Physics

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Summary. In the teaching of physics information technology has been adapted for a variety of instructional strategies. IT has been valuable as physics teachers modify their instruction based on research concerning the teaching and learning of physics. Thus, the most common use of IT is in student laboratories. There, students collect data using video and measurement software tools or sensors interfaced to a computer. IT is also used to enhance interactive learning in large classes and to help students understand abstract concepts even when they do not have a strong mathematical or scientific background.

Physics teachers were early adopters of information technology and multimedia techniques for interactive instruction. Almost as soon as desktop computers became available, physics teachers began creating interfaces that allowed students to collect data from experiments in the classroom. At about the same time physicists were developing instructional materials for analog, interactive videodiscs – an early form of today's interactive multimedia. Programming simulations and using productivity software such as spreadsheets also became components of physics teachers' "toolboxes." To date all of these methods have advanced significantly while sophisticated model building and computer algebra have been added to the collection of available materials. Today, information technology has become a vital part of the physics teachers' presentations and the physics students' education.

One area in which physics teaching has moved to the forefront is in the use of information technologies to have students collect data from experiments. This data collection is conducted primarily with either interface boxes that connect the computer to sensors in the classroom or with video from which students can make measurements. (At present the use of audio for this type of data collection has been rather limited, but it may be increasing in the future.) Throughout the development of these IT techniques, emphasis has always been placed on student-centered materials rather than using IT for demonstration purposes.

1 Underlying Instructional Principles

The emergence of information technologies (IT) for use in physics education has coincided with the development of physics education research as a significant force in understanding how students do and do not learn physics. For the past 25 years, several groups, primarily in Europe and the United States, have been investigating what students learn when teachers teach physics. These studies have ranged from case studies to interviews with small groups of students to collecting large amounts of data with multiple-choice instruments. (McDermott & Redish, 1999) Much effort has been focused on student understanding of the concepts in physics rather than the algebraic manipulations. (McDermott, 1991; Redish, 1999) Another line of work has looked at how physics instruction contributes to students' overall intellectual development. (Zollman, 1996) For example, one would hope that completion of a physics course would help students improve their abstract reasoning skills, hypothetical-deductive reasoning, and ability to build models to explain observations. All of these studies have reached conclusions that have strongly affected the way IT is used in physics instruction. One important conclusion is that students build conceptual models of the physical world even though they have never had a physics course. Because they live in a world where motion, forces, and electrical interactions are apparent every day, the students create their own principles of physics long before they have formal instruction in the topic. These naïve views of the world cannot be ignored when teachers teach their physics class. Instead, instruction must help students confront directly these preconceptions and help them modify their preconceptions to become consistent with the more generalized principles of physics.

While standard lecture style instruction can be effective in teaching students to use the equations of physics, it has some definite limitations when one considers the concepts that underlie those equations. Richard Hake (1998) has coined the phrase "interactive engagement" to distinguish a form of instruction which involves the students in an active intellectual way in their own learning. Looking primarily at conceptual understanding of Newton's Laws, Hake has shown that the interactive engagement methods are significantly better in helping students understand the concepts than the more traditional instruction. These results seem to be independent of whether the class involves algebra or calculus, high school or university students and independent of the students' level of knowledge when they enter the course. Because almost all physics teachers have a strong interest in having their students learn concepts as well as mathematical manipulations, interactive engagement has become increasingly popular in the teaching of physics.

The general intellectual development of students is almost always a goal for physics teachers. Research on students' intellectual development, which began in the early 1970s for college students, shows that the instructional strategies that are used can be critical to fostering a variety of reasoning skills. (McKinnon & Renner, 1971; Renner & Lawson, 1973) Many different strategies have been developed over the past 20 years, but all of them have some common features. First, they engage the student in an active learning process prior to introducing a new concept. This active learning frequently involves hands-on experiments or interactive information technology. It also provides the first way for students to confront any preconceptions they might have about the topic. After these exploration activities, students learn a new concept or a few new concepts that tie various components of the activities together. Immediately after the new concepts are introduced, the students apply them to new situations. These applications, again, involve interactive engagement in a variety of ways that will bring out issues that were not clearly understood. In the late 1970s Karplus (Karplus, 1977; Karplus, Renner, Fuller, Collea, & Paldy, 1975) developed this *learning cycle* which he based on Piaget's model of intellectual development. Since then many variations on the basic theme have been created for the teaching of physics and the other sciences. All of them have had a profound influence on the development of IT applications.

