Integrating Technology in Teaching Secondary Science and Mathematics

Effectiveness, Models of Integration, and Illustrative Examples[1]

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1 Introduction

The last four decades of the twentieth century witnessed unprecedented advances in electronic technologies in general, and information technologies in particular. These advances have profoundly impacted the nature and practices of the scientific enterprise. Computation is becoming an increasingly crucial aspect of scientific investigation. Breakthroughs in micro- and super-computer hardware and software design, and developments in networking capabilities are rendering the analysis, modeling, and visualization of complex systems an increasingly important component of various scientific disciplines. For example, in the physical sciences, current understandings of atomic and molecular structure and complex states of matter rest largely on computation. In the biological sciences, the ability to reconstruct genomes (human and otherwise) relies on supercomputers as much as on automated and rapid sequencing machines, since these latter machines produce random fragments of genetic code that must be assembled like a vast one-dimensional jigsaw puzzle. Similarly, computing capabilities that were not available only two decades ago are transforming the very nature of mathematical "proof." In mathematics, which was once almost entirely a deductive enterprise, inductive approaches to proofs—made possible by almost infinite iterations of varying mathematical representations performed by supercomputers, are being increasingly recognized and utilized.

The use of computer-based instructional technologies (which will be referred to as "IT" in the present paper) in teaching pre-college science and math goes back to the 1970s in the form of Computer-Assisted Instruction (CAI) (Christmann & Badgett, 1999). These early uses of IT, nonetheless, were limited to simplistic, unidimensional, drill-and-practice applications, which did not carry much promise for educators especially in light of enhanced and deeper understandings of the realties and complexities of learning and classroom environments (Mandinach & Cline, 1994). However, since the early 1980s, science and math educators have become increasingly interested in the educational implications, both curricular and pedagogical, of advances in information technologies. First, educators realized that such technologies were increasingly becoming an integral part of science and math, and that this change in the nature of the scientific enterprise had significant implications for pre-college science and math curricula. To successfully prepare students for future careers in science and math, as well as for citizenship in an increasingly scientifically and technologically laden world, pre-college curricula need to incorporate learning about information technologies as target instructional outcomes (information technology as "ends") (American Association for the Advancement of Science [AAAS], 1990, 1993; National Council of Teachers of Mathematics [NCTM], 1987, 1989, 1991, 1995; National Research Council [NRC], 1996). Second, educators came to believe that technological advances greatly enhanced the potential of IT as effective pedagogical tools, which could enhance the learning of science and math content and processes (information technology as "means") (Bereiter, Scardamalia, Cassells, & Hewitt, 1997; Hannafin & Land, 1997; McCluskey, 1994; Scardamalia & Bereiter, 1996). The present paper focuses on this latter pedagogical potential of IT in secondary classrooms and is divided into four main sections.

First, the paper summarizes the (refereed, published) empirical research that assessed the effectiveness of IT in promoting learning in secondary school (defined here as grades 7–12) science and math classrooms during the last decade. Second, the paper explores effective strategies for integrating IT into the teaching of secondary science and math. The third section presents an illustrative list of science and math teaching software packages and tools.

Finally, the last section provides an overview of the implications of the inclusion of IT in secondary science and math teaching.

2 Effectiveness of IT-Enhanced Secondary School Science and Mathematics Teaching

2.1 IT in Secondary Science Classrooms

Science educators have argued that IT could help teachers provide students with varied and rich opportunities to learn science content (e.g., facts, principles, and theories) and processes (e.g., collecting, analyzing, and evaluating evidence) (Duschl, 1990). To a large extent, technology in science education is still an emerging field and research in this area has primarily focused on a small number of relevant variables (Weller, 1996). Thus, while such research will hardly furnish any firm conclusions regarding the effectiveness of ITs, it will nonetheless shed light on the potential of such approaches, and the realm of associated instructional possibilities. The range of technologies explored in this line of investigation includes CAI, simulations and microworlds, microcomputer-based laboratories, and interactive videodiscs, multimedia, and hypermedia.

2.2 Computer-Assisted Instruction

CAI includes approaches that utilize computers to deliver information in a step-by-step manner that is similar to programmed learning. CAI aims to enhance student achievement of specific content-related instructional objectives (Simonson & Thompson, 1994; Weller, 1996). Findings on the effectiveness of CAI are, at best, equivocal.

Jegede, Okebukola, and Ajewle (1991) compared the achievement of 12th grade Nigerian students who studied biology for three months under two different approaches. The first utilized traditional lecture/demonstration while the second approach made use of an interactive CAI instructional package, which presented students with text and graphics followed by question-and-answer sessions. No significant differences were found between the biology achievement of the experimental and comparison groups.

Lazarowitz and Huppert (1993) assessed the influence of integrating a computer-assisted learning program into classroom-laboratory instruction on 181 (82% female) grade 10 students' knowledge of bacterial growth and science process skills. The treatment spanned three 45-minute periods per week for four weeks. Compared to students in the control group who received conventional classroom-laboratory instruction, students in the experimental group used the program to simulate and construct graphs of microorganism growth. Females in the experimental group achieved significantly higher scores than the control females on content knowledge and science process skills (specifically, interpreting data and controlling variables). No such differences were found for male students in the experimental group.

Yalcinalp, Geban, and Ozkan (1995) compared the effect of utilizing a CAI tutorial program versus traditional recitation sessions to supplement classroom instruction on students' understanding of chemical formulas and the mole concept. Participants were 101 grade 8 students in two general science classes. Both experimental and control students attended the same lectures, but received differential supplementary instruction (i.e., CAI versus recitation sessions). Students in the experimental group scored significantly higher than those in the control group on a test that assessed their knowledge and comprehension of the target concepts, as well as their ability to solve problems involving these concepts. It should be noted, nonetheless, that the above three studies did not control for significant confounding variables, such as novelty and teacher effects, and the increased efforts usually invested in novel approaches that are introduced into otherwise traditional educational settings.

Christmann, Badgett, and Lucking (1997) conducted a meta-analysis that compared the academic achievement of students in grades six through twelve who received either traditional instruction or instruction supplemented with computer-assisted instruction (CAI) across eight curricular areas. The mean effect size for science—derived from eight relevant research studies, was 0.639 in favor of the CAI students. This mean effect size, it should be noted, was highest among all eight academic areas investigated and indicates a relatively substantial effect for CAI on the achievement of secondary science students.

