Serious Design for Serious Play

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Citation

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Background to this article

This article is being prepared at the invitation of Ward Cates of Lehigh University for a special upcoming issue of Educational Technology. The goal of the special issue is to see how a group of experienced instructional designers approach the same design problem. Ward gave us a detailed description of the subject matter which we presume will also be published in the special issue. Our job was to design one specific lesson, but we were not obligated to do any development work.

Abstract. We present our approach to designing a physical science lesson according to the specifications outlined in this special issue. We also discuss our learning and design philosophy, the assumptions under which we worked, and try to show how these influenced our design decisions. We designed a series of activities which are consistent with the typical constraints found in an average school, yet take advantage of the availability of master teachers. The activities also encourage divergent, motivating experiences for students to pursue on their own. Our philosophy is based on a confluence of motivational and cognitive elements, best summed up by the play experience. We discuss serious play as a design goal, yet we are careful to point out its limitations. By using digital manipulatives and computer simulations we feel that students will learn the concepts and principles through active, mindful engagement.

At first glance, this design problem seems very straightforward. An introductory lesson on the topic of energy involves just three main principles and several fundamental concepts. These concepts and principles, and the relationships

among them, are clear and well-defined. This subject matter pervades all aspects of our physical lives - walking, running, sports, driving, racing, and even dancing - so it should be easy to gain students' attention and to show how the content is personally relevant. If any design problem was well-suited for instructional systems design (ISD), surely this is it. Besides, this material has been taught in virtually every high school in most countries for decades, so one would assume that we should already know by now exactly how to teach this stuff, right?

However, if you talk to physics teachers and students you will learn a different story. Students do not master this content easily, nor do they see it as being particularly relevant to their lives (diSessa, 1993). If a cross-section of adults who graduated from high school were surveyed, we suspect that few would remember any of these formula and would struggle to apply them properly even if the formulas were provided to them. A clear understanding of how these principles and concepts underlie everyday examples remains strangely vague and elusive. Historically, student achievement and motivation is quite "normal" for this content - a few doing very well, a few doing very poorly, and the rest just happy to get through the material.

Is ISD the best approach here? ISD is frequently argued as being well-suited for general guidance on macro-design strategies, such as selecting, organizing, and sequencing well-defined content over many lessons and units. But the design of learning environments and instructional strategies that lead to "meaning making" on the part of students requires more than consideration of how the content is organized. For example, designing instruction for this subject matter is complicated by the fact that it involves both qualitative and mathematical analyses. That is, one can think qualitatively about the dynamics of physical objects independently of performing the calculations to precisely determine an object's motion (position, speed, direction) at any point in time. Although one would think that ISD is a powerful enough tool to inform the decision either to design instruction from the qualitative or mathematical point of view, it turns out that this is not as straightforward a decision as it first appears. There is, in fact, much debate among physics teachers about which should come first (White, 1993; White & Frederiksen, 1998). This decision alone points to profound differences in the final form that the instruction will take and illustrates that the nature of the content cannot alone be a trustworthy guide to the design of instruction.

Fortunately, other useful design literatures exist such as the constructivist concept of a microworld (Papert, 1981; Rieber, 1992) and the extensive literature on simulation and modeling (de Jong & van Joolingen, 1998). The degree to which one sees these literatures as complementary or counter to ISD depends a great deal on one's interpretations and experiences with ISD and one's philosophy about learning, teaching, and education. For example, the literature on designing microworlds is strongly rooted in constructivism, hence has

historically little in common with ISD whereas simulation design has a history of practice by individuals both with and without an ISD affiliation.

Interestingly, our research over the past decade has focused almost exclusively on introductory mechanics, specifically Newton's laws of motion and their application to the relationship between acceleration and velocity (examples include Rieber, 1990, 1991, 1996a; Rieber & Noah, 1997, March; Rieber & Parmley, 1995; Rieber et al., 1996). Our research has shown us that these concepts and principles are very difficult to teach and grasp. One problem is that people (adults especially) exhibit typical "math anxiety" when the subject of physics is brought up. Many quickly point out that they were "not good at this" in high school. Another very different problem is that some people think they already know this material. After all, words like speed and acceleration invoke everyday experiences because of the ubiquitous nature of automobiles. But the way in which people think about these concepts and use these labels often contrast with explanations found in textbooks. The principle of acceleration is a good example of where people quickly get confused - it is hard to understand or imagine how a car slowing down at a stop sign is actually best described by physicists as accelerating in the opposite direction in which it is moving! All our experience designing computer-based learning environments for this physics material makes us appreciate just how difficult it is for people to really understand the relationships at a level necessary to solve a given problem.

