DESIGNING APPLETS THAT FOSTER CONSTRUCTIVIST TEACHING AND LEARNING

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ABSTRACT
The Modular Approach to Physics (MAP) project makes extensive use of "educational objects" which include Flash animations, Java Applets and Java Applications. A paramount concern in the design of these objects has been to work from an overtly constructivist philosophy. In this paper we will look at the design of educational objects and provide examples of how constructivist principles can be applied to the development of effective computer based learning objects. Our talk will include a demonstration of some of the JAVA applets and Flash animations currently used in the MAP project and a "behind the scenes" look at how and why they were constructed.

KEYWORDS:
Computer Aided Instruction, Conceptual Physics, Constructivism, HTML, JAVA, FLASH, Pre-Conceptions

INTRODUCTION

It is safe to say that the term constructivism is as ubiquitous as it is problematic in the today's science education research literature (Philips, 2000). The present paper makes no attempt to alleviate the tension that exists over the possible meanings of "constructivism" as either a pedagogical principle or an epistemology for science education. Despite this, and whether the reader's views range from the radical constructivism of Von Glaserfield or Gergen to the somewhat more moderate views of Driver, it seems safe to identify the following as "givens" when discussing constructivism as it applies to science pedagogy:

1. Successful science teaching must develop strategies and tools that acknowledge the existence of powerful, preexistent frameworks of ideas which students bring to bear on the ideas that we teach (see, for example Driver and Oldham, 1986, Berg and Brouwer 1991)
2. Constructivist teaching provides students with sufficient experiences to interact with their held beliefs and to enable students to construct their own understandings of concepts and ideas.

It is against this backdrop that we present the following brief discussion of how educational objects in the form of JAVA applets developed in the Modular Approach to Physics Project (MAP) (Martin et. al. 1999) are designed to encourage constructivist learning and teaching.

CONSTRUCTING CONCEPTUAL UNDERSTANDING

Eric Mazur (Mazur, 1997; see also Halloun and Hestenes 1985, Hestenes 1987) was one of the first to comment on the apparent paradox that often the brightest students (those most adept at solving difficult quantitative problems) fair no better than their seemingly less competent peers when solving conceptual (qualitative) questions. If one values the development of conceptual understanding (which the authors do!) then new strategies for teaching and evaluation are in order. In keeping with the broad constructivist principles alluded to earlier, it will not be sufficient (or appropriate) to merely "explain" a correct conceptual understanding to a student. Rather, a sufficiently rich and engaging environment must be created to enable the student to situate his or her understanding of concepts and principles over against the concept being taught. To this end we have designed a series of applets dubbed "preconception applets" that illustrate the following features:

1. they are designed to address a well-known preconception (ie one identified in the research literature)
2. they are entirely qualitative in both "input" and "output"
3. they allow the student to draw directly on the applet the expected outcome and then to compare this with the "correct" result simulated by the computer
4. the applets are designed to be attractive and "non-intimidating".

SOME SAMPLES OF PRECONCEPTION APPLETS

The following two applets are illustrative of our approach to using applets to address conceptual growth and especially address the problems posed by pre-concepts held by students.

Force and Motion

The inappropriate co-joining of the concepts of force and motion by many students is widely recognized (Arons, 1997) and remains a surprisingly robust preconception even after formal teaching at a college level. Figure 1 shows a snapshot of the applet **motion1D** in which a student is asked to draw (by dragging the mouse) an

Figure 1 **Sample screen from the applet motion1D showing a cannon ball (predicted and ghosted images).**

arrow which represents the direction of the force acting on a cannon ball at three different (and strategically selected) points on the ball's trajectory: part way up, at the apex and part way down. At each stage the motion resumes after the student draws the force vector and the student's ***implied*** motion appears along with the "correct" motion which appears "ghosted" or in a light gray motif. In this example the student was asked to draw the force vector for the case in which the ball was at the top of the trajectory. A very common preconception (the one shown here) is to draw a null (zero-force) vector at this point. When the motion resumes the student then sees that the cannon ball would remain suspended in mid-air if her prediction was correct. Meanwhile the ghosted image is seen to fall downward. At this point the student is invited to revise her prediction and the same scenario plays out again until the student has chosen the correct force representation.