More recently, Christmann and Badgett (1999) conducted a meta-analysis of the research that assessed the effect on the academic achievement of science students exposed to—versus those not exposed to, CAI within four academic areas (general science, biology, chemistry, and physics) and across three educational settings (urban, rural, and suburban). Eleven research studies met predetermined selection criteria (related to research design, sample size, and data analysis) and were included in the analysis, which revealed a positive but small overall mean effect size of 0.266. For the 2343 students included in the analysis, this overall effect size means that "the difference in academic achievement resulting from CAI was an improvement of 10.4 percentile ranks from the central region on the distribution" (p. 140). However, effect sizes for the different subject areas varied substantially: General science: 0.707, physics: 0.280, chemistry: 0.085, and biology: 0.042. Similar differences in effect sizes were found across educational settings with students in urban settings achieving the highest gains (0.685) and those in rural settings achieving the lowest (effect size: 0.156). Students in suburban settings achieved relatively small gains (0.273). The authors concluded that CAI was more effective than traditional instruction in enhancing achievement among science students. Nonetheless, this conclusion should be viewed with caution given the relatively small overall mean effect size.

2.3 Simulations and Microworlds

Computer simulations allow learners to interact with representations of theoretical systems or of the natural world. Learners can change the states of a system by manipulating certain variables, thus allowing them to explore relationships between these variables or assess their impact on the entire state of the system. Microworlds are elaborate and complex simulations that allow learners to design investigations and collect data to test their own hypotheses. According to Thomas and Hooper (1991), simulations could be classified into four categories: (a) "experiencing" simulations, which allow learners to explore a certain topic prior to the formal presentation of related content, (b) "informing" simulations, which are used in lieu of textbooks to transmit certain bodies of information to learners, (c) "reinforcing" simulations, which aim to reinforce learners' understanding of specific instructional objectives by providing them with opportunities to apply previously learned concepts, and (d) "integrating" simulations, which allow learners to integrate their knowledge and understanding of a number of seemingly independent facts and concepts that were learned more-or-less separately. According to Weller (1996), a fifth category includes "conceptual change" simulations. The use of these latter simulations is aligned with conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982), which assumes that learners bring into the learning environment strongly held preconceptions about the workings of natural phenomena. These preconceptions are often at odds with scientific conceptions and have been shown to survive traditional science instruction. Conceptual change simulations are designed to challenge learners' preconceptions and allow them to assess the viability and fruitfulness of alternative conceptions, which are aligned with canonical/scientific conceptions, in the hope of getting students to revise their extant ideas.

Geban, Askar, and Ozkan (1992) investigated the effects of computer-simulated experiments on students' chemistry achievement, science process skills, and attitudes toward chemistry. Participants were 200 grade 9 students assigned to two experimental conditions and a control group. Over the course of nine weeks, students in the control group studied chemistry under a traditional approach, whereas students in one of the experimental conditions used computer-simulated experiments to investigate chemical concepts. The results indicated that the simulation-based approach produced significantly greater achievement in chemistry and science process skills, and fostered better attitudes toward chemistry than the conventional approach.

Friedler, Merin, and Tamir (1992) compared the impact of conventional laboratory instruction and similar instruction with an integrated simulation on grade 10 students' learning of enzymatic reactions. The simulation itself did not include questions or provide answers, but served to reinforce participants' understanding of the target concepts. Experimental students demonstrated better learning outcomes than comparison students. White (1993) found that six grade 8 students who studied force and motion over the course of two months using a microworld achieved higher scores on a test that assessed their ability to apply the target concepts to real-life problems than students who studied the same concepts under a conventional instructional approach. Both studies, however, did not seem to control for the instructional method in use or the novelty effect (Weller, 1996).

In a qualitative study, Roth (1995) analyzed student-student and student-teacher discourse that was captured as students conducted force and motion experiments using a Newtonian microworld (*Interactive Physics*). Participants were grade 11 students enrolled in a qualitative physics course. Roth found that as students interacted with the microworld and with each other, their initially jumbled and fragmented discourse about the target concepts was slowly transformed into well-defined descriptive and explanatory categories, which were consistent with canonical Newtonian ideas.

In the genre of studies that utilized "conceptual change" simulations, Grosky and Finegold (1994) assessed the impact of simulations on the learning of students in grades 9-12. The simulations in use elicited participants' preconceptions about "force" by asking them to predict the behavior of the system under study and then presenting them with the corresponding representation of the system. Next, to engender dissatisfaction with their naïve ideas, participants were presented with an alternative representation of the system's behavior resulting from the application of canonical models of force. As hoped for, the resultant discrepancies led students to revise their naïve conceptions of force, albeit to varying extents. Similarly, Weller (1995) found that grade 8 students revised their naïve concepts of dynamics in response to simulations, which presented them with representations that were at odds with these preconceptions. Almost all 60 participants in Weller's study ascribed to three naïve ideas of dynamics and were randomly assigned to experimental and control groups. The experimental students interacted with two simulations on free fall and horizontal motion while the control students completed an irrelevant task. Contrary to students in the latter group, students in the experimental group showed significant and desirable changes in their understanding of dynamics.

Hennessey et al. (1995) assessed the impact of instruction that utilized simulations coupled with practical activities on grade 10 students' conceptions of force and motion. Intervention students worked in small groups and their interactions with the simulations were guided by worksheets. Similar to the above two studies, these simulations were designed to make students aware of the limitations of their own ideas and to present them with more accurate conceptions with the aim of helping them build alterative frameworks that were internally coherent and consistent with observations of the simulated environment's behavior. Relative to their counterparts in comparison classes, students in the intervention group demonstrated more sophisticated reasoning and understandings of the target concepts as measured by immediate and delayed tests. Tao and Gunstone (1999) assessed the impact of computer simulation programs, which were developed to confront learners' naïve ideas, on 12 grade 10 students' conceptions of mechanics. Students worked collaboratively in pairs to conduct "predict-observe-explain" tasks with the simulations. In addition to administering pre-, post-, and delayed post-tests, data were collected throughout the study to generate profiles of participants' conceptions at different junctures of the intervention. Only a few students achieved context independent and stable conceptual change. The remaining students demonstrated a range of naïve and scientific conceptions, which were fluid and dependent on the context within which they were invoked. Tao and Gunstone concluded that to be successful in engendering stable improvements in learners' conceptions, learners using conceptual change simulations must be guided to perceive the commonalities and accept the generality of the target science concepts across contexts.

Finally, Jimoyiannis and Komis (2001) investigated the role of computer simulations in challenging student alternative conceptions and developing their functional understanding of the concepts of velocity and acceleration in the motion of projectiles. Participant grade 12 students were assigned to experimental and control groups. Both groups received traditional classroom instruction. Additionally, computer simulations were used to augment instruction for the experimental group. Students working with simulations achieved significantly higher scores than their control counterparts on a posttest that assessed their understanding of the target concepts. Thus, there is growing evidence to suggest that, when properly designed and implemented, simulations could foster conceptual change in secondary students' naïve ideas.