This lesson is a good candidate for the design of an interactive learning environment. We have argued elsewhere that there are benefits to designing interactive learning environments based on the blending of microworlds, simulations, and games (Rieber, 1996b; Rieber, Smith & Noah, 1998). The best designs, in our view, conjure up the play experience - not a trivial kind of play that indicates that one has nothing better to do, but a serious kind of play that involves an intense, mindful, and personally satisfying activity in which a person is almost on "auto-pilot" as he or she engages in the activity. This article provides us with a good opportunity to demonstrate how these views may be put into practice.

Assumptions

Here are some specific assumptions under which we have worked:

1. This design is meant to be instructional in nature. That is, there are specific learning outcomes that must be achieved in a timely fashion.
2. This lesson is to be used in a formal educational environment, such as a middle or high school classroom, with all of the typical constraints that such an environment entail, such as limited time and the associated pressure to accomplish the school's or district's curriculum.

3. The learning environment includes a professional teacher to work with the students.
4. The design is to be based on existing technologies. We resisted the temptation to delve into "science fiction" and invent technologies currently not possible (like the "hover board" from the various Back to the Future movies).
5. Schools that use our product have an adequate technology infrastructure. While we were mindful of assumption #2, we did not want to unnecessarily constrain ourselves to only a one-computer classroom.

We also wanted to design a lesson that would work under the above assumptions while being flexible enough to accommodate other instructional assumptions and learning scenarios. For example, we take a strong view of the relationship between motivation and cognition and wanted to design something that would naturally trigger a student's curiosity and desire to learn. We wanted something that, although usable in a school, would not at first appear "school-like." A teacher should be able to see our design and say "yes, I can use that" as well as a student saying "that's cool, let me try." We also wanted to design something that would allow students to excel in the presence of a master teacher. This aligns with our belief that technology actually elevates the role and value of teachers by freeing them of the demands of knowledge dissemination to allow them to facilitate learning by providing that uniquely human element that technology cannot provide (Hooper & Rieber, 1995). Frankly, we find any design touted as "teacher-proof" to be both misguided and distasteful. But we also wanted a product that a student, when properly motivated, could learn well with independently albeit not to the degree possible when a teacher is available. Finally, we also challenged ourselves to "think outside the box" to imagine situations other than a student staring at a computer screen. Subject matter such as physics especially lends itself to students getting out into the world to learn. Obviously, we have high expectations for anything we design.

Learning and Design Philosophy

We characterize our learning philosophy as constructivist, but we are not radical constructivists. We do not believe that "anything goes." Ultimate truth may be unattainable, but we feel certain ideas are more usable and consistent with accepted theory (this is akin to von Glasersfeld's 1993 concept of viability). Even if our universe turns out to be a game cartridge in some alien's Nintendo video system, some ideas are more consistent with its programming than others. Physics is a perfect example of this. Newton's laws of motion are still viable because they have practical uses even though they are no longer considered "true" by physicists. Likewise, we feel that there are times that instruction is reasonable, needed, and expected. We describe ourselves as "eclectic constructivists" to show our interest in all good ideas for promoting learning

regardless of their philosophical roots. (See Footnote 1.) We take the position that teachers and students have certain roles, responsibilities, and expectations. However, we accept the epistemology of constructivism that meaning is an individual construction, though usually in a social context. Probably the best way to describe our design philosophy is "look for ways to trigger serious play."

We have described the role of play elsewhere (Rieber, 1996b; Rieber et al., 1998b). We define serious play as an intensive and voluntary learning interaction consisting of both cognitive and physical elements. Serious play is purposeful, or goal oriented, with the person able to modify goals as desired or needed. Most important, the individual views the experience of serious play as satisfying and rewarding in and of itself and considers the play experience as important as any outcomes that are produced as a result of it.

We consider serious play to be an example of an optimal life experience. Csikszentmihalyi (1990) defines a optimal experience as when a person is so involved in an activity that nothing else seems to matter. The person is so absorbed that they seem to be "carried by the flow" of the activity, hence the origin of the theory's name. A person may be considered at flow during an activity when experiencing one or more of the following characteristics: Hours pass with little notice; challenge is optimized; feelings of self-consciousness disappear; the activity's goals and feedback are clear; attention is completely absorbed in the activity; a feeling of control; and the feeling of being freed of other worries. It is tempting to equate serious play with flow, however, one key difference is that learning is an expressed outcome of serious play. Much of the satisfaction comes from the feeling that something previously unknown or confusing is now understood. The instructional strategy is to look for ways to trigger a person's natural tendency to "tinker" with certain problems until they are solved.

