interactive engagement learning strategies. In this chapter we are going to focus our attention on these two different trends in the research in physics education movement. We believe they are broadly applicable to the other disciplines in higher education. First we will discuss recent work in conceptual learning and its basis in cognitive science and physics education research. Second, we will turn our attention to a variety on approaches to interactive learning with special emphasis on the use of computers and educational games.

Conceptual Learning

Physics Education Group: University of Washington

In the years since the original Physics Teaching and the Development of Reasoning workshop, a number of studies and teaching methods have built on the basic notions of the ***Learning Cycle***, learner's construction of knowledge, and the importance of conceptual knowledge. Notable among these is the work by the Physics Education Group (PEG) at the University of Washington. Under the direction of Lillian McDermott PEG has investigated the student as a learner since 1973. Housed in the Department of Physics PEG is one of the first disciplined-based education research programs (McDermott, 2001). This work focuses on student understanding of physics, rather than general educational theory or methods. This work has identified many misconceptions held by physics students and the ineffectiveness of standard lecture methods (teaching by telling). In case after case, PEG has found that students in traditional physics courses perform no better after the course on qualitative questions then they had before the course. In other words, while they may have been able to solve mathematical physics problems, they did not understand the underlying physical concepts.

These revelations led to two major curriculum development projects: *Physics by Inquiry* and *Tutorials in Introductory Physics.* In parallel to the ***Learning Cycle***, *Physics by Inquiry* creates learning experiences that seek to elicit student preconceptions by creating a situation where known, common errors are exposed (Exploration); after students recognize the inadequacy of their existing models, they are lead through the reasoning needed to resolve their models (Invention); and finally students are given the opportunity to apply and generalize their newly acquired knowledge (Application).

The PEG describes features and effectiveness of *Physics by Inquiry* through its structure causing students to go:

"…step-by-step through the reasoning needed to overcome conceptual hurdles and build a consistent coherent framework. There are also other features that we think are important. Collaborative learning and peer instruction are integrated into PbI. Students work with partners and in larger groups. Guided by the questions and exercises, they conduct open-ended explorations, perform simple experiments, discuss their findings, compare their interpretations, and collaborate in constructing qualitative models that can help them account for observations and make predictions. Great stress is placed on explanations of reasoning, both orally and in writing. The instructor does not lecture but poses questions that motivate students to think critically about the material. The appropriate response to most questions by students is not a direct answer but a question to help them arrive at their own answers." (McDermott, 2001)

Force Concept Inventory and Modeling Instruction

Another effort to identify student understanding and misunderstanding of physics is the Force Concept Inventory (FCI). The FCI creates a taxonomy of misconceptions like students' failure to discriminate between position and velocity or between velocity and acceleration and acceleration implies increasing force.

Hestenes states:

"…it has been established that (1) commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects, (2) conventional physics instruction produces little change in these beliefs, and (3) this result is independent of the instructor and the mode of instruction …students have evidently not learned the most basic Newtonian concepts… They have been forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks." (Hestenes, 1992)

In overcoming the limitations of traditional instruction Hestenes has developed "Modeling Instruction" Modeling instruction aims:

"…to organize course content around *scientific models* as coherent units of structured knowledge; to engage students in *making and using models* to describe, explain, predict, design, and control physical phenomena; to involve students in *using computers as scientific* tools for collecting, organizing, analyzing, visualizing , and modeling real data; [and] to *assess student understanding* in more meaningful ways…" (Hestenes, 1987; Jackson, 2008)

In a parallel to the ***Learning Cycle***, Modeling Instruction is based on phases. The first phase is model development demonstrations and discussions (Exploration). During the second phase students form a model of the phenomena under investigation (Invention). In the model deployment phase students apply their newly discovered model to new situations (Application). Like the ***Learning Cycle***, Modeling Instruction changes the role of the teacher from provider of knowledge to that of a facilitator, guiding students to construct their own knowledge. And like Piagetian theory, Modeling Instruction is based on the belief that students' concept misunderstandings are due to 'filtering' new experiences through existing mental structures.

Investigative Science Learning Environment

Investigative Science Learning Environment (*ISLE*), is a teaching method

"…that helps students learn physics by engaging in processes that mirror the activities of physicists when they construct and apply knowledge. These processes involve observing, finding patterns, building and testing explanations of the patterns, and using multiple representations to reason about physical phenomena.