2.4 Microcomputer-Based Laboratories

A microcomputer-based laboratory (MBL) is a program that interfaces electronic probes or sensors, which are used to collect analog data (e.g., temperature, pressure, force, acceleration, pH) about a physical system, with a microcomputer or graphing calculator display. MBLs convert the collected data into digital input, which is then transformed into graphical representations in real time (Nakhleh, 1994). Many science educators (e.g., Huetinck, 1992; MacKenzie, 1988; Mokros & Tinker, 1987; Nakhleh, 1994; Weller, 1996) believe that MBLs hold the most promise of all computer-based science teaching tools for fostering inquiry environments in which students design and conduct investigations, and collect data to adjudicate between alternative hypotheses and explanations. Compared to other IT-assisted science instruction (e.g., simulations, microworlds, interactive videodiscs) students using MBLs still interact firsthand with physical phenomena rather than with (simplified) abstract representations of those phenomena. Indeed, as MacKenzie (1988) noted, MBLs represent the middle grounds between two science laboratory extremes. The first being the traditional laboratory, which is inaccurate, limited in scope, and time intensive, and the second being computer simulations, which are abstract and eliminate the hands-on kinesthetic involvement of students with the investigated phenomena.

To assess the validity of this latter point, Beichner (1990) conducted a media-comparison study in which a MBL experiment on projectile motion was changed into a simulation by substituting computer graphic representations for kinesthetic experiences with an actual projectile. Participant high school students worked in small collaborative groups and were assigned to one of several conditions: (a) MBL groups who performed the simulation experiment with and without viewing an actual projectile demonstration, (b) conventional groups who conducted the experiment using traditional stroboscopic photographs with and without viewing an actual projectile demonstration, and (c) control groups who were limited to non-laboratory instruction and did not perform experiments. Students in the MBL simulation group did not perform any better than those in the conventional and control groups. Thus, there is evidence to suggest that the kinesthetic feedback component of MBLs might represent an advantage over other computer-based approaches lacking such a component.

Adams and Shrum (1990) assessed the impact of MBLs on grade 10 general biology students' ability to construct and interpret graphs. Twenty students were split into two groups. The first used MBL exercises and the second group used conventional laboratory exercises as instructional supplements. No significant differences were found between participant students' ability to construct or interpret graphs even after controlling for cognitive developmental level, graphing ability, and gender. It should be noted, however, that MBLs could not have been expected to offer students opportunities to learn graph construction given that in this medium the computer automatically generates such graphs.

Nakhleh and Krajcik (1994) assessed the impact of three approaches—MBLs, pH meters, and chemical indicators, on 14 grade 11 students' understanding of acids, bases, and pH. Following their study of acid-base chemistry, participants completed a set of titrations using one of the above three approaches. Concept maps were used to assess students' understanding of the target concepts. Participants who used MBLs achieved substantially higher scores on their concept maps than students in the other two groups reflecting a higher degree of differentiation and integration of their knowledge of acids, bases, and pH.

Kelly and Crawford (1996) used systematic discourse analysis to study the interactions and interpretations of specific tasks of four grade 12 laboratory groups working with MBLs. The MBL experiments were designed to help participants make links between oscillatory motion and corresponding graphical representations. The use of MBLs allowed students to acquire, manipulate, and analyze data, which facilitated the initiation of rich discourse about the target phenomenon and the construction of understandings that approximated accepted scientific concepts.

Finally, Alessi and Pena (1999) compared the effects of computer-augmented instruction versus traditional expository instruction on students' ability to understand physical concepts. Computer-augmented instruction featured three presentation formats: MBL, simulation, and computer-based text. Students learning under the computer-augmented approaches demonstrated significantly better understanding than comparison students.

Moreover, both MBL and simulation presentation formats were more effective than computer-based text.

2.5 Interactive Videodiscs, Multimedia, and Hypermedia

Definitions of interactive videodiscs, multimedia, and hypermedia abound in the literature (Liao, 1998). For instance, interactive videodiscs are defined as mediums in which a videodisc is linked to, and consequently controlled by, a microcomputer allowing information on the videodisc (e.g., print, still images, moving images, and computer graphics) to be combined into instructional units that react to the learner's behaviors (Weller, 1996). Interactive multimedia are defined as instructional programs that include "a variety of integrated sources . . . intentionally designed in segments, [such that] . . . viewer responses to structured opportunities influence the sequence, size, content, and shape of the program" (Schwier & Misanchuk, 1993, p. 324). Hypermedia are defined as "software programs which consist of networks of related text, graphics, audio files, and/or video clips through which users navigate using icons or search strategies" (Gayeski, 1993, p. 5). These definitions, nonetheless, are consistent in two major respects. The first is the multiplicity in presenting and representing information, and the second is interactivity between the user and the information (Liao, 1998). In general, the terms interactive videodiscs, multimedia, and hypermedia, are used synonymously and interchangeably in the literature.

Levin (1991) used an interactive videodisc-enhanced *HyperCard* stack to enrich instruction on earthquakes for grade 7 students in five science classes. Immediate posttests indicated that females achieved significantly higher scores than their counterparts who did not use the videodisc-enhanced medium. Male achievement in the intervention group, nonetheless, dropped slightly. The increased female achievement was attributed to the fact that students worked in collaborative groups, which is a mode of learning preferred by females. Moreover, students without the videodisc enhancement achieved higher scores than the intervention group on a delayed retention test.

Turner and Dipinto (1992) found that grade 7 students who use hypermedia to create multimedia reports on mammals achieved the same level of content learning as students who used traditional word processors to prepare their reports. Qualitative data collected during the 16 35-minute sessions during which intervention students were using hypermedia tools, indicated that these students achieved a new and qualitatively more elaborate perspective on organizing information about living organisms. Beichner (1994) conducted a similar but extended qualitative study that focused on nine grade 7 and grade 8 students as they carried out a two-year investigation of animals in a nearby zoo. Participants used multimedia tools to produce a set of screens augmented with relevant textual information to be used in a touch-screen visitor information booth at the zoo. Analyses of students' discourse as they engaged the task and their responses during formal and informal individual interviews, and examinations of student products indicated that they achieved gains on several levels. These students demonstrated a stronger tendency to work independently, reviewed and retained a sizable body of information about the zoo animals they investigated, and developed metacognitive skills, such as those involved in prioritizing concepts to be reported about the target animals.

In contrast, Orion, Dubowski, and Dodick (2000) assessed the impact of multimedia authoring on student learning about earthquakes in the context of a multi-disciplinary environmental unit. Thirty-two grade 12 students participated in the study and were provided basic background information about earthquakes using laboratory experiments and field trips. Next, students conducted in-depth independent projects on selected topics related to earthquakes and used multimedia software to prepare and present their projects. Analyses of data collected using questionnaires, interviews, observations, and concept maps, and analyses of student projects indicated that an integration of laboratory exercises, field trips, and independent projects, resulted in meaningful learning of the target concepts. However, contrary to findings reported by Turner and Dipinto (1992) and Beichner (1994), the present study found no evidence to support the claim that using multimedia contributed to knowledge acquisition.