Acceleration and Velocity

Another common point of confusion for students is the failure to understand the distinction between the concepts of velocity and acceleration. Figure 2 shows the applet **accelVel** in which the student is invited to draw on the screen both velocity and acceleration vectors for a ball rolling down an inclined plane. The applet begins by showing the student the motion (the ball rolls down the incline and comes to rest to the right of the point labeled 3). A common misunderstanding on the part of students is to fail to see that velocity and acceleration can act simultaneously in opposite direction.

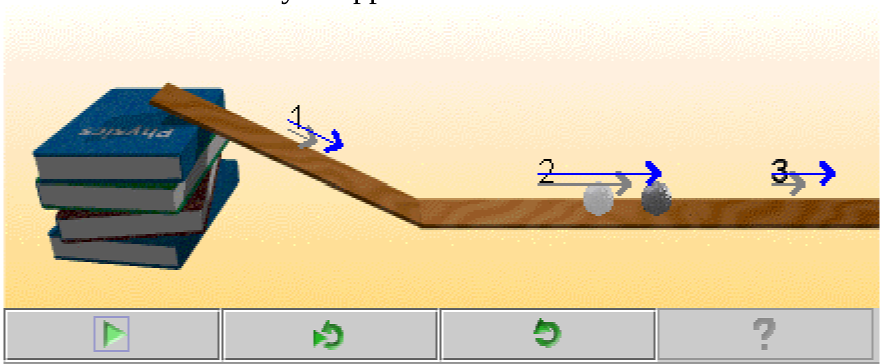

Figure 2: Applet accelVel which tests the students understanding of the concepts of acceleration and velocity.

In the case shown the student has correctly drawn the velocity vectors but has not drawn the acceleration vectors correctly. As a result, the student sees the ball continue to speed up and to begin to separate from the correct path shown by the "ghosted" image.

APPLETS THAT AUGMENT STUDENT EXPERIENCE

Many of the concepts that we teach are essentially foreign to students' everyday experience. The naive notions, for example, of force, acceleration and velocity that are held by students are not isomorphic with the technically correct concepts which we wish them to acquire. To this end we have designed a large set of applets that exist solely to give students experience with abstract ideas. The applet **accel2D** is a case in point and is shown in Figure 3. In this applet the student can launch a projectile by dragging a velocity vector in any direction with the mouse. On release the projectile begins to move. The student can control the motion of the projectile by drawing and tracing out an acceleration vector in the circular region at the top left of the applet. In so doing the student receives immediate visual input on how the two concepts (acceleration and velocity) are related.

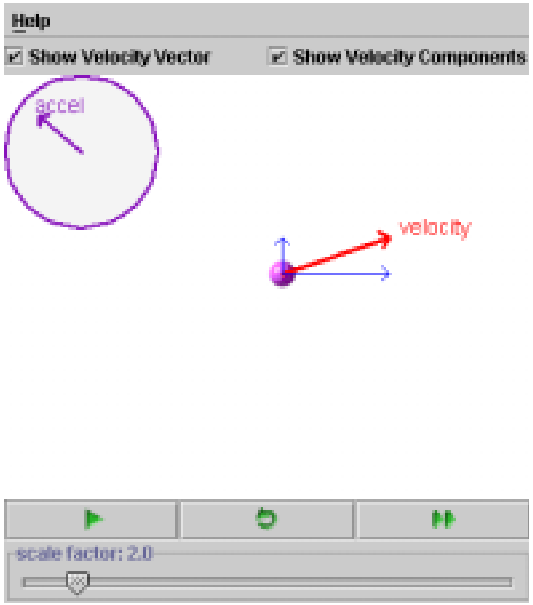

Figure 3: Applet accel2D which allows the student to observe the motion of an object in response to a user variable acceleration vector.

Again the applet is purely qualitative – no numerical information is required or given. The intent is to augment the student's range of experiences with the ideas and concepts being developed. The tasks that can be assigned with this applet range from open-ended "play" to the reproduction of specific trajectories (circular, parabolic, etc).