One feature involves students' development of their own ideas by

(a) observing phenomena and looking for patterns,

(b) developing explanations for these patterns,

(c) using these explanations to make predictions about the outcomes of testing experiments,

(d) deciding if the outcomes of the testing experiments are consistent with the predictions, and

(e) revising the explanations if necessary.

Another key feature is encouraging students to represent physical processes in multiple ways, thus helping them develop productive representations for qualitative reasoning and for problem solving." (Etkina, 2007)

Again, in parallel to the ***Learning Cycle*** ISLE has three main phases, *Observational experiment; Testing experiment,* and *Application Experiment*. In the *Observational experiment*, students do just what the name applies, observe a new phenomena. Subsequently, students create

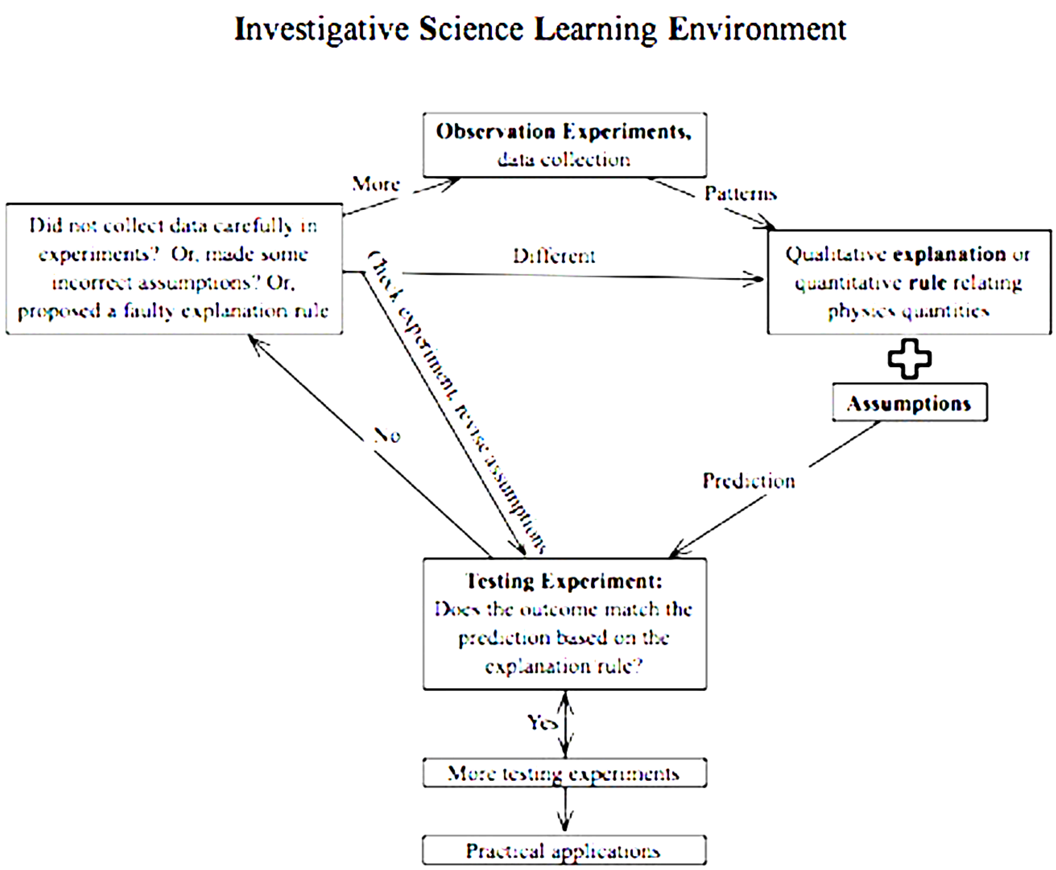

Figure 12-1. The ISLE Cycle

explanations of the phenomena (Exploration). During the *Testing experiment*, students conduct an experiment to see if their theory is correct (Invention). Finally, the *Application experiment* extends the theory to new areas (Application). (Etkina, 2002).

ISLE's parallels to the ***Learning Cycle*** become even more apparent when Etkina explains its key features in terms of a constructivist approach to cognition:

• "Students are not told about physics concepts but construct them actively.