Yildirim, Ozden, and Aksu (2001) assessed the relative impact of hypermedia learning environments versus traditional instruction on the acquisition and retention of declarative, conditional, and procedural knowledge in biology. Participants were 39 grade 9 students who were assigned to experimental (hypermedia learning environment) and control (traditional instruction) groups using a matched-pair procedure. Both groups were administered pre-, post-, and retention tests. No significant differences were found between the two groups in terms of acquiring declarative, conditional, and procedural knowledge. However, the experimental group retained all three types of knowledge significantly better than the control group.

Finally, Liao (1998) conducted a meta-analysis of research studies that investigated the effects of hypermedia versus traditional instruction on students' achievement between the years 1986 and 1997. Of the 35 studies that met the selection criteria and were included in the analysis, five were specifically related to science. The overall grand mean for all 35 study-weighted effect sizes was 0.48 indicating only a moderately positive impact of hypermedia environments over traditional instruction. However, the overall mean effect size for the five science-specific studies was 0.89 indicating a high positive effect (Cohen, 1977) on student achievement of using hypermedia in science instruction as compared to more traditional approaches.

2.6 IT in Secondary Math Classrooms

2.6.1 Computer-Assisted Instruction

CAI in mathematics is mainly related to structured drill-and-practice or tutorial software. Drill-and-practice software are often cast in the form of computer games that embed practice exercises in interesting contexts. Tutorials present information in a direct teaching mode, which is coupled with problem-solving or question-and-answer sessions. Thompson and Riding (1990) designed an animation software to display a transformational proof of the Pythagorean Theorem. Participant middle school students were assigned to one of three groups: The first was presented with the animated proof, the second with a discrete computer representation of the same proof, and the third group saw the proof on paper. A posttest indicated that the animated-simulation group scored significantly higher than the other two groups.

Funkhouser and Dennis (1992) assessed the impact of CAI software on 71 high school students' mathematical achievement and problem-solving ability. Participants were assigned to a treatment group in which instruction was supplemented with the use of a problem-solving software, and a control group, which experienced traditional mathematics instruction. The treatment spanned a full semester. After controlling for grade point average, students in the experimental group performed significantly better in mathematics than those in the control group. However, no significant differences in problem-solving ability were evident between the two groups.

Schumacker, Young, and Bembry (1995) assigned 294 grade 8 and 9 students to an experimental group, which studied algebra over the course of one semester using a commercially available software, and a control group, which received lecture/discussion instruction. Participants were administered an algebra achievement test, and three attitude scales to assess their anxiety, attitude toward success in math, and confidence in learning math. Data analyses indicated that the traditional lecture group scored significantly higher than the experimental group on the algebra achievement test. The traditional group mean algebra score was 0.72 standard deviations higher than that of the CAI group. Moreover, no significant differences were found between the two groups in terms of their scores on all three attitude-scales.

As noted earlier, Christmann et al. (1997) conducted a meta-analysis across eight curricular areas comparing the academic achievement of secondary school students who received either traditional instruction or traditional instruction supplemented with computer-assisted instruction (CAI). However, unlike their aforementioned findings regarding science (see above), the mean effect size for mathematics was positive (in favor of the CAI students) but low (0.179), indicating, at best, a minimal practical effect of CAI on secondary students' math achievement. As such, the research results are mixed as far as the effectiveness of mathematics CAI goes.

2.6.2 Simulations and Microworlds

The term "microworlds" was first introduced by Pappert (1980), who invented the Logo programming language. Math microworlds, which are often designed using Logo, are computer programs that present models of the real world and allow students to explore, manipulate, and experiment with these models. Microworlds provide environments for students to experience mathematical ideas and discover the processes with which they will interact with such ideas. Several exploration goals could be generated within a certain microworld by virtue of various teacher input. Important features of microworlds include their potential to motivate students and provide them with immediate feedback, and their flexibility in generating a multiplicity of problem situations and a variety of dynamic connections between symbol, graphic, and numeric representations (McCoy, 1996). Most of the research on microworlds has been conducted with elementary school students (e.g., Clements, Battista, Meredith, Swaminathan, & McMillen, 1994; Johnson-Gentile, Clements, & Battista, 1994; Thompson, 1992) and indicates a relatively moderate positive impact on students' mathematical achievement. A somewhat negative point about microworlds, however, is that students sometimes manipulate a microworld and achieve visual solutions to problems without achieving the corresponding conceptual understanding of relevant mathematical concepts (Simmons & Cope, 1990).

Edwards (1991, 1995) assessed the impact of a microworld for transformational geometry with graphical, visual, and symbolic representations on middle school students understanding of this construct. Participants interacted with the microworld as an exploratory learning environment over the course of several weeks. The researcher collected rich qualitative data in terms of observations of, and individual interviews with participant students and found that the microworld was effective in helping students build a rather deep understanding of the complex construct of transformational geometry.

Roberts and Stephens (1999) compared the geometry achievement of three groups of high school students. Each group comprised 16 students whose grade levels ranged from sophomore to senior. The first group attended regular classroom instruction using paper, pencil, compass, and ruler. The second group attended a computer laboratory once a week in addition to activity-based classroom learning. The third group had experiences similar to those of the second group. However, students in this latter group worked in the computer laboratory twice a week. The second and third groups utilized commercial geometry software that allowed them to build and manipulate geometrical worlds. Over the course of the treatment which spanned one full semester, participants covered 12 geometry chapters and were administered semester pretests and posttests, as well as an achievement test for each of the 12 chapters. No significant differences were found between the three groups save on their test scores for an introductory chapter and the chapter on transformational geometry. However, in both of these latter cases, students in the traditional instruction group scored significantly higher than those in the two experimental groups. These results stand in contrast to those reported by Edwards (1991, 1995). Clearly, more research on the impact of microworlds on the mathematical achievement of secondary school students is needed. Barely any, even tentative, generalizations could be made based on the few research studies available.

2.6.3 Programming Languages

Accessible programming languages, such as Logo and BASIC, transform the microcomputer into a sort of mathematical laboratory in which students actively construct and manipulate mathematical ideas and concepts, and practice and develop reasoning skills. While programming, students "create math" and the computer provides them with immediate feedback, which guides them in exploring, building, and refining mathematical ideas and concepts (McCoy, 1996). Research findings prior to 1990 were summarized by Liao and Bright (1991) who conducted a meta-analysis of 65 research studies that compared the effects of using programming languages versus more traditional approaches on student cognitive abilities. The overall mean effect size was 0.41 in favor of programming students, an effect which Liao and Bright characterized as depicting a "mildly effective approach for teaching students cognitive skills in the classroom setting" (p. 262). The meta analysis revealed two additional findings. First, Logo and Pascal were significantly more effective than BASIC, which is explicable on the fact that both Logo and Pascal provide more structured environments than BASIC. Second, students in high school programming courses achieved significantly lower than their counterparts in elementary classrooms. This latter finding could be attributed to the fact that the one-semester high school courses were less structured and lacked clearly defined objectives and assessments compared to the shorter more concentrated or longer more stable courses often offered at the elementary level (McCoy, 1996).