Because research into student learning of physics was emerging at about the same time as IT applications in teaching and learning, each has had a very strong influence on the other. Research has frequently taken advantage of the capabilities of IT so that the collection of information about student understanding could become more efficient and more complete. At the same time, developers of IT applications have responded to the ever-increasing knowledge of how students do and do not learn physics. In particular, IT applications in the teaching of physics are frequently:

- centered on active student engagement rather than teacher presentation,
- focused on development of conceptual understanding as well as analytical manipulations,
- constructed to recognize that students bring well-developed models of the physical world to their physics instruction, and
- consistent with attempts to improve the long-term intellectual development as well as knowledge of specific ideas in physics.

These goals are reflected in the applications and examples that are described below.

2 Data Collection with Video

Using video for the collection of data seems to have developed more in physics instruction than in any other field. (Zollman, 1993; Zollman & Fuller, 1995) While many multimedia developers will use video sequences to exemplify a point or even to offer choices among several scenarios, physics teachers are somewhat unique in providing the means for students to collect physical measurements directly from the screen and even to complete these measurements from videos that the students have taken themselves. The techniques used for this type of instruction provide powerful means for connecting abstract models to concrete, real-life events.

This type of instruction began in the early 1980s with the advent of the interactive, analog videodisc. With the introduction of the videodisc, which was read by a laser, for the first time one had the capability of stopping a video scene indefinitely on an individual picture (called a frame) or playing the video at a variety of speeds both backward and forward. These capabilities offered the physics teacher a new way to present motion and to have students collect measurements from scenes.

Early efforts to have students collect data from video scenes preceded along two different fronts. In one case the developers attempted to control the videodisc with an external computer and mix computer video with that coming from the videodisc. Because broadcast television and computer video have many incompatibilities, this approach was limited to a few relatively expensive and cumbersome systems. The lower tech approach involved a stand-alone videodisc, a clear acetate transparency, and marking pens. (Zollman, Curtin, & Noble, 1987) With this rather simple early multimedia system, students could mark locations of objects as they appeared on the screen, then move forward a few frames and mark them again. From this process, the students learned the position of the object of interest in each of the frames. They could easily determine the time for the motion because video frames are recorded at a precise rate (30 frames per second in NTSC video and 25 frames per second in PAL and SCAM). While this process was a little cumbersome, it became reasonably popular because the data collection could be done quickly and the resulting data could be easily connected to graphs of the results. (Beichner, 1996; Brungardt & Zollman, 1995)

Teachers also went beyond simply collecting data points. Students were introduced to using simplified models to describe complex motion and connecting those models directly to the real objects. (Zollman et al., 1987) For example, a question posed on the *Physics of Sports* videodisc (Zollman & Noble, 1986) was, "Why does a high jumper go through such complex motion in order to clear the bar?" This question can be answered by using physics. However, one cannot treat the high jumper as a simple point of mass. Instead, she must be considered as an extended body that has components that move relative to one another. Thus, the student must adopt some of the research methods of kinesiology in order to answer this question. A model in which the athlete is considered to be a small number of rigid segments with hinges as the joints can adequately answer the question. When students use one of these models and draw them on top of the athlete as she completes her motion, they see that the center of mass of the athlete does not necessarily go over the bar. Thus, they are able to use a rather complex, contemporary research technique to apply physics to a situation that has inherent interest for a large number of students.

While the analog videodisc and marker system is still being used in some situations, it has been replaced in most instruction by a combination of digital video and software that has been developed especially for collecting data such as that described above (for more information on digital video see Chapter 9). With video that has been digitized in any of the common formats, the incompatibility between the video and the computer output disappears. Thus, it is possible to easily create a system in which the students move a cursor over a point of interest, click, and the computer collects data on the location of the object. (Laws & Pfister, 1998) In this case the computer knows the time between consecutive pictures so it can automatically collect two dimensions in space and one in time for each mouse click. Modeling complex objects such as the high jumper can be done rather easily with software such as *Videopoint* (Luetzelschwab, 1998), *VideoGraph* (Beichner, 1998), and *VidShell*. (Davis, 1998).

In situations where students are looking at models of complex events, this software can provide advantages far beyond the convenience of not needing to draw on the screen and take physical measurements. Once the students have collected the data and marked all of the points of interest on each of their video frames, they can play back the model as an animation. Playing the video and animated model together provides students with a way to see both the application of their model and its limitations in a particular situation. For example, students could be limited to a model in which the body must be represented by two rigid segments with a hinge.