• Observational experiments that start every conceptual cycle are chosen in a way that students are able to describe them in their own words, thus connect-ing them to prior knowledge.

• Students use their prior knowledge to generate explanations for observed phenomena.

• Students undergo conceptual change when they design and conduct testing experiments for their explanations and when they use new ideas to explain real-life phenomena" (Etkina, 2007)."

Studio Physics

The success of the ***Learning Cycle*** and similar models cannot be attributed just to the small size of classes or working in small groups. Rensselaer Polytechnic Institute (RPI) instituted Studio Physics.

A studio environment is one where:

"The defining characteristics of Studio Physics are integrated lecture/laboratory sessions, small classes of 30–45 students, extensive use of computers, collaborative group work, and a high level of faculty–student interaction. Each section of the course is led by a professor or experienced instructor, with help from one or two teaching assistants. The teaching assistants' roles are to circulate throughout the classroom while the students are engaged in group work." (Cummings, 1999)

Two years later conceptual learning in Studio Physics students was measured with the *Force Concept Index*. It was found that the students in the Studio Physics format scored no better than in the large lecture classes. On the surface Studio Physics classes are highly interactive and students appear to be engaged in learning.

Subsequently, theory based techniques from the physics education community were introduced the Studio Physics instruction. One in particular has the hallmark of the *Learning Cycle*: Interactive Lecture Demonstrations ILD's incorporate microcomputer-based laboratories (MBL) and were designed to be an active learning experience. In an Interactive Lecture Demonstration:

1. The instructor describes and performs the demonstration without the use of MBL tools.

2. Students record their names and individual prediction on a *Prediction Sheet* that is to be collected at the end of the demonstration period.

3. Students engage in small group discussion about these predictions.

4. Students make any desired changes to their predictions on the prediction sheet.

5. The instructor elicits common student predictions from the class.

6. The instructor performs the demonstration with MBL tools which allow the data to be displayed to the entire class. Attention is called to the most important features of the graphs, and how they relate to the physical situation.

7. Students record and discuss the results.

8. The instructor discusses analogous physical situations. (Cummings, *ibid*)

In a formal study it was found that the:

"…introduction of research-based techniques and activities does have clear beneficial effects. Interactive Lecture Demonstrations generated significant gains in conceptual understanding with remarkably little instructional time." (Cummings, *ibid*)

Cognitive Studies' Impact on Physics Teaching

In the early 1990's Edward Redish described 'cognitive studies' as opposed to cognitive science feeling that,

"…little in cognitive science satisfies the scientific criteria we are used to in physics of being precisely stated and well-tested experimentally, as well as useful." (Redish, 1994)

Cognitive studies was an apt term at the time. And although the discipline of cognitive science has advanced in the ensuing years, cognitive studies still describes much of the field. This is not to disparage the field or minimize its influence on our understanding of student learning. It is more to remind us that cognition and learning are not rooted in formal logic. Rather thinking is fuzzy and often inconsistent, ill-formed, contradictory models are often simultaneously maintained by individuals.

After reflecting on numerous cognitive studies by researchers including Arons, Inhelder, and Piaget, Redish identified four broad principles:

1 .The Construction Principle

2. The Assimilation Principle

3. The Accommodation Principle

4. The Individuality Principle (Redish, 1994)

The Construction Principle states that people organize their experiences into mental models. Mental models may be made up of images, rules, procedures. There may be contradictory and incomplete elements. There are no well-defined boundaries between model elements, which means different, but similar models may get confused. Finally, models function to minimize mental effort. This frequently causes people to go to considerable lengths to fit experiences into their existing mental models.

The Assimilation Principle states that it is easy to learn something that closely matches or expands existing mental models. Conversely, it is difficult to learn something for which we do not have an existing, closely related mental model. This means, new information should be put in the context familiar to the learner. In communications studies this is called the "given-new principle" and implies that much learning is done by analogy.

The Accommodation Principle states that it is difficult to change existing mental models significantly, yet for learning to take place, changes to mental models must occur. In order to change a mental model, predictions based on the existing mental model are in strong conflict with new experience and the new, replacement model must be understandable, plausible, and useful. (Posner, 1982)

The Individuality Principle states that each individual creates his or her personal mental 'ecology'. Therefore, different students have different mental models for physical phenomena as well as different models for learning. This implies that there is no best way to teach a concept and our own experiences cannot tell us what to do for others. Further, it suggests that the goal of teaching is to have students build proper mental models that are coherent, organized and accessible.