We recognize that serious play is frequently at odds with our second assumption, that of our lesson being compatible with typical constraints and expectations found in schools. Serious play takes time. A student who wants to explore a domain via serious play will be pressured to "move on" by school administrators, teachers, and parents. Serious play is most compatible with long-term goals, such as the development of a deep understanding and true love of a content area or topic. In contrast, the scope of most school curricula is very large, demanding that a great many topics be covered in a relatively short amount of time. Interestingly, society accepts the point of view that student learning should be relegated to a shallow understanding of many areas, instead of deep understanding of a few. Frankly, we think it's time to rethink this "a mile wide and an inch deep" mentality. As Perkins (1986, p. 229) points out:

...fostering transfer takes time, because it involves doing something special, something extra. With curricula crowded already and school hours a precious resource, it is hard to face the notion that topics need more time than they might otherwise get just to promote transfer. Yet that is the reality. It is actually

preferable to cover somewhat less material, investing the time thereby freed to foster the transfer of that material, than to cover somewhat more and leave it context-bound. After all, who needs context-bound knowledge that shows itself only within the confines of a particular class period, a certain final essay, a term's final exam? In the long haul, there is no point to such instruction.

Likewise, the way in which students are evaluated in most school environments is likewise counter to serious play. We seem satisfied to have students demonstrate mastery on tests of short-term performance and place little emphasis on the application of what has been learned in long-term pursuits.

Instructional Model

It would be a mistake to believe that any of the design ideas or guidelines we present here are anything more than general heuristics that depend on a creative and experienced designer working closely with users. I (Rieber) have previously argued for interactive design based on a blending of microworlds, simulations, and games (Rieber, 1992; Rieber, 1996b). This position is based on contemporary views of user-centered design, how people learn, epistemological perspectives of knowing and making meaning, and the interactive affordances of computer-based technologies.

We will briefly describe both the macro- and micro-instructional models that guided our design. Macro-instructional design models guide the selection, sequencing, and organization of a group of lessons (that is, units and courses), whereas micro-instructional design models guide the design of individual lessons. Even though our task was specifically targeted at the lesson level, it is difficult for us to design one lesson without careful attention to what students have already learned and what they are going to learn in future lessons because we believe that no individual lesson, to be meaningful, can be designed well otherwise. At the macro level, we have been influenced by rapid prototyping methodologies (Northrup, 1995; Schrage, 1996; Tripp & Bichelmeyer, 1990) and elaboration theory (Reigeluth, submitted for publication; Reigeluth & Curtis, 1987; Reigeluth & Stein, 1983). We will only briefly describe the most critical aspects of these approaches as they apply to this design.

Rapid prototyping is a user-centered design methodology. Unlike traditional ISD, a critical aspect of rapid prototyping is that determination of the instructional objectives occurs concurrently with the development and evaluation of early prototypes (Tripp & Bichelmeyer, 1990). This not only allows users to provide feedback on the early designs, but also shapes how the prototypes are designed and revised. This is a powerful idea because it allows the user to help determine what actually needs to be taught and how. In a sense, the user can be considered a "co-designer." Of course, rapid prototyping is only possible given

development tools that allow for quick turn around of an idea into a testable prototype. Fortunately, most contemporary multimedia authoring tools, such as Authorware and Director, are very good examples of tools that are both "plastic" and "modular," allowing for the construction of early prototypes even when the design is unclear. This is analogous to how word processing has transformed the writing process. A word processor is both a design and development tool - it allows a writer to struggle with the organization and content for a piece (design) while at any time permitting the document to be printed and shared with others (development). Similarly, we tend to use authoring tools as much for the way they permit us to design an interactive product as for the interactive opportunities they afford in our software. (See Footnote 2.)