Since the early 1990s much of the math education research with programming has been done with Logo. Logo programming is often used to improve students' knowledge and understanding of geometry through experiences with what is referred to as "Logo turtle geometry." The "turtle" is a (diamond-shaped) figure, which could be made to move along the microcomputer screen by using Logo programming commands. Students are challenged to write programs that would cause the turtle to prescribe certain geometrical figures. In this way, students are provided experiences with, and explore the features of geometrical figures thus providing them with opportunities to learn about geometry and develop creative, critical, and reasoning skills.

Olive (1991) assessed the impact of learning Logo programming in a semester-long course on 30 grade 9 students' knowledge of geometry in a discovery-oriented environment. Data included records of participants' keystrokes as they engaged various tasks, and scores on posttests that assessed their knowledge of geometry and programming. Results indicated that success in learning Logo was necessary but not sufficient for learning geometry. In other words, to learn the target geometrical concepts students had to perform well on relevant Logo tasks. However, such performance did not guarantee learning the geometrical concepts.

Mevarech and Kramarski (1993) assessed the impact of cooperative and individualized Logo environments versus traditional instruction on 83 grade 8 students' creativity, including figurative-originality, verbal-flexibility, and verbal-originality. Students in the individualized and cooperative Logo groups outperformed students in the traditional environment on all three measures of creativity. Additionally, students in the cooperative Logo environment developed more positive interpersonal relationships than students in the other two groups. These findings indicate that embedding Logo learning tasks in a cooperative environment not only enhanced students' figurative creativity, which is important in developing geometrical thinking, but also promoted the development of better interpersonal skills, which are associated with more positive attitudes toward self, fellow students, and subject matter.

In two similar but independent studies, Yusuf (1994, 1995) assessed the effects of Logo based instruction on secondary students' understanding of four fundamental concepts in geometry: Points, rays, lines, and line segments. Participants in the first (Yusuf, 1994) and second study (Yusuf, 1995) were 32 and 67 grade 7 and 8 students respectively. Participants were assigned to either an experimental condition, in which Logo was utilized to solve geometrical problems, or a control condition, which featured more traditional instruction. In both studies, the same teacher—the regular classroom teacher, taught the experimental and comparison groups in order to control for teacher effects. Participants were administered pre and post achievement and attitude tests. Also, a sample of participants was individually interviewed to assess their conceptual understandings of the target concepts. In both studies, students in the experimental group scored significantly higher than their counterparts in the control groups on all administered measures and demonstrated a deeper conceptualization of all four fundamental geometrical concepts.

More recently, Kramarski and Mevarech (1997) investigated the effects of augmenting a problem-solving based Logo approach with metacognitive training on 68 high school students' ability to construct graphs. Four intact classrooms were randomly assigned to one of two treatment groups. The first was exposed to a problem-solving based Logo environment with metacognitive training, while the second group experienced the same Logo environment without the metacognitive training component. Students were administered a graph construction examination prior to and at the conclusion of the study. In addition, exist interviews were used to assess participants' cognitive and metacognitive behaviors following the treatment. Although both groups demonstrated significant improvements in their graph construction abilities, those students who were exposed to the metacognitive treatment tended to construct graphs better than their counterparts who were not exposed to such treatment. In addition, interview data indicated that the metacognitive training also enhanced students' information processing, social-cognitive interaction, and error detection. Combined with results from their aforementioned study (Mevarech & Kramarski, 1993), these results indicate that the effects of Logo-based approaches to teaching geometry could be maximized by embedding Logo instruction in cooperative learning environments and augmenting it with metacognitive training.

This examination of the literature indicates that Logo programming, especially turtle graphics, is an effective approach for providing students rich experiences with, and enhancing their knowledge and understanding of geometrical concepts. This effectiveness is particularly increased when classroom teachers are heavily involved in planning Logo instruction and monitoring its implementation (Clements & Battista, 1990; MaCoy, 1996).

2.6.4 Mathematics Tool Applications

Mathematics tool applications comprise software that assists students in performing math functions. Such tools are often answer/product oriented. They help students with routine computations, thus allowing them to focus on achieving conceptual understandings of mathematical ideas. Both algebraic and geometrical mathematical functions could be performed with computer tools. These tools could also be used with higher-level math, such as pre-calculus and calculus.

<u>Computer algebra tools</u>. These tools include a variety of programs that allow for algebraic symbol manipulation and accept data in either tabular or equation format and produce corresponding graphic representations of these data (McCoy, 1996). Computer algebra tools include graphing and symbolic calculators, graphing software, and integrated computer packages. Among these tools, graphing calculators are probably the ones most often used in secondary mathematics classrooms. Graphing calculators are considered to be computers because they are programmable and support several functions that computers can perform. These calculators are assumed to facilitate student understanding of functions by allowing for a multiplicity of representations (e.g., tabular, graphic, symbolic) of the same function. In addition to these latter attributes, some integrated algebra packages (e.g., *Maple, Mathematica*) allow students to experiment with symbols and functions, and to build their own understanding of algebraic concepts by linking algebraic, tabular, and graphic representations, such that any change in any one representation is simultaneously reflected in the others.

Guttenberger (1992) found that high school students who used a computer graphing tool to learn trigonometry achieved significantly higher posttest scores than students who learned the same materials through a more traditional approach. Ruthven (1990, 1994) assessed the impact of using graphing calculators on high school students' ability to represent graphs in algebraic symbols. Compared to students in the control group, students using graphing calculators demonstrated better abilities to achieve the target task. Similarly, Avolas (1994) found that programmable graphing calculators served as an effective tool to introduce middle school students to algebraic concepts and symbols.

Hinerman (1997) assessed the impact of two problem-solving methods on the achievement of two classrooms of advanced placement high school calculus students. The first method used a traditional paper and pencil approach to solve calculus problems, while the second utilized graphing calculators. Participants were administered a total of four assessments on various calculus topics over the course of six-weeks. Data analyses indicated that the graphing calculator section achieved significantly higher test scores than the traditional group on two of the four assessments. No significant differences were evident in participants' scores on the other two assessments.

More recently, Hollar and Norwood (1999) investigated the effects of a graphing-approach curriculum employing the TI-82 (Texas Instruments-82) graphing calculator on student algebra learning. High school students in the graphing-approach classes demonstrated significantly better understandings of functions than did students in the traditional-approach classes. Additionally, no significant differences were found between the graphing-approach and traditional classes in terms of their traditional algebra skills or attitude toward mathematics. Merriweather and Tharp (1999) investigated the effects of instruction using the TI-82 graphing calculator versus discovery learning on grade 8 students' attitudes toward mathematics and using graphing calculators. Participants were in three intact classes, two of which were assigned to the experimental condition, whereby students used the TI-82 to explore concepts and solve algebraic word problems. Students were administered pre- and post-attitude surveys. Additionally, participants were individually interviewed. The two groups did not differ in their attitudes toward using calculators: Indeed, both experimental and control groups were positively inclined to use graphing calculators. However, given the short duration of the study (two weeks), some students in the experimental group expressed some frustration with actually using the calculators. The authors argued that graphing calculators should be used over extended periods of time, thus allowing students to develop the expertise needed to render these tools effective vehicles to the learning of mathematics.