Interactive Learning

"I believe that the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks." Thomas Edison, 1922

"At the time of its creation more than 50 years ago, instructional television (ITV) was regarded as a means of increasing the quality of teaching by replacing the traditional classroom teacher." (Hendry, 2001)

So much for predictions. Still, there are technologies that are disruptive. That is, the make major changes in business and society. Personal computers have been available since the mid-70's. But it was not until the Internet reached the home that that the impact of information technology was transformative. Newspapers are closing as more and more people get there news from alternative sources like the Intern. Wikipedia has been shown to be as reliable as a professional written encyclopedia. Social networks like Facebook transform personal communications.

These changes are possible because the vast majority of homes have a computer and broadband Internet. Until every student has their own computer in their classroom, in-school education will not see the same impact. Undoubtedly, that day will come. If you consider smart phones, which contain microprocessors, that day is almost here. Certainly computers and the Internet have transformed how students learn and do homework and research at home. Some would argue, not necessarily for the better. Nonetheless, this is one genie that will not return to the bottle.

Games as Entertainment

A recent study found that 97 percent of American youth play video games (Lenhart, 2008). The study used a nationally representative sample of 1,102 young people, ages 12 to 17, and their parents, finding 99 percent of boys and 94 percent of girls play video games, with little difference in the percentages among various racial and ethnic groups and incomes. A recent article on designing games (vonAhn, 2008) notes with citations that more than 200 million hours are spent each day playing computer and video games in the U.S., and that by age 21, the average American will have spent more than 10,000 hours playing such games. Games are clearly entertaining as judged by their use, but what if they had educational benefits?

While studies have shown that through exploring some virtual worlds children develop scientific methods (Steinkuehler 2008), few would argue that American youth learn science from their game play. Here we focuses not on general computer and video games, but on educational games, and for this we turn to a theory of intrinsically motivating instruction based on a rigorous study of educational computer games by Thomas Malone (Malone, 1981). The foundation for Malone's work was Piaget's theories of how learners construct knowledge. His work and much recent work (Gee, 2003, Squire, 2004, Aldrich, 2004) has shown learning and fun are far from mutually exclusive. As Marshall McLuhan famously said:

"Those who draw a distinction between education and entertainment don't know the first thing about either."

Educational Games

There have been a number of studies on the role of visual fidelity in computer-based systems on learning. More than twenty years ago, it was shown that with added realism in a simulated experimental device, students improved in their physics learning (Stevens, 1985). Visual fidelity and frame rate were shown to both increase retention and create a more positive attitude about the subject being studied by students (Christel, 1994). In this study, students presented with higher frame rate video actually retained more facts. More recently, a 3D virtual world was built with a commercial game engine for elementary students to explore ecological environments. A study of fourth grade students found that visual fidelity and navigational freedom had beneficial effects on learning, activity in-situ, and emotional reactions (Harrington, 2006).

Like the difference between viewing images of a film one at a time and seeing them presented at 24 frames per second, there is a threshold where the experience is fundamentally different. These studies have shown that subtle, not consciously perceived differences affect learning. Unfortunately, most developers assume that visual fidelity and frame rate have little effect on user experiences and certainly none on learning. These assumptions, along with the complexity of creating 3D environments, have led to the development of 2D simulations that are often low in resolution, frame rates, and fidelity having unintended, negative consequences for learners.

Here we ask:

What makes games fun?

Can physics games be fun?

How can purpose be designed into games?

Can games have an educational purpose?

How can interest, engagement, and creativity across a diverse audience of male and female users be stimulated with respect to new concepts?