APPLETS THAT BRIDGE THE TRANSITION FROM QUALITATIVE TO QUANTITATIVE

The work of people such as Mazur and Arons illustrates convincingly that "quantitative competence" can be achieved in the absence of solid conceptual understanding. Indeed, the need to develop robust quantitative skills is still essential to physics education at high school and university levels. The MAP project has developed well over one hundred high quality applets that can be used both qualitatively and quantitatively to enhance student experience and foster the development of understanding. Figure 4 shows a snapshot of **circuit**, an applet that allows students to construct complex electrical circuits.

In this example the student has constructed a simple parallel circuit with three light bulbs as shown by the image on the left. The student is then asked to predict the outcome of closing the switch that forms the parallel branch in the circuit (image on the right). Such examples abound in the research literature and all report the same basic finding; apparently strong students capable of calculating the resistance and current across circuit elements are at a loss to make a prediction based on simple conceptual thinking. Students simply lack much needed experience on which to build conceptual schema that will enable them to arrive at answers to questions like the one posed above.

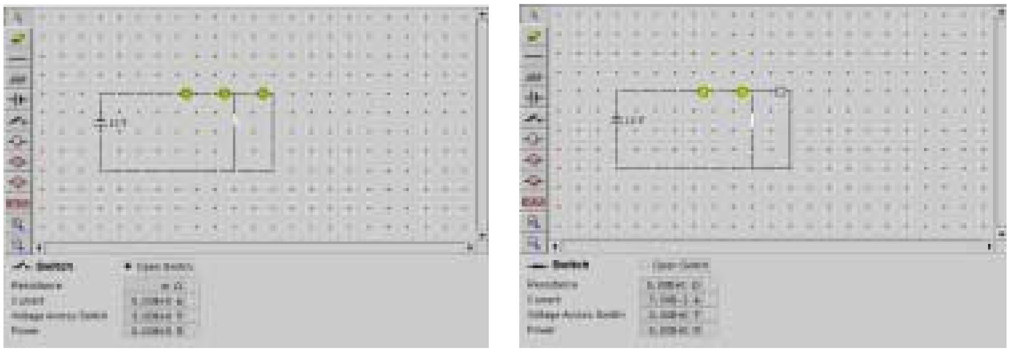

Figure 4 The applet circuit which enables students to construct any number of basic electrical circuits that can be used both to test conceptual growth as well as quantitative mastery of the basic concepts of circuits.

In the same way, Figure 5 shows the applet **accelIncline** which depicts an accelerating surface which can be oriented at any angle. A mass sits on top of this surface.

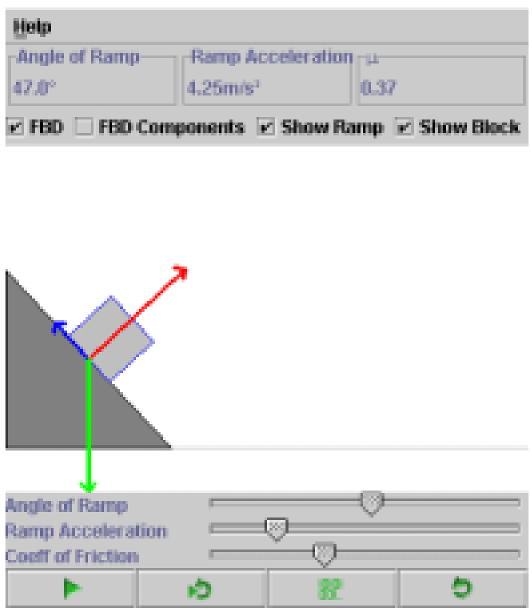

Figure 5 The applet accelIncline which enables students to investigate the physics of friction and skidding motion.

The applet can be used to investigate conditions of skidding as well as plumbing the student's understanding of such basic concepts as normal and frictional forces. This represents a sophisticated set of concepts working together and its introduction would most likely have been preceded by a number of simpler, primarily conceptual applets.

A final example of applets designed to enable the development of quantitative competence is provided by **atwood**. This applet, shown in Figure 6, enables the student to simulate an Atwood's Pulley in which both pulley mass and the supported masses can be adjusted. A particular feature of this applet is the creation of "data collection objects". These are primitive variables (time, velocity etc) from which the student can build and graph more complex expressions. Data Collection Objects are a feature of all MAP project applets that employ the graphing classes and hence data collection can be activated in any MAP applet where this feature would be appropriate.