Elaboration theory has long appealed to us because it deals well with content that one needs to learn about continually, reflect on, and use. Again, physics is a good example. One does not learn a principle like "force equal mass times acceleration" and then move on to completely new principles. Instead, this simple formula is both profound and incredibly useful. It is profound in the way it encapsulates a great deal of understanding about the physical world. A person on his or her way from physics novice to expert will continually revisit the complexity and richness of Newton's second law as his or her understanding of physics increases. Likewise, the usefulness of this law has bearing on such a wide array of problems that it is learned exactly because it is relevant to so many problems. Elaboration theory is rare in its attention to the need to continually revisit previously learned material so as to discover additional richness and complexity in ideas that were previously understood at a simpler level. Elaboration theory also has elements that serve well to bridge macro- and micro-instructional design attributes. The most well known is that of the epitome and the expanded epitome (Reigeluth, submitted for publication; Reigeluth & Curtis, 1987). Briefly, an epitome is an entire lesson that contains representations of all the essential ideas to be later expanded in the instructional unit or course. It serves us well here because it is aligned with the idea of providing students with an organizing activity upon which successive learning experiences can build. We prefer to design an instructional epitome with a strong experiential tone - again, learning by doing. This is the kind of experience that engenders in learners a desire to seek out explanations in order to understand better what was just experienced. The experience triggers "why" questions from students and gives the teacher, or the instruction, a wonderful opportunity to explore a topic in depth with motivated learners.

Our micro-instructional design is guided by an eclectic assortment of theories, models, and approaches. Most relevant to our lesson is the design of simulations and games. In particular, games offer a way to combine an effective organization strategy for the content with a motivating experience. A good game has clear goals and offers clear feedback as to progress in attaining the goals. From a design standpoint, most educational game designers fall into two camps- those who embed the content effectively into the game context and those who design

games in which almost any content can be fitted. Games of the latter variety often use question/answer formats. Although this type of game offers the advantage of integrating game design into almost any content, we feel this type also often sends the unfortunate message to students that no one in their right mind would want to learn this stuff for its own sake. While such games have obviously been successful in the commercial market, our design favors wedding the game with the content to the point that it is not possible to tease out the content without destroying the game (see Malone's description of "intrinsic fantasies" (1981; 1987) and Kafai's (1996) description of "intrinsic integration"). Such games are much harder to design, but worth the effort.

In addition, we have found over the years that most of the serious efforts at understanding instructional design can also be very useful to consider. A good example are Gagné's Events of Instruction (Gagné, Briggs & Wager, 1992). Although these are usually touted as the archetype of ISD at the lesson level, we see no reason why they cannot be applied well given a constructivist philosophy. Of course, there are some key differences. For example, the events of instruction have traditionally been applied for deductive learning designs with a typical sequence as follows: 1) orient students to the lesson (that is, gain their attention, help them remember important prerequisite information, give them expectations about what it is they will be learning; 2) present the new lesson content; 3) provide opportunities for interactivity (practice and feedback); and 4) enhance retrieval and transfer. In our case, we adapt Gagné's model to accommodate an inductive approach to learning based on an heuristic of "experience first, explain later." Therefore, our sequence begins with giving students the opportunities for interaction which serve as "experiential anchors" for individual and group reflection, followed by debriefing led by a teacher or more knowledgeable peer combined with discussion. Explanations, whether given by a teacher or by technology, should be called for by the teacher at just the right moments. (See Footnote 3.) That is, students are challenged by the activities and are curious about what is going on. Of course, we would hope that many students would also seek out such meaningful explanations on their own without external guidance, but this strikes us as too idealistic.

Specifics of the Design

One of the first questions we asked ourselves in considering the design concerned the context for the lesson. We felt it was important to choose one context that would be meaningful and interesting to students as well as provide the potential for a rich and divergent set of examples or cases to situate the content. Some of our research on providing students with different metaphors, or model cases, for understanding the relationship between acceleration and velocity is useful to mention here. We have investigated how a variety of different metaphors help to make the most essential aspects of the relationship more

salient and the content more meaningful. Our research has explored the following three metaphors: a ball rolling on a board in which the user controls the board's tilt; a space ship floating in outer space; and a refrigerator gliding on a frictionless floor (which we have informally labeled the "rogue refrigerator" model). While all three illustrate exactly the same physical principles and allow the user the same level of control, we have found that students by and large gravitate to the "rogue refrigerator" model. As shown in Figure 1, this model asks students to imagine a refrigerator that somehow started to glide on a frictionless floor. They control the acceleration of the refrigerator which is represented by one or two men who are pushing against the refrigerator with the same size force either from the left or right. Our research indicates that people somehow associate with this model more than the others. For some reason, it seems easy for people to imagine themselves in the position of one of the two animated fellows. Likewise, it also seems easy for people to imagine what it feels like to push against a refrigerator, either to speed it up or to slow it down, despite the fact that we doubt many have had any experience even remotely similar to that in the simulation. Most probably, the refrigerator easily denotes the concept of a "massive thing" which helps conjure up tactile imagery.