Games with a Purpose

In the context of physics instruction, the recognition that teenagers were devoting significant time to arcade games for entertainment, and that the appeal of games could be leveraged for better multimedia physics instruction (at the time, computer-controlled videodiscs), dates back to early 1980s work by Robert Fuller and Dean Zollman (Fuller, 1985). Fuller noted the popularity of the first videodisc arcade game “Dragon’s Lair” and reflected that students interactively learn through such games while physics instruction has traditionally been locked into a batch, lecture-based mode. In the 1980s the University of Nebraska Computer Learning Experiment began applying Malone’s theory of intrinsically motivating instruction to physics simulations. The first such game was so successful that from then on the project created no computer-based materials in any format other than a game (Fuller, 1985), and went on to win the First National EdGame Challenge with *The Benjamin Franklin Computer Game of Electric Charges and Fields* (Fuller, 1983). Considering the success of these games and interactive videodiscs, it may seem surprising how little has been done in the intervening years. Much of this early work was funded by the NSF and other foundations and was quite costly, while publishers have little economic incentive to create educational games. And to date they are very difficult to develop.

A Theory of Educational Games

Experiences that are fun/captivating fall into two broad categories. Those that use a story and those that do not. They are different things that are designed differently.

Entertainment experiences that do not require a traditional story may be purely fun, video games, or they may have a learning component, Oregon Trail type games. On the other hand, story has been part of human culture for thousands of years. The combination of game mechanics and story in support of learning is creating powerful learning environments in all disciplines.

Malone's work in educational computing looked at what makes games so captivating. His research identified a number of motivating factors including challenge (goals with uncertain outcomes), curiosity (sensory and cognitive), and fantasies (especially intrinsic fantasies where the fantasy depends crucially on the task). Fuller described Malone's theory and how it could be applied to the development of educational physics games (Fuller, 1985).

Challenge

An educational game is challenging if it provides a goal that is uncertain to attain. A good goal is one the learner can personally identify with, is obvious, and easily understood. The educational game must provide performance feedback so learners know how well they are doing in attaining the goals of the experience.

Uncertainty can derive from several factors. Levels of difficulty is one factor. A higher-level goal can depend on the successful completion of a lower-level goal. It can also depend on the performance in the lower level goal, i.e., how fast it was completed or how few errors were made. In an educational game, the difficulty of levels can be automatically determined based on past performance, chosen by the learners to match their perceived abilities, or determined by the skill of an opponent. Also, uncertain goals can be achieved by hiding information from learners, which is something that provokes curiosity. Randomness has also been shown to heighten interest.

Challenge can be generated by playing against an opponent, either the computer or another student. It can be as simple as who completes a task first, or as complex as requiring cooperative problem solving. Challenge is captivating because it engages the learner's self-esteem. Success in challenging educational experiences makes students feel better about themselves and motivates them to take on further educational challenges.

Curiosity

Malone showed that learning environments evoke curiosity by providing an optimal level of complex information. The experience should be novel and surprising while still within the abilities of the learner. The experience should not be too complicated nor too simple with respect to the learner's existing knowledge. Cognitive curiosity stems from the desire to bring one's knowledge structures in line with experience. Learners want their knowledge to be complete, consistent, and parsimonious.

This suggests that educational games that reveal the learners' knowledge to be incomplete, inconsistent, or confused will engage their curiosity. In an optimally complex educational game, a learner will know enough to have expectations about what will occur, but where these expectations are sometimes not met. Thus, an educational game should sometimes be surprising but also constructive in helping the learner remove the misconceptions that caused them to be surprised in the first place.

Sensory curiosity involves the attention-attracting value of changes in light, sound, or other sensory stimuli. Educational games provide a myriad of possible visual and auditory sensory provoking effects that can be used to enhance the fantasy, as a reward, and as a representation system that may be more effective than words. With new input devices in consumer game consoles haptic and kinesthetic sensory curiosity can be added to computer learning experiences.

Fantasy

Learning experiences can be made more fun and interesting through the use of fantasy. Physics education already uses fantasies such as frictionless surfaces and point particles, but these are not fantasies that evoke students' interest. An easy way to increase the fun of learning is to overlay a fantasy on an existing lesson. The fantasy should cause the learner to progress toward a goal or avoid a catastrophe. An *extrinsic fantasy* is where the fantasy depends on the skill but not vice versa. For example, in the classic game "Hangman" the fantasy could just as easily be used to teach arithmetic as it is for spelling problems, so this classic game makes use of extrinsic fantasy.

In the best design, the fantasy depends on the knowledge being used and new knowledge grows from the fantasy. Malone called such a model *intrinsic fantasy*. Here the fantasy not only depends on the skill, but the skill relies on the fantasy. This means that problems are presented in terms of fantasy-world elements and learners receive a natural, constructive feedback. Malone showed that intrinsic fantasies add beneficial cognitive and emotional aspects to learning and help students apply old knowledge to new situations.