They must decide whether to put that hinge at the hips, the knees, or somewhere else. By trying each model they can discover the advantages and disadvantages of each and at the same time learn how scientists must make compromises in order to have simplified models fit the real world. By removing the video and playing just the model students then take another step in abstraction. Thus, they begin to learn how science moves from real world events to relatively simple abstract models that can be used to both explain and predict.

Moving reference frames can also be dealt with very well with video measurement software. Some of the measurement systems have the ability to change the origin of measurement from one frame to the next built into them. This option opens up these measurement techniques to almost any commercial video independently of the motion of the camera. For example, students who are interested in how special effects are created in film could see how the laws of physics apply to any scene even though the camera moved and the measurement capabilities are somewhat obscured. Video analysis has also been used to teach the concepts of reference frames and Galilean relativity directly. (Escalada, Zollman, & Grabhorn, 1996; Escalada & Zollman, 1996) Students may complete video analysis by placing a camera in a moving reference frame and looking at an event that is either in the moving reference frame or in a frame fixed to the earth. By looking at the same event in both fixed and moving reference frames, the students can learn about the invariance of the principles of physics as one changes from one inertial system to another. These techniques have proven to be quite effective in teaching this topic that requires some rather abstract reasoning to be able to understand it.

The advent of inexpensive video capture for personal computers has enabled many teachers to allow students to collect data from experiments that they do themselves. A significant advantage to this approach is that the students know that the video has only real components in it. They, of course, see on film and TV that special effects can do anything. Thus, recording the video themselves assures them that they are analyzing a real world event. Research on this type of teaching and learning indicates that students learn very effectively from these types of video experiments and that these instructional methods are quite consistent with many students' learning styles.

Today, collection of data via video and software can be easily done with almost any standard multimedia computer. While it is helpful to have a camera so students can collect their own video, a large amount of video is available for this purpose and can be obtained easily. Thus, the video analysis is a convenient and inexpensive way for physics teachers to interactively engage their students with information technology.

3 Computer Based Laboratories

Using sensors to collect data about physical events and feeding the resulting information into a computer has long been a part of experimental physics research. Thus, it is no surprise that physics educators quickly embraced the concept of student use of sensors and computers to collect information in a laboratory. (Jong & Layman, 1984; Shirer, 1965; Tinker, 1986) When desktop computers were relatively small and slow, the term microcomputer based laboratory (MBL) was coined to describe this type of instruction. While the computers today are far from "micro," the acronym MBL has stuck and is still frequently used to label any system of instruction that includes a computer, an interface box, and a collection of sensors to collect data.

One of the earliest and most ubiquitous forms of data collection was a device that collected distance/time information through a relatively simple range finder. The range finder emits pulses of ultrasound and measures the time for the echo to return to the sensor. (Thornton, 1994; Thornton & Sokoloff, 1990a) In this way it can simply calculate the distance between itself and the object off which the sound has reflected. While the device was originally developed for automatic focus on Polaroid cameras, its use in physics teaching was immediately apparent. Thus, the development of an interface and software that enables a computer to interpret these signals and create distance time curves has long been a favorite device for use in teaching kinematics. The sensors available today provide physics students and teachers with the opportunity to collect data over the entire range of topics taught in an introductory physics class. Force, acceleration, temperature, voltage, current, and radioactivity are among the variety of variables that students can measure with an MBL system. All of these data can be collected quickly and analyzed with a variety of specialized or productivity software packages. Thus, MBL has become a significant part of student-centered physics instruction.

The most obvious advantage of using MBL is its convenience over more traditional data collection techniques. Students do not need to painstakingly record a large number of data points and then enter them into either computers or calculators for analysis. Further, they can quickly repeat a measurement if they make an error in setting up or executing an experiment. However these advantages pale in comparison to the pedagogical advantages for which there is significant evidence. (Laws, 1997; McDermott, 1990; Redish, Saul, & Steinberg, 1997; Wilson & Redish, 1989)

For students who are developing their hypothetical deductive reasoning, concrete examples of answers to the question, "What if. . . ?" are always very useful. With an MBL system answering such questions is relatively easy. For example, research has shown that students frequently believe that mutual force on two colliding objects is a function of the masses of those objects. Contrary to Newton's Third Law many students will tell us that the more massive object in a collision will exert a greater force on the less massive one. Rather than relying on the abstract reasoning of Newton's Laws, a teacher can simply ask a student, "What if the mass of one cart is twice as much as the other? What does that mean about the relative sizes of the forces?" With two carts and two force probes students can quickly answer this question for themselves. The graphs and numbers that come from the experiment provide ample concrete evidence of the validity of Newton's Third Law. To assure themselves that this law is generally applicable, the students can easily and quickly collect data for a variety of different masses of each cart and see that in each case the forces applied are equal and opposite. Thus, students see in a concrete way the validity of the general principle that has long proven difficult for students to understand and resistant to change through traditional instruction.