Beyond all of the physical attributes, we have also come to believe that much of the reason this model has been so successful is that it lends itself to story making more than the other metaphors. Who are these two guys? Are they brothers? Are they twins? How did they manage to find themselves in this predicament? Perhaps they were moving into a new house and the refrigerator got loose as they rolled down off the truck. If so, why were they moving? What do these guys do for a living? Do they have trouble with any other major appliances? Research on stories, humorous and otherwise, shows their importance as cognitive organizers (Just & Carpenter, 1987; Schank, 1990; also see Noah et al., 1999) and "anchors" for learning (for example, the success of the Jasper Woodbury Problem-Solving series by Cognition and Technology Group at Vanderbilt (1992, 1993).
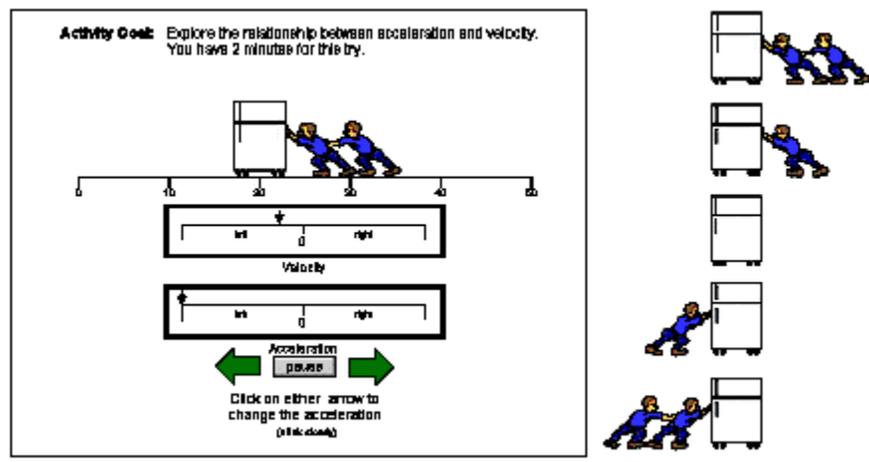
Figure 1. The "Rogue Refrigerator" model depicting the relationship between acceleration and velocity. A snapshot of the computer screen is shown on the left. Depending on which of the five acceleration positions is chosen, one of the five graphics is animated on the screen to depict the magnitude and direction of the force (high-left, low-left, none, low-right, high-right).). A working example of this simulation can be found on-line at "http://itech1.coe.uga.edu/faculty/lprieber/shocked/accvel/accvel.html".

The first obvious context we thought of was the use of a particular sport, such as baseball. Though trite, sports are dependent upon physical relationships of people and their equipment. Billiards is often used to depict physical interactions among discrete objects. However, upon further reflection, we decided against a sports context for several reasons. We could not find a sport that adequately contained the physical concepts and principles for the entire unit within which our lesson was situated. Some sports, such as hockey, baseball, and billiards, provide good opportunities for the instantaneous acceleration and resulting velocity, but don't capture the more subtle differences between acceleration and velocity. Also, these sports do not readily elicit examples dealing with work, power, and energy. Those that do, such as bobsledding, are hardly typical sports in which high school students participate! The other difficulty with sports is that they also act as an easy means for quickly excluding people solely on the basis of interest, prior knowledge, and even gender. Any single sport may give rise to a wide distribution of emotions among learners -while some may love it, others may hate or feel apathetic toward it.

The context we decided upon for our lesson was driving a car. Not only does this context lend itself easily to all aspects of the content, it also resonates strongly with the age group - virtually all these students are either driving, learning to drive, or eagerly awaiting the chance to do one or the other.

Many aspects of our design are inherently computer-based. Our lessons involves simulation and gaming activities using a guided discovery approach. Much of the interaction occurs in front of a desktop computer individually and in groups with and without teacher guidance. However, our design also calls for a new technology referred to as digital manipulatives. Digital manipulatives are similar to traditional manipulative materials (such as blocks, balls, and Cuisennaire Rods), but they have computer technology physically embedded in them (Resnick, 1998). Consequently, they are programmable and have computational abilities. Current examples include the Lego brick, bitballs (rubber balls with an embedded accelerometer), and digital beads. Digital manipulatives provide many opportunities for interaction and serious play. Most significant is the fact that they are independent digital devices which can be taken out into the world to be explored. Although our design is based on a digital manipulative that does not currently exist, we feel it does not violate our "no science fiction allowed

assumption" because it is based on existing technologies. (One could argue that all designs are fictitious until developed.)