Figure 6 The applet atwood which simulates the motion of an Atwood's pulley. By pressing the appropriate buttons the student can display free-body forces or a graphical representation of salient variables.

In this example the student has created an Atwood's pulley with a pulley mass of 0.768 kg and with masses of 0.284 kg and 0.716 kg respectively. When the student presses the play button the masses and pulley begin to accelerate. Figure 7 shows the graphical output from this instance. In particular it shows the result of graphing total potential and kinetic energy as well as total energy for both masses. The total energy line (blue curve) is not constant indicating "missing energy" from the system which, of course, resides in the rotational energy of the pulley.

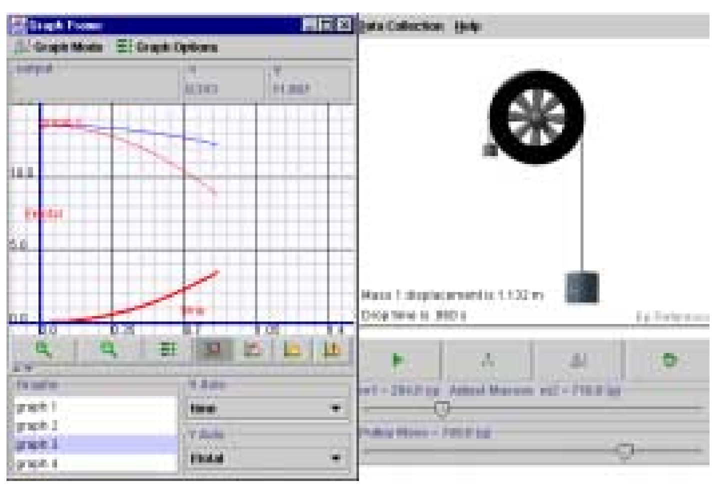

Figure 7 The applet **awood** used with data collection in effect showing the ptoential and kinetic energy of the masses but not the pulley in this system.

In all of the applets developed by the MAP project the design philosophy has been guided by a constructivist intent to create tools that enable and require student input and engagement. This sometimes comes at the cost of "performance" or apparent sophistication of the applet but is consistent with a desire to encourage the development of rich educational environments in which student understanding can take root and grow.

BUT DO THEY WORK?

The MAP project is entering its fourth year of development and over the past year many of the applets and modules developed by MAP have been used in pilot studies at The University of Alberta and The King's Universtiy College, Edmonton. As a significant part of his doctoral studies in the Department of Secondary Education at The University of Alberta, Mr Guoqiang Zhou (Zhou et al, 2000) has investigated the efficacy of the MAP materials in influencing student conceptual growth and attitude development in first year physics. Although the main study is not yet complete and the details will be published elsewhere, two interesting results have emerged. First, the Force Concept Inventory Test or FCI (Hestenes et al 1992, Mazur, 1997) has been administered to 7 first year classes (n = 600) divided as 4 control groups and 3 treatment groups. All three treatment groups demonstrated a statistically significant improvement in performance on FCI post-tests compared to their control group counterparts. This is encouraging.
Second, the control and treatment groups were also given attitude post and pre tests to assess any shift in their enjoyment or assessment of physics (did they find physics hard, did they enjoy physics etc). In this case there was no significant difference between control and treatment groups and no significant change between pre and post test results. While we would have "liked" to see a positive change here, there are many factors that influence a student's disposition toward a subject. Since the control and treatment groups were, for the most part, students taking physics to fulfill other program requirements, it may be overly ambitious to expect our materials to have great impact here.

CONCLUSIONS

At the time of writing the MAP project has created a rich array of Educational Objects (Flash animations, JAVA applets and HTML modules) which cover the first term of material presented in most North American university physics courses. Work is progressing to extend the range of topics developed to include second and third terms of physics. In all cases an underlying constructivist philosophy motivates this work. Students are challenged to be active users of the applets and this has translated into a measured improvement in student conceptual growth. Computer hardware and software are finally reaching a level of power and sophistication that will enable teachers and researchers to develop subtle and effective methods to encourage constructivist teaching techniques. The challenge that lies ahead is the large-scale transformation of the pedagogical practices of science teachers to better utilize these emerging tools. It is our hope that the MAP project and its outcomes will play a significant role in this transformation.

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