The vivid images of a fantasy world can help students remember what they have learned while satisfying some emotional needs. For example, what is more likely to motivate and interest a student: a bare vector addition numeric problem or a game of finding buried treasure that happens to need the use of vector addition?

As another example, when studying electric fields typically students are given the location and size of electric charges and asked to calculate the field at some other point. Fuller turned this into an intrinsic fantasy game where the task is to search for hidden charges in a cloud (Fuller 1985). The student becomes Ben Franklin and places a kite in the sky to try and find hidden charges. The game computes the field and displays it as an arrow with numerical values at the bottom of the screen. Unfortunately for Ben, a high force destroys his kite and he must buy a new one. Fortunately, he gets paid a sum of money from a local physicist for every charge he correctly identifies as to sign and magnitude. Formal studies of the game showed that students found the game exceptionally enjoyable, spending up to two hours to complete the game.

Fuller noted that space adventures are excellent fantasies for physics problems. Students have grown up with Star Trek and Star Wars, easily imaging zero gravity, zero resistance environments. Even an experiment that investigates density lends lends itself to a space fantasy, shown in Figure 12-2 as described in (Fuller, 1985):

The Planet Puzzle (from Fuller, 1985)

A starship visited four planets in the Greekon system where they collected representative samples of material from each planet. The samples were cut into rectangular parallelepipeds and covered with a protective coating. Unfortunately, proper codes were not placed on the samples.

You are given a sack containing 13 of these samples. Without damaging the coating, separate these samples into four classes which you think represent the material of each planet.

What are the properties that you can use to classify them?

Figure 12-2. Example of space fantasy to motivate physics problem solving.

The fantasies in educational games should also respect *Theatrical Convention* and *Aesthetic Distance:* the unwritten contract between audience member and actor, that allows the audience to ‘bridge the gap’ between their physical location and the actual happenings upon the stage, in the film, or in the educational game. The audience will accept that Cleopatra is speaking English, but not that she would use a cell phone.

When Harder is Better

Laboratories have been defined as contrived learning experiences in which students interact with materials to observe phenomena (Hofstein, 1982). In the educational videodisc, The Puzzle of the Tacoma Narrows Bridge Collapse a laboratory experiment in the physics of standing waves on strings is simulated. Students are to observe phenomena related to standing waves. In addition they are to manipulate variables affecting the phenomena under study and use the data collected to deduce relationships between the variables. How students manipulate the variables in order to separate and control them is central to formal thinking.

In the traditional laboratory students use an electric vibrator, various strings, and a set of weights to test study standing waves (see Figure 12-3).

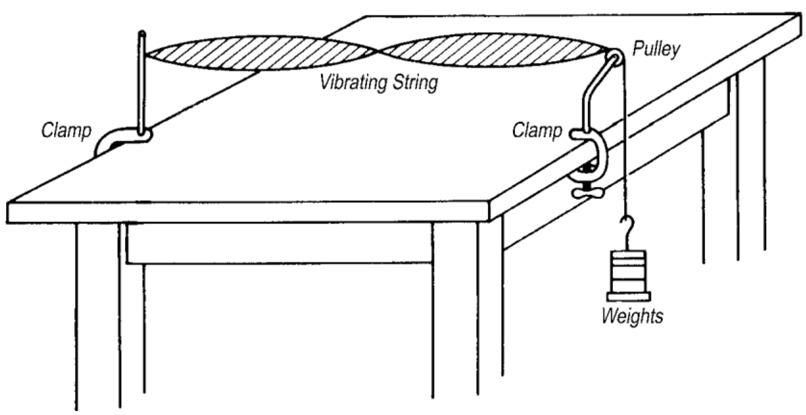

Figure 12-3. Laboratory setup for standing wave experiment

Like Hofstein's definition of traditional laboratories, "The Puzzle of the Tacoma Narrows Bridge Collapse" (TNB) videodisc laboratory is also a contrived learning experience in which students interact with materials to observe phenomena (see Figure 12-4). In the videodisc laboratory the students interact with videodisc images through the computer keyboard and a joystick. Student had complete freedom over the manipulation of the variables. Like the traditional laboratory, the videodisc laboratory allowed the students to add weights to the string, change the length of the string, and change the string itself (the linear mass density of the string).