We were also mindful of the social connectivity of computers and the Internet. While we believe our design affords many interesting possibilities for the Internet, in the interest of space we decided to forego considerations of networking applications even though the possibilities are intriguing, such as players separated geographically competing and cooperating on challenging problems.

e-Hot Wheels

Our lesson will make use of a special digital manipulative, as illustrated in Figure 2 - an electronic, programmable matchbox-sized car. Think of it as "e-Hot Wheels". The user can both upload programs to the car and download data from it. The car will use wireless data to communicate with either a desktop computer or a personal digital assistant (PDA). It can be used on any reasonably smooth surface, such as tables or floors, and even the commonly available plastic Hot Wheels tracks. Through the use of the PDA, students will be able to monitor and store certain characteristics of the car and its motion (including mass, velocity, acceleration, time, distance, and even friction) in a variety of locales (including outdoors) without having to be connected to a desktop computer. Of course, this information could then be uploaded later to a desktop computer for analysis. In addition, two or more cars can be used and student teams can compare the effects of different manipulations on each car at the same time. Student teams can take this one step further and engage in competitive gaming situations given to them or which they design themselves.

These digital manipulatives will also provide feedback to students while they are being used via lights and speakers. For example, the bitball can be programmed to flash a red light when it has been sharply accelerated, such as when being thrown or caught (Resnick, 1998). We envision our digital manipulative car to also be able to provide feedback using sound. For example, it would whistle or chirp up or down the musical scale as its speed, acceleration, or momentum increased or decreased, depending on how it was programmed. The pitch of this whistle or chirp could likewise be increased or decreased depending on the car's mass.
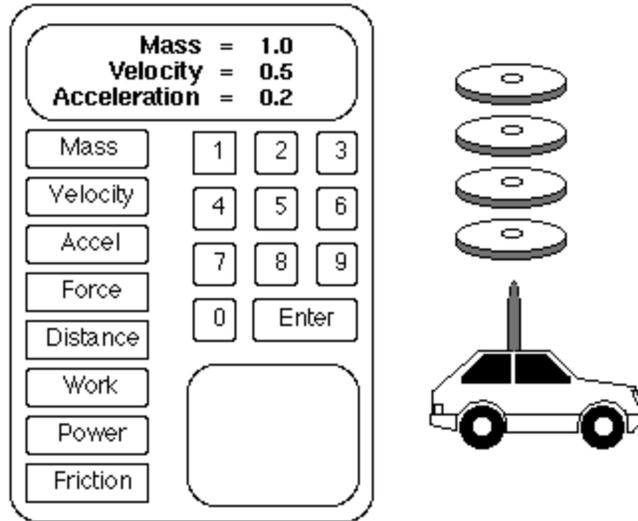
Figure 2. A hypothetical digital manipulative in the shape of a toy car along with personal digital assistant (PDA) that could be used to program the digital manipulative in a field setting. Weights could be added to the car. After one or more activities, the car could subsequently upload its data to the PDA for later analysis on a desktop computer.

Computer-Based Simulations and Games

The second critical element in this design is the desktop computer. Whereas digitally controlled cars allow students to see the various physics principles at work, a computer simulation allows them to get involved in learning situations that would not be possible using the e-hot wheels cars. These simulations will also involve the use of the same metaphor, driving a car, but in contexts that would not be recommended for use in the classroom, such as a car race or demolition derby.

After much brainstorming, we generated some ideas about how to teach the concepts of work and energy and the principles of conservation of energy, momentum, and interactions among physical objects. We think these are good, creative ideas. However, it is important to realize that these ideas are lacking one important feature - feedback from people in the intended audience, that is, high school students. We feel that without building and testing the simulation and game prototypes with actual users we cannot actually represent in this article how we do design. We see this as a critical "missing link" in our efforts here. (See Footnote 4.) The importance and complexity of this missing link needs a little elaboration. First, we see a clear difference between learner-based and learner-centered approaches to design. The former is closely aligned with cognitive approaches to standard ISD and the latter coincides with our heuristic

of "making the user a co-designer." We believe that learned-based design uses a process most closely aligned with traditional formative evaluation whereas learner-centered design uses a process most closely aligned with rapid prototyping. There is a clear difference between an attitude of having learners try out and give feedback on our designers versus considering them as true collaborators. A good example of the latter is our Project KID DESIGNER (Rieber, Luke & Smith, 1998) in which adults (university folks, teachers) collaborated with elementary and middle school students to develop educational computer games. The design of these games originated with the children. The adults worked for them as their programmers and also facilitated the design process.