Drawing and interpreting graphs is another area where student understanding has been below the level that is desirable for good physics instruction. Graphs, of course, can quickly provide visual clues to data that have been collected or to the relation among variables in a general principle. However, if students do not have the ability to look at a graph and understand what it means, these visualization techniques are of little use. Research into the value of MBL in helping students understand graphing has been rather extensive. Conclusive results show that students who complete a variety of exercises in which they plot motion and simultaneously see the graph develop on the computer screen helps in their ability to understand and interpret graphs. Sokoloff and Thornton have completed several studies in which they investigated the ability of real-time graphing to help students understand and interpret kinematics graphs. (Thornton, 1994; Thornton & Sokoloff, 1990a, 1990b) Many of these experiments compared students who were able to watch motion and the graph at the same time and then discuss the results. When compared with students who were taught about kinematics graphs in a more traditional format, the MBL students show a significant improvement in their abilities to interpret graphs that they had not previously seen.

Kinesthetic procedures have also been quite important in teaching about motion graphs. (Pfister & Laws, 1995) Students are presented with a graph of motion, sometimes X versus T and sometimes V versus T, and asked to reproduce the graph by moving themselves in front of a motion detector. By recreating this motion the students actually feel the motion. Thus, they are able to increase their understanding by putting themselves through the motions and seeing their own graphs in comparison to the one that they were supposed to produce.

The value of the real time nature of MBL has also been investigated. The results of these studies indicate that being able to see the graph of the motion at the same time that the motion is developing produces greater learning than even a short delay between the time at which the motion occurs and the graph is observed. (Beichner, 1990; Brasell, 1987)

While the greatest amount of research on student learning has been conducted with respect to motion and forces, MBL activities have been introduced in the teaching of almost all concepts in introductory physics classes. In many of the most important applications these activities are not treated as isolated experiments to be performed separate from the rest of the course. Instead, Laws, Wilson, and others have used these activities as part of an integrated, student-centered physics course. (Cummings, Marx, Thornton, & Kuhl, 1999; Laws, 1991; Wilson, 1994) In some cases such as *Workshop Physics*, the traditional lecture is removed entirely from the first physics course. Instead, students use combinations of activities that are IT based and others that are using more traditional instructional techniques to construct their own knowledge of the physics under investigation. Another approach, commonly called *Studio Physics* also removes the traditional lecture from the physics class. In

Studio Physics as developed at Rensselaer, student-centered learning activities were created using the Comprehensive Unified Physics Learning Environment (CUPLE). (Wilson & Redish, 1997) This environment was developed over a number of years and provides some basic tools for the creation of interactive instructional materials. (Wilson & Redish, 1989) In CUPLE, an author has visualization, graphing, and computer-based laboratory modules which can be used in a larger context. At present, several universities have used this authoring environment to create materials appropriate for student-centered learning.

4 Portable Laboratory Measurements

In recent years, a relatively low-tech version of computerized data collection has added a new dimension to this type of instruction. The *calculator based laboratory* (CBL) developed by Texas Instruments, which has recently released a new version (`http://www.ti.com/calc/docs/sdata.htm`), is an interface box that enables students to use sensors and store the resulting data in a programmable calculator. This system and a similar one marketed by Casio (`http://education.casio.com`) offers physics teachers a rather low-cost way to have their students collect real-time data. While programming the interface device through a calculator is somewhat more cumbersome than using the computer, many of the same advantages as with the computer are available. In addition, both, the interface box and the calculator, are battery-operated. Thus, the students are not physically tied to a computer that must be connected to a power source. They are able to take data in any location where they can carry the small CBL interface box. In fact, the interface itself has some internal memory, so it can be disconnected from the calculator once it is told what type of data it is collecting. Students have collected kinematics data on devices ranging from roller coasters at amusement parks to bicycles.