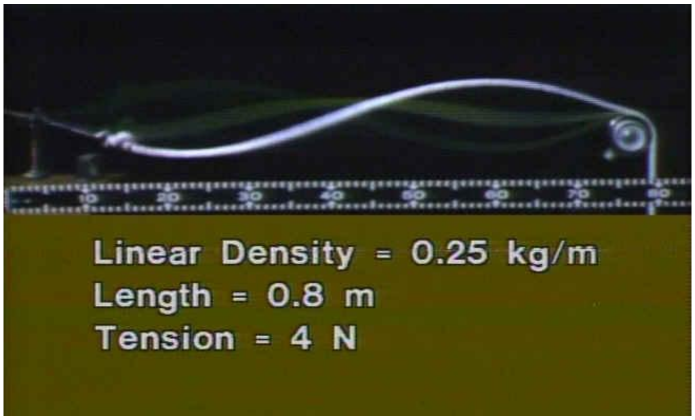

Figure 12-4. TNB video laboratory.

Unlike the traditional laboratory, it is just as easy to change the string as it is to change the length or the weight. Students choose the values of the variables from a three-by-three matrix (see Figure 12-5). Students took data on the effect that changing independent variables had on a dependent variable. Students in the traditional laboratory used a systematic approach to investigating the effect of these variables, holding two of the variables constant while they change the third. This process is repeated for each of the independent variables. Students in the virtual laboratory used a non-systematic approach characterized by frequently changing more than one variable at a time (Stevens, 1985).

Linear Density	Length	Tension
High	High	High
Medium	Medium	Medium
Low	Low	Low

Figure 12-5. Variable Selection Matrix

Students at the concrete stage of development do not think in abstract terms. The variable selection matrix is clearly an abstract representation of the operations of: putting strings on vibrators; adjusting their length; and adding weights to the strings. Rather than viewing the items in the variable selection matrix as representing physical operations, concrete thinkers view these items as the objects of interest.

Symmetry abounds in the everyday world. Some theories of vision suggest that symmetry plays an important role in visual recognition (Marr, 1982; Rock, 1984). In the variable selection matrix, students highlighted symmetric patterns at a statistically significant higher rate compared to non-symmetric patterns. This indicates that students treated the visual objects in the variable selection matrix as primary objects of interest, not representations of objects in the video.

This work has led to the following design guidelines for educational games (Stevens, 2009):

Educational game designers should analyze the way objects are used in real-world situations.

The user interface should allow the user to manipulate simulated objects directly, making the user manipulate the simulated objects as they would real objects.

The overall educational game design should direct the general approach to inquiry while concurrently allowing the users the flexibility to explore on their own.

The experience requires the user to analyze the situation while they are involved with it.

Finally, the design requires the user to use the objects and concepts in new and different ways.

Educational game designers must understand the phrase, “I am not the user.” They must not design for themselves, but for the target learner.

Game Design

In his groundbreaking book, Schell identified 100 “lenses” through which developers view game design (Schell, 2008). Many of these resonate with Malone. The lens of endogenous value examines what is valuable inside a game and notes that they only have value inside the game. For example, Monopoly money only has meaning within the game of Monopoly and only has high value while playing the game. The game has given it meaning. It has no value outside the game. This idea guides the determination of how compelling a game might be. For example, the game of roulette does not have to be played with real money; it could use tokens or play money like Monopoly. But people will only play roulette when real money is at stake, because it is not a compelling game.

To design for endogenous value, Schell asks about players’ feelings about items, objects, and scores in the game. What is valuable to the players and how can you make things more valuable? What is the relationship between value in the game and players’ motivations? Think about what users care about and why.

Schell lists 10 qualities of games:

> 1) Games are entered willfully. 2) Games have goals.3) Games have conflict. 4) Games have rules. 5) Games can be won and lost. 6) Games are interactive. 7) Games have challenge. 8) Games can create their own internal value. 9) Games engage players. 10) Games are closed formal systems.