As we prepared this article, we (Rieber and Matzko) talked often about the issue of learner-based versus learner-centered design. We had different experiences with both approaches and saw value in each. Frankly, oftentimes there are forces at play in a project that can lead the design effort toward or away from each approach. For example, a commercial venture for this physical science project involving a large team would probably find it difficult to practice true learner-centered design due to the difficulty in forming a close partnership with representative high school students.

Some design ideas worth exploring

Table 1 contains an outline of the lesson activities that we propose. Prerequisite to our lesson are the concepts of force, mass, velocity, and Newton's Laws of Motion, though we expect students to use and explore these further as they develop a sense of the meaning of work and power.

ACTIVITY	CONTENT
Digital Manipulative	
Driving the Car	Work
Incline Car	Energy, Conservation of Energy
Weighted Cars	Momentum and Interactions
Computer Simulation	
Car Racing	Work
Virtual Inclined Car	Energy, Conservation of Energy
Virtual Demolition Derby	Momentum and Interactions

Table 1. A suggested unit outline.

Although it is usually tempting at first to organize a lesson or unit based on the content we felt that the lesson should be focused around the activities. Therefore, this section describes our design in terms of activities using the digital manipulative and computer simulations. We are remaining deliberately vague about what constitutes a "lesson". Instead, we are proposing a group of activities which all could be explored at the beginning of this unit. Clearly, we are offering

more than could possibly be accomplished in a 50- or 75-minute class period, but we do not think this distinction matters at this point.

Driving the Digital Manipulative

The e-hot wheels car will be used in three different scenarios. In the first scenario, Driving the Car, students will be provided with an opportunity to operate the cars at various rates of speed. A readout on their PDA will show the velocity and acceleration of the car for each trip. The PDA will also show how much work was produced after each trip, revealing that the amount of work will always be the same regardless of the amount of time it takes the same care to cover the same distance.

The second scenario, Incline Car, involves placing the car on an inclined surface. The PDA will display typical graphical feedback, such as line graphs that will dynamically adjust as the car rolls down the incline. Building on the previous scenario, the PDA will also show the car's velocity and acceleration. The interrelation between potential energy, kinetic energy and thermal energy will be indicated on the PDA. This scenario will also provide audio feedback to denote the difference between potential energy and kinetic energy. One unique sound would be produced to represent the level of potential energy and another sound would represent kinetic energy. For example, when the car is at rest on the incline, there will be a steady sound representing potential energy. When the car is released, the sound for potential energy will slowly fall and the sound for kinetic energy will rise at the same rate. Both sounds should be able to represent the relationship between decreasing potential energy and increasing kinetic energy.

The third scenario, Weighted Cars, is an adaptation of the previous scenarios with the additional feature that the mass of the cars can be changed. The cars can then be rolled without power down inclined planes of differing heights onto a flat surface. Multiple cars can be used for races. Audio feedback can also be used in this scenario, such as a continuous tone mapped to each of the car's momentums. When the cars begin to move this tone will change in pitch to represent each car's current momentum.

Computer Simulations

We envision three computer simulations to complement the e-hot wheels activities. Car Racing is a computer-based game/simulation in which students pick different sized cars of varying mass. Much in the same way that students were able to manipulate the variables for each of the e-hot wheels cars, the students can either race their simulated cars against time or race against each other. The computer will graphically display the relationship between mass and acceleration and how they interrelate with the value of force. This should allow students to develop a conceptual understanding of inertia by having opportunities

to explore different combinations of mass and velocity. This game will also allow students to replay a given race in order to freeze or slowly replay the action, thus allowing students to examine each variable acting on their car at a specific point of time during the race.