Some of the computer interface boxes have also been made in a portable version. Both Pasco (`http://www.pasco.com`) and Vernier (`http://www.vernier.com`) market interface boxes that can be connected to a computer and programmed to collect data from specific sensors. Then, the battery-operated interface box can be disconnected from the computer and taken into the field. With the sensors still attached the student can turn the data collection on and off as needed. When the data are collected, the interface box is attached to the computer again and the data are downloaded into the computer for analysis. This system provides more sophisticated software tools for the analysis than the CBL but it does so at a somewhat greater cost.

With any of these portable systems, limitations in the memory can limit the amount of data that students can collect. Euler et al. (Braune, Euler, Schaal, & Zollman, 2000; Euler, Braune, Schaal, & Zollman, 2000) have attempted to overcome this limitation by storing data on audiotape. Their application involved collecting distance-time data for bicycles being ridden by students. They used a standard sensor from a bicycle speedometer that changes voltage each time a magnet passes the sensor. This change in voltage produces a sound if the voltage output is connected to the microphone input of a tape recorder. While audiotape is a rather old-fashioned data storage device, it provides an inexpensive way to obtain almost unlimited data. These data can be brought into a computer through any standard sound board and with a little bit of software manipulation be turned into appropriate kinematics data for a bicycle's motion.

5 Expanding the Topics Which Can Be Taught

A significant advantage of applying IT to physics teaching is the ability to use numerical and visualization techniques and introduce more sophisticated concepts to lower level students. Eisberg (Eisberg, 1976) published one of the earliest examples of this procedure when he showed how numerical methods could be used with programmable calculators to provide students with graphical experiences about concepts ranging from falling objects in the presence of air resistance to Schrödinger's equation. Prior to the advent of IT in the physics classroom, topics such as objects falling through air generally were avoided because of the complexity of solving the differential equation that results from applying Newton's Second Law to such a situation. However, simple numerical techniques allow one to treat this equation as a series of steps each one of which involves only simple arithmetic. Students with no background in calculus or differential equations can understand the reiterative nature of a process such as Euler's method.

The repetitive nature of numerical solutions to differential equations lends itself nicely to productivity software such as spreadsheets. (Misner & Cooney, 1991) The numerical display of the spreadsheet enables students to understand how simple arithmetic can be used repeatedly to solve relatively complex physics problems. Thus, the spreadsheet has become used frequently in many different levels of physics instruction. Other software has been developed specifically to provide interactive visualizations for students to study topics that have heretofore been considered too abstract and advanced for beginning students. The Visual Quantum Mechanics project (Zollman, 1999, 2000) has incorporated interactive visualization with hands-on experiments and traditional paper-and-pencil exercises to provide introductory students with an understanding of contemporary physics. The visualizations enable students to create models of atomic processes so that they can see how their observations lead to conclusions such as the quantization of energy in an atom. Other activities provide students with interactive means to understand how the wave nature of matter provides a theory to explain this quantum effect. Similar graphic representations presented in an interactive format are available in materials such as *Graphical Schrödinger's Equation* (Jarecki, 1997), *Quantum Science Across the Disciplines* (Garik, Abegg, Brecher, Robblee, & Hurwitz, 1999), and several efforts to animate the time development of a wave function (Lacks, 1996a, 1996b). In each of these teaching units, the authors have developed visualization materials that enable students with a limited mathematical background to learn about the abstract science of the atom. Solutions to differential equations are replaced with graphical representations of those solutions. Students are provided with the necessary knowledge to be able to interpret those graphical representations and come to an understanding about the physics involved.

While quantum physics is perhaps the most obvious topic for which the building and testing of models can be completed with students who might otherwise be unable to do so, many other projects have addressed model building and hypothesis testing using IT for other concepts in physics. The Constructing Physics Understanding (CPU) project is notable for providing students with interactive programs in which they can create models of systems such as electrical circuits and optical instruments and test their models by manipulating components which behave in realistic ways. (Goldberg et al., 1999) These types of hypothesis creation and testing activities have long been goals of physics teaching but have been elusive to implement before the advent of modern IT technology.

Using an environment similar to a video game has not been exploited extensively in physics teaching. *Electric Field Hockey* is an exception. In this simulation students must places charges on the screen so that another charge will follow a path that enables it to reach a goal. In *Guilty or Innocent* (Fuller, Winch, Armstrong, & Fuller, 1994) students play the role of an expert witness to an automobile collision and must apply physics to determine the cause of the crash. However, very few other examples of games which directly teach physics are available.