Schell likens our educational system to a game. Students (players) are given a series of assignments (goals) that must be handed in (accomplished) by certain due dates (time limits). They receive grades (scores) as feedback repeatedly as assignments (challenges) get harder and harder until the end of the course when they are faced with a final exam (boss monster), which they can only pass (defeat) if they have mastered all the skills in the course (game). Schell’s Lenses show why traditional education does not feel like a game. Most educational methods lack surprise, lack pleasure, and lack community.

Lectures, books, and video are all linear, and linear media are poor at conveying complex systems. The best way to understand a complex system is to *play* with it, getting a holistic sense of how parts are connected. Some systems that are best learned through simulations such as the human circulatory system and nuclear reactors. In physics, demonstrations and laboratories are all simulations, traditionally with physical objects, apparatus, and measuring devices.

Based on the foundations laid by Malone, Fuller, Schell, and others, the hypothesis is that immersive 3D simulations and games incorporating surprise and building community will captivate students in a way that no tabletop lab exercise or textbook problem can. Consider that physics teachers have used trips to amusement parks as a motivational tool for over 30 years (Roeder, 1975; Natale, 1985; Reno, 1995). Obviously this is at best a once a year event for a select few. 3D worlds provide the ability for all students to experience amusement park physics. Figure 12-6a shows a typical lab setup to study energy transformation. Contemporary simulations (PhET, 2008) are flat 2D experiences (see Figure 12-6b). Which would motivate students more, a traditional lab, a 2D simulation reminiscent of a 1980s game, or a high-fidelity 3D roller coaster simulation (see Figure 12-6c) that permitted students to manipulate the course and study the effects of various designs, while measuring kinetic and potential energy throughout the course as they “ride” on the coaster? But creating pedagogically sound, fun educational environments is difficult.

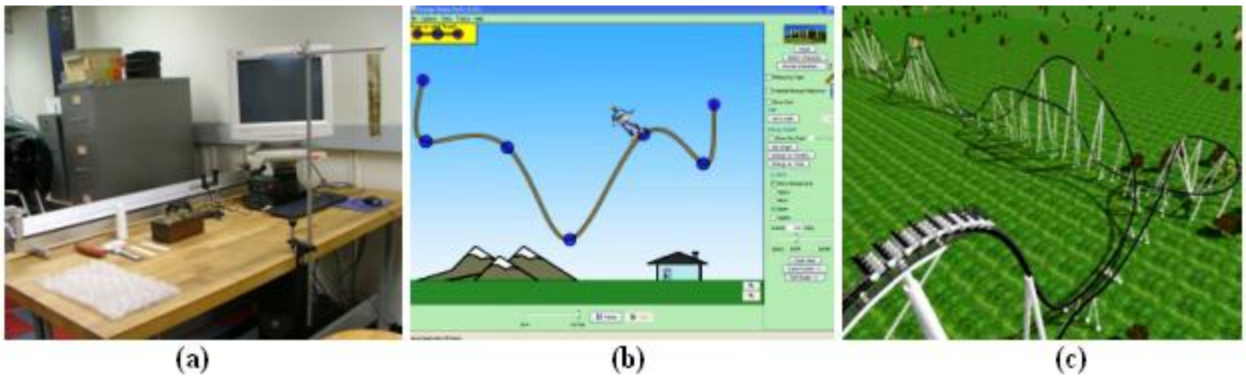

Figure 12-6. The study of energy transformations with (a) traditional lab apparatus; (b) 2D simulation; and (c) a hypothetical roller coaster interactive simulation with routing and other factors under user control.

The challenges to educational game designers and developers are:

How to make entertainment and learning fun?

How to design interactive experiences in ways that captivate and intrigue people, illicit emotions, cause them to reflect, and educate them?

In addition an effective educational game should be *Realistic, Believable, Enjoyable,* and *Engaging* plus*:*

Interactions must be meaningful. Interactions must effect the experience. Fantasies (stories) must be intrinsic. Interfaces (worlds) must be intrinsic

Concluding Remarks

A common theme in this book is that an essential property of being human is the desire to understand ones environment. There are fundamental, intrinsic rewards to learning that naturally encourage humans to want to learn more. Intrinsically motivated, play-like activities are essential for many kinds of deep learning. So people are engineered to like them. They are fun. We need to know what a character in a game will find around the next corner. If a game design is based on what we know is intrinsically motivating to users, they will spend more time in the activity, they will learn more, and they will have more fun in the experience

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