The use and effectiveness of graphing calculators in secondary math classrooms are the subject of continued controversy (NCTM, 1999). However, both sides of the controversy base their claims as to the effectiveness or ineffectiveness of this approach less on well designed and conducted empirical investigations and more on personal, isolated, and somewhat idiosyncratic short-lived experiences with using calculators in math teaching. The available evidence suggests that graphing calculators have the potential to positively influence student achievement and understanding in as much as they are thoughtfully used in well-designed teaching interventions with clear objectives and ample time for students to master using the technology itself.

Computer geometry tools. These programs allow students to build a variety of geometrical constructions, while providing immediate measures of relevant attributes, such as distance, area, and angles. More importantly, these software packages, such as *The Geometric Supposer* and *The Geometer's Sketchpad*, provide a geometry environment for experimentation by supporting dynamic measures, such that any change that students introduce into a single measure of their geometrical constructions is accompanied by changes in all related measures. Problems or challenges posed by teachers provide departure points for geometrical experimentation. Students then proceed by making conjectures and testing them in these dynamic geometrical environments. It is noteworthy, however, that very little empirical research is available on the "effectiveness" of computer geometry tools. Most of the relevant literature is dedicated to describing these environments and/or associated modules and lessons.

Gordon (1990) found that high school students who used *The Geometric Supposer* demonstrated better abilities to discern patterns, make conjecturers and generalizations, and interpret diagrams. These students were also motivated to explore and experiment with the software, and demonstrated discernable development in their geometrical thinking. McCoy (1991) studied two geometry high school classes, one of which used *The Geometric Supposer* during one school year. The experimental group scored significantly higher than the control group on higher-level application questions. No significant differences were evident in students' performance on lower level knowledge and comprehension questions. As such, the use of the software helped students develop higher-order thinking skills in mathematics, without influencing their achievement of lower level knowledge and comprehension instructional objectives. Additionally, Yerushalmy (1991) attempted to enhance grade 8 students' acquisition of basic geometrical concepts through an instructional intervention that focused on constructing meaningful definitions by incorporating the use of *The Geometric Supposer* into regular classroom instruction. Results indicated that students in the experimental group acquired more complete and accurate concepts given that they did not exhibit the widely held misconceptions demonstrated in the comparison group's performance. Finally, Chiappini and Lemut (1992) used a similar geometrical software of their own design to help grade 7 students' learn about three-dimensional figures, such as cubes. The study had a one-group pretest-posttest design. The software provided students with immediate feedback on, and validation of their geometrical conjectures, and allowed them to acquire integrated understandings of the target materials.

2.7 Effectiveness of IT-Enhanced Secondary Science and Math Teaching: A Summary

The diversity of software and instructional strategies used, and the variety of objectives sought by the research studies reviewed in this section make a comprehensive synthesis of the presented research very difficult. This difficulty is compounded by the fact that many of the above studies featured short-term interventions and failed to control for confounding variables, such as teacher and novelty effects, and student mastery of the technical skills needed to effectively use the newly introduced technologies. Nonetheless, a few patterns do emerge from the reviewed research studies. First, evidence regarding the effectiveness of CAI in science and math teaching is, at best, equivocal. Not only were the research findings in this regard mixed. Also, positive impacts, when found, were relatively small as reflected in low mean size effects reported in the reviewed meta-analysis studies. In light of the fact that CAI software are basically of the drill-and-practice variety and mainly target lower level knowledge and comprehension instructional outcomes, investments in these software might not yield desirable educational returns unless these latter instructional outcomes (e.g., mastery of bodies of information, algorithmic problem solving) are valued in the target educational context.

Second, as far as IT-enhanced science teaching is concerned, there is growing evidence to suggest that, when properly designed and implemented, simulations and microworlds could foster conceptual change in secondary students' naïve ideas of natural phenomena. Thus, these technologies could be meaningfully integrated into instructional approaches that specifically target helping students abandon entrenched misconceptions and adopt alternative canonical scientific ideas and explanations. Similarly, studies on MBLs and microworlds furnish promising indications that these tools could be used to create effective inquiry-oriented instructional environments in which students explore phenomena, collect data, test ideas, and build understandings of scientific concepts. Finally, the evidence suggests that, compared to more traditional approaches, videodiscs, multimedia, and hypermedia have a positive but moderate impact on students' science achievement.

Third, with regard to IT-enhanced math instruction, the above examination of the literature indicates that Logo programming, especially turtle graphics, is an effective approach for providing students rich experiences with, and enhancing their knowledge and understanding of geometrical concepts. Clearly, more research on the impact of microworlds on the mathematical achievement of secondary school students is needed. Barely any, even tentative, generalizations could be made regarding the impact of microworlds based on the few research studies available at the secondary school level. Moreover, in general, students who used math computer tools achieved significantly better than control students in conceptual area, as well as in the computation and manipulation areas. Indeed, there is evidence to suggest that computer algebra tools, especially graphing calculators, could foster better learning of algebraic concepts, such as functions. Finally, even though more research is needed to make a stronger claim, geometry tools seem to be effective in helping students develop higher-order thinking skills in mathematics, without influencing their achievement of lower level knowledge and comprehension geometry instructional objectives.

As such, even though evidence regarding the effectiveness of the various aforementioned computer-based science and math teaching approaches was mixed, it is very hard to dismiss—in light of positive evidence furnished by some of the reviewed studies, the immense potential of these approaches in providing exploration and inquiry based learning environments that could promote secondary science students' learning of not only science and math content, but also of mastering science and math processes, inquiry, and problem solving skills, and metacognitive and higher-order thinking skills. However, if any definitive claim could be made based on the above review, then that claim would be that IT, in and of itself, is *not* a panacea for secondary science and math teaching. A detailed examination of the specific instructional interventions used in above studies was not possible given space limitations. Nonetheless, such an examination reveals that, to be effective, IT-assisted instruction needs to meet certain conditions. First, instructional interventions should have clear and specific objectives, and should be carefully and thoughtfully planned to include IT in the context of science and math lessons. A simplistic add-on approach is not enough. Second, science and math teachers themselves should be comfortable with the technology and pedagogy in use, and integrally involved in all stages of developing and implementing the IT-enhanced approaches. Indeed, technologies are as effective as the individual teachers who use them. Third, the interventions should be undertaken and evaluated only after ample time is provided for students (and teachers) to overcome the frustrations associated with debugging the technical difficulties of, and learning to effectively use, a new technology or software. These aspects of successful IT interventions will be explicated in the next section on effective strategies for integrating IT in secondary science and math teaching.