The second computer activity is Virtual Inclined Car, a simulated version of the actual incline that students used with the digital manipulative. Students will slide cars down the incline at different speeds and on surfaces that produce different amounts of friction, as shown in Figure 3. The computer will depict the different levels of each type of energy throughout the course of the simulation. Like the previous simulation, students will also be able to replay any given event so they can stop the object at various points along its trajectory to get an exact measurement of the object's energy (potential, kinetic and thermal) at specific points in time.
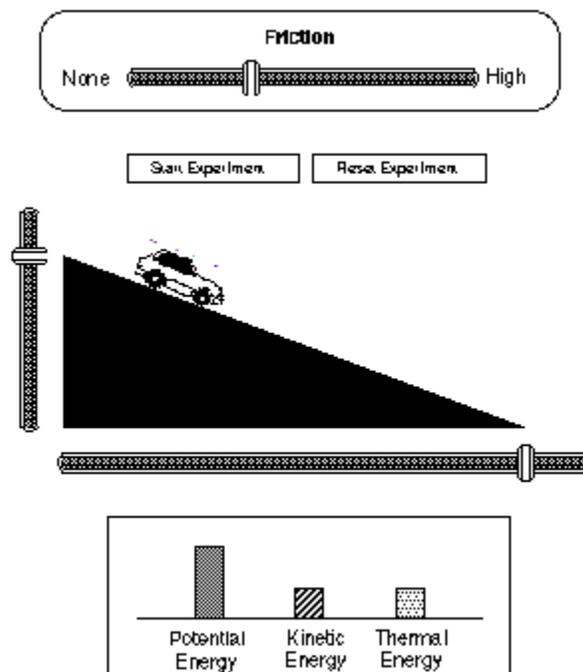

Figure 3. A hypothetical computer simulation in which the user can control the two dimensions of an inclined plane as well as the friction between the object (in this case a car) and the surface of the inclined plane. Read-outs of the various forms of energy are provided.

Of all the ideas we generated, the one we both liked the most is a computer simulation called Virtual Demolition Derby. We feel this is an idea that is sure to

spark creative suggestions from high school students. Cars of differing masses and velocities are run on a variety of race courses with the expressed goal of producing collisions. Collisions can be predicted and analyzed under a wide array of conditions and options, such as giving students control over friction and each car's elasticity. The computer will display the levels of momentum and show how that momentum is passed on from object to object. One critical affordance of a computer simulated demolition derby is the ability to structure or constrain the demolition derby in ways that allow students to focus on certain critical concepts. For example, one constraint could be that the user can only manipulate the two cars in one-dimension, similar to two train cars about to collide. Such control over this experiment would allow the user to participate in the scientific process of hypothesis testing.

Closing

Our designs obviously all have strong gaming influences. While we have described a few of our ideas, taking the learner-centered design approach liberates us from worrying too much about whether our ideas are the best ones. The line between practicing ISD with strong influence of user feedback versus a true constructivist approach that supports learners in their designs is often blurry. In this paper, we have shared some ideas on how to design some learning environments that help students learn about physical science. We have tried to design materials and activities to be flexible enough to take advantage of the experience and ideas of a master teacher working in a school with a standard curriculum, but yet interesting enough for students to want to continue exploring the resources on their own time and for their own reasons. Our design has a structure and organization that is consistent with the content, but yet lead to divergent outcomes and allow creative manipulations that we could never anticipate. Until prototypes of some of these ideas are built, used, and revised with the participation of high school student, we remain our own healthy skeptics of their effectiveness. We have learned not to be too presumptuous in thinking that two adult males can possibly have total insight into the minds, feelings, and hopes for the diverse range of high school students for whom our materials are intended. Our hope is to design something that leads students to construct their own understanding of these physical laws, but with the assistance of teachers, parents, and more knowledgeable peers. Most important, we hope that our design sparks enough curiosity in students to motivate them to ask interesting questions which can be answered in authentic and interesting ways with the range of interactions that our materials afford.

Footnotes

1. This is a term we invented. This is not easy. A few years ago (Good, Wandersee & St. Julien, 1993) identified 15 adjectives used in the literature to modify a constructivist position, such radical, social, pragmatic, and socio-historical). Our purpose is not to add to the jargon, but to show our displeasure in using a philosophical position to discount any idea that might be brought to bear on a design problem.
2. Both of us like to use Authorware as a interactive multimedia design tool much like a writer uses a word processor. Of course, this is only possible because we know this tool so well (to the point that we both tend to "think" of design problems in Authorware terms).
3. Constructivist teachers always warn against taking away the "Aha!" experience from students. That is, even though the principle of Newtonian mechanics has been known for centuries, you want students to feel as though they have just invented or discovered the principle on their own. Eliciting such reactions from a large proportion of students given school's pressure to learn it and move on to the next lesson is a hallmark of a master teacher and is well aligned with the constructivist idea of "teacher as facilitator."
4. It was only during the writing of this article that we identified how essential this "missing link" would be to our design task here. This prompted me (Rieber) to initiate my own special design project on the topic of bicycle safety while preparing the final draft of this article. I designed an interactive simulation/game while also keeping a design journal. Most important, I saved prototypes of my work as my design evolved. Both the journal entries and the prototypes are available on the following web site: http://www.NowhereRoad.com.

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