6 IT for Large Classes

While some teachers have dropped the large lecture class entirely from their teaching in favor of small group interactions using computer or multimedia programs, others have embraced IT to provide a greater degree of interactivity in lecture hall environments. Sokoloff (Sokoloff & Thornton, 1997) has pioneered the development of interactive lecture demonstrations that use MBL measurement devices. He can set up a situation in which sensors will take measurements and graphs will be displayed in the lecture hall. He asks the students to sketch out predictions for the shapes of the graphs and to use physical models and laws to explain their predictions. Once the data are taken and the graphs are displayed, the students are asked to compare their predictions with the actual results of the experiment and resolve any differences. This approach provides students with a direct confrontation with many of the misconceptions that they may have about the physical laws under investigation. The resolution of these conflicts based on evidence from experiments has been shown to be a valid way to allow the students to construct their own knowledge about physical principles.

Others, most notably Mazur (Mazur, 1997), have used lecture response systems both as a means of checking how well students are understanding the physical principles being presented in a class and as a means to have the students confront their own learning difficulties. In Mazur's "Peer Instruction" he presents a conceptual question that the students are asked to answer individually. Once all of the students have answered the question and entered their answer into the keypads in the lecture hall, Mazur asks the students to discuss their answers with their neighbors and to resolve any differences in opinion about the correct answer. Thus, the students' peers help them confront any incorrect responses and to understand what the correct answer is and why it is correct. Research on student learning in this environment has indicated that conceptual understanding of the laws of physics has increased as a result of the peer instruction.

Web-based homework submission and feedback systems have also proven to be rather valuable in many courses but particularly in courses with large enrollments. Systems such as the *Computer-Assisted Personalized Approach* (CAPA) and *WebAssign* provide means by which teachers can give each student in a class an individual assignment (Kashy et al., 1993; Titus, Martin, & Beichner, 1998). Because the systems accept a wide variety of different types of input as responses, the homework problems can be very similar to those that would be assigned if they were to be graded from written work. In most systems students will need to complete the homework solutions with paper and pencil and then enter the results into a web page. Immediate feedback on the quality of the answer enables students to check their understanding quickly. At the teacher's discretion students can be allowed to rework the problems that were not correctly answered the first time. The web-based homework systems cannot provide the type of feedback that would be available if a teacher could individually grade each homework problem and provide students with information about the process they took to get to the answer as well as the answer itself. However, because of limited staffs, many physics courses cannot provide that type of feedback for its large enrollment classes. Thus, the present level of web-based grading of homework offers a way to motivate students to complete the homework and some significant feedback on the quality of their work. As the software develops further, it is likely to come closer to providing the type of feedback that is now only available through human interaction.

7 Advanced Level Instruction

Stand-alone software that addresses issues of teaching and learning beyond the introductory physics courses has been developed in a limited quantity. A notable collection is the *Consortium for Upper-Level Physics* that created a large number of individual programs that could be used in various advanced undergraduate physics courses. (Antonelli et al., 1995; Bigelow, Philpott, & Rothberg, 1995; Brandt, Hiller, & Moloney, 1995; Danby, Kouzes, & Whitney, 1995; Ehrlich, Roelofs, Stoner, & Tuszynski, 1995; Gould, Spornick, & Tobochnik, 1995; Hawkins & Jones, 1995; Hiller, Johnston, & Styer, 1995; Keeler, Rollins, Spicklemire, & Johnston, 1995) These materials provide the students and teachers with interactive graphics that allow them to explore physical principles related to concepts ranging from classical mechanics through astrophysics.

Similar programs on specific topics are available from Physics Academic Software (`http://webassign.net/pasnew/aboutpas.html`). These programs have been peer-reviewed and generally focus on one topic in physics. While many of them are for an advanced level student, some are useful in introductory courses.

At the advanced level attention has also been paid to the use of algebraic software such as MAPLE and Mathematica for instruction. (Gass, 1997; Horbatsch, 1995; Tam, 1997) Several authors have created code that can be put into these programs and then manipulated in a variety of ways. Output is generally in the form of graphical solutions that the students then interpret in much the same way as was discussed above for the introductory students.

8 Conclusions

Overall information technologies have made a profound change in the way that physics is taught at all levels of instruction. Because physics teaching has always emphasized experimentation, it is not surprising that one of the greatest influences and changes has been on the introductory instructional laboratory. However, these technologies have also had a profound influence on how physics is taught outside the laboratory and even on what topics are presented to students and at what level the teacher feels comfortable presenting them. Explorations into how to teach a variety of topics are likely to continue for the foreseeable future, as is research on the effectiveness on IT in the teaching of physics at all levels.

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