3 Effective Strategies for Integrating IT in Secondary Science and Math Teaching

Probably the most significant notion to realize when approaching effective strategies for the integration or implementation of IT in secondary science and math teaching is that IT, in and of itself, is *not* a teaching approach. In other words, it cannot be simply assumed that the introduction of IT into classrooms, whether in the form of software packages or other tools, will automatically and necessarily result in improved teaching practices and/or enhanced student outcomes. Albeit admittedly more powerful, ITs are instructional tools, in the same manner that blackboards, overheads, rulers, and Bunsen burners are instructional tools. And like any other instructional tool, IT can be abused or put to good and powerful use in the service of teaching and learning.

IT could be abused and investments in IT could be rendered ineffective if these technologies are assimilated into traditional outdated pedagogies and modes of teaching. (An exception would be science and math CAI software, which are actually designed to support the acquisition of factual information and provide drill-and-practice in algorithmic problem solving.) For instance, MBLs could well be used as tools to conduct traditional verification type laboratory exercises in which students are didactically introduced to certain concepts and then engaged in a cookbook laboratory activity to "show them" that the presented ideas are valid. Of course, such an approach might have some merit in reinforcing student understanding of scientific concepts, but it would be a less-than-optimal use of the valuable and rich resource that MBLs represent (Nakhleh, 1994). Math teachers could (and sometimes do) prepare Logo programs for their students to walk into the computer laboratory, type in, and then observe the movements of the "turtle" on the monitor, thus, foregoing all the potential of this programming language to foster conceptual understanding of geometrical concepts. Similarly, science teachers could use an interactive videodisc to prepare a one-dimensional presentation about a certain taxonomic family, which is then used to supplement a traditional lecture with a few colorful images about the organisms under discussion. And even though this latter use might represent an improvement over a lecture-only lesson, it does not nearly start to realize the potential of multimedia in science teaching (Adams, 1996). One could go on, but it is hoped that the above examples would suffice to convincingly make the point that a large investment in technological resources could be rendered ineffectual by assimilating IT into "teaching as usual."

The effectiveness of ITs could be maximized, and their potentials realized by integrating such technologies into teaching practices that are consistent with a constructivist pedagogy, in which students are actively engaged in their own learning (see the fourth section for a more elaborate explication of this idea). Even though a variety of approaches have been presented under the general rubric of "constructivism," the greater majority of these approaches share a core of basic elements (Chiappetta, Koballa, & Collette, 1998). These elements include: (a) using students' preconceptions or naïve ideas of the target science and math concepts as a departure point for planning and conducting instruction, (b) providing students with opportunities to explore the target phenomena or concepts through varied and rich experiences with these phenomena and concepts, (c) encouraging students to generate their own solutions for a problem, or ideas to explain a set of observations or data (which the students could collect themselves or could be furnished with) and test those solutions and ideas through a variety of methods, (d) presenting students (where needed) with alternative explanations or concepts that are more consistent with canonical scientific and mathematical conceptions, (d) encouraging students to compare their own ideas with alternative explanation or ideas by reference to criteria, such as evidence, and explanatory and predictive power, and (e) structuring opportunities for students to reflect on the whole process for the purpose of deriving "lessons" about the target concepts and processes. It should be noted that the aforementioned elements fit into a larger process that emulates the production and validation of scientific and mathematical knowledge. As such, while engaging activities under a constructivist approach, students develop, practice (or could be taught) crucial science and math process and thinking skills.

By now, it should become clearer how the science and math ITs explored in the first section of this paper could effectively contribute to a student-centered constructivist teaching approach. A few illustrative examples will hopefully suffice to explicate such use and provide images of possible and effective uses of IT in secondary science and math teaching. These technologies could be used to effectively elicit student ideas about target concepts. A physics or a math microworld could be used to construct a simple mechanical system (e.g., an inclined plane) or graphical system (e.g., blocks of different sizes) respectively (Roth, 1995; Thompson, 1992). Students are then asked to predict the behavior of the systems when certain events are made to happen or if certain variables are changed within the system. For example, students can be asked to predict what would happen if a car were to be released from the top of, and then half-way on the inclined plane, or they could be asked to predict the number of blocks of one size needed to fill the space occupied by a block of a larger size. As could be seen, these challenges would help the teacher to elicit student ideas about Newtonian mechanics, and fractions and decimals respectively. It is not hard to see how the elicited students ideas could be used to design an instructional sequence in which their elicited ideas are challenged and/or in which students could be asked to generate ideas and explanations for the behavior of these systems and then test them by changing more aspects or variables in the system. Students can "see" what would happen for themselves by simply running the simulation.

In the same manner, students could use an interactive videodisc or hypermedia to explore a large set of organisms (e.g., mammals) or geological features (e.g., volcanoes) and try to find commonalities between these natural objects and generate their own categorization and concepts of them (Adams, 1996, Escalada & Zollman, 1997; O'Bannon, 1997). Next, students could be asked to extrapolate their ideas to new situations and explore the multimedia environment further to see whether their categorization or concepts apply to more cases and broader sets of data. Still another example, would be for students to explore algebraic functions using a graphing calculator (Cassity, 1997). Students could write functions of any form or order and the calculator would immediately generate corresponding graphical representations. By comparing algebraic and graphical representations, students could develop some intuitive ideas regarding the nature of the explored function. Next, students test these ideas further by changing different components of the function and observing the associated changes in the graphical representations.

IT provides the tools and the opportunity to engage learners in such student-centered inquiry-oriented learning environments because of several advantageous characteristics. The utilization of these characteristics should be maximized to achieve to the most effective use of IT in science and math teaching (Denning & Smith, 1997; Escalada & Zollman, 1997; Woolsey & Bellamy, 1997). First and foremost is richness and flexibility. A single science or math simulation or microworld could generate a very large number of possible worlds allowing students to explore a vast space of possibilities and test a large number of ideas, conjectures, and variables. Second, these ITs provide immediate representations and feedback, thus saving valuable instructional time and maximizing student engagement in the learning process by eliminating the need to carry out time-consuming, repetitive, and routine processes or calculations. For instance, when using a MBL, a student could change a certain variable (e.g., pH, temperature) and observe the associated changes in a graph, for instance, in real time. As such, students can test their ideas without having to go through the process of collecting a large number of data points and then plotting a graph every time they manipulate a variable in their system. Third, ITs make possible the exploration of certain events and phenomena that could not otherwise be experienced by students because they are dangerous (e.g., hazardous chemical reaction), inaccessible (remote geographical and geological feature or astronomical bodies), or beyond computation abilities usually available to teachers (e.g., 3-D graphs that could be rotated and examined from different perspectives in real time). It could thus be seen that ITs have the potential to support learning environments that improve student learning. However, realizing the potential of IT in science and math teaching is a challenge, to say the least. After exploring a few illustrative examples of science and math software and tools in the following third section, some of the challenges associated with using IT are briefly explored in the fourth section.

4 Illustrative Examples of Secondary Science and Math Teaching Software and Tools

Appendix A and Appendix B present illustrative examples of science (Tables 1.1 through 1.4) and math (Tables 2.1 through 2.4) teaching software and tools respectively. These software and tools are grouped according to the conceptual categories discussed in the first section of the paper (CAI, simulations and microworlds, videodiscs, etc.). For each software or tool listed, the tables provide the name of the developer/supplier, a World Wide Web address, corresponding grade levels, subject and topic(s) addressed, and minimal system requirements (where applicable) for the PC platform. (Many of the listed software are also compatible with the MAC platform.) In addition, the tables provide brief descriptions of each listed software or tool.

Obviously, the lists provided in Appendixes A and B are by no means comprehensive. There are literally tens of available software and tools under each category. This is especially the case for science and math CAI software packages, which provide drill-and-practice exercises and generally address lower level knowledge and comprehension instructional outcomes. The software and tools listed in Appendixes A and B were chosen either because they were used in exemplary research studies or received strong reviews from science and math teachers who have actually used them in their teaching. The listings in the appended tables are meant to define the conceptual space of computer software and tools available for teaching secondary science and math, and provide the reader with a schema for approaching these software as regards their potential usefulness and use.

Nonetheless, the task of choosing certain software packages from among the tens available in each category can be an overwhelming task. However, science and math teachers could ask a set of questions, and refer to a few signposts to aid them in achieving this task (Good, 1986). Teachers or IT-specialists could:

1. Start by defining the subject area and specific topic(s) in the context of which the software will be utilized. A search of the World Wide Web using a robust search engine (e.g., Netscape, Google, and InfoSeek) followed by an "advanced" or "refined" search could be used to identify a few relevant software packages.

2. Identify the original publisher/developer. Avoid retailers who do not usually provide technical and educational support. Once identified, check whether the publisher/developer is an educational entity or has a strong commitment to K-12 education. Such commitment is often reflected in accessible technical and educational support, educational discounts, free downloads and trial periods for teachers and educators, and associated teacher manuals and other resources, as well as affiliations with teacher organizations, research teams, and institutions of higher education.

3. Identify the category to which the software belongs. The descriptions of the various categories of science and math software and tools provided in the first section of this paper should prove useful for such identification. The teacher could then ask: Does the software cater for lower level knowledge instructional objectives (e.g., drill-and-practice software) or does it allow students to explore or inquire, build their own understandings of the target concept(s), and develop basic, integrated, and higher order thinking skills?

4. Refer to the technical literature on the software to identify the appropriateness and applicability of the software for the targeted need, as well as its flexibility: Is the software developmentally appropriate for the target students' grade and age level? What technical skills are needed to effectively use the software? Does the software address a very specific topic or does it relate to a range of topics in the subject area at hand? Software reviews are very helpful in answering these questions. However, the teacher or educator needs to make sure to refer to independent and published reviews written by teachers who have used the software as compared to "commercial testimonials" often provided by the software developer or supplier. In this regard it should be noted that the software developer/supplier not furnishing relevant educational information and materials (suggested age group or grade level, model lessons that utilize the software, references to successful instructional practices for using the software, etc.) should serve as a red flag in the process of selecting instructional software.

5. Identify the technical requirements of the software: Is the software compatible with the available microcomputer platform (e.g., PC or MAC), microprocessor (e.g., some software require Pentium-equivalent or faster processors to run properly), display (e.g., some simulations require “true color” displays and are not supported by 16 or 256 color displays), plug and play applets (e.g., some multimedia software require special sound cards and/or real-time video players), etc? Does purchasing the software entail technical difficulties or hidden costs in terms of expert troubleshooting services or updating extant hardware or software?

6. Assess the price tag on the software or tool in two respects. First, compare the pricing of similar software packages or tools relative to their features. For example, some expensive graphing calculators have added feature that high school students will not use in meaningful ways. Cheaper calculators could perform equally well on functions needed for the particular instructional objectives at hand. Second, assess the price in terms of the value-added by purchasing the software or tool and its versatility. For example, in some situations it might be educationally more beneficial, and more efficient and cost-effective in the long run to purchase more expensive microcomputers to run MBLs than purchasing graphing calculators, because the latter might not support some functions vital to the use of the MBL software and sensors in different contexts for the purpose of achieving different instructional outcomes.

7. Always pilot-test a new software or tool. As noted above, most educational publishers provide free trail periods for teachers. Even if this option is not available, teachers should purchase a single copy of a software package and pilot it in their own classrooms to assess whether it will serve their specific needs and the needs of their students.

These are a few helpful hints for acquiring instructional science and math software and tools. However, acquiring the technology is only a fist step in a more involved process. The following section provides a broad overview of the implications associated with the decision to integrate IT into the teaching of science and math at the secondary level.

5 Implications of the Integration of Technology in Secondary Science and Math Teaching: An Overview

The decision to integrate IT in the teaching of secondary science and mathematics has implications on the curricular, pedagogical, and teacher professional development levels (Becker, 1998; Buckley, 1995; Greenberg, Raphael, Keller, & Tobias, 1998; Pedretti, Mayer-Smith, & Woodrow, 1998; Usiskin, 1993). First, as noted earlier, developing an understanding of technology and technological systems, and skills in using technology (especially information technologies) could be thought of a goal for K-12 education. Such a goal has been emphasized in recent reform documents in science and math education (AAAS, 1990, 1993; NCTM, 1991; NRC, 1996). Thus, decisions regarding what technologies to use and how best to use them in the context of any efforts to integrate IT into secondary science and math teaching should take into consideration curricular outcomes in terms of the technological understandings and skills that secondary school students are desired to attain. Needless to say, if such outcomes are not part of the curriculum, then efforts to integrate IT in teaching should serve as an incentive to reconsider extant curricular goals.

More importantly at the curricular level, current approaches to integrating IT into science and math teaching are consistent with major trends in K-12 science and math education. Foremost among these is a shift from "covering the content" of science and math to an emphasis on attaining deeper and conceptual understandings of carefully selected content, and of the processes involved in the development and validation of scientific and mathematical knowledge. This shift is exemplified in a "less is more" and "depth rather than breadth" approaches to science and math curricula (AAAS, 1990, 1993; NCTM, 1991; NRC, 1996). According to these approaches, students should focus on an in-depth study of a few major ideas in science and math, rather than superficially covering an extensive list of topics. While delving deep into a few topics using exploratory and inquiry approaches, students will come to attain conceptual understandings and develop process, critical, and higher order thinking skills, as well as metacognitive skills. Such understandings and skills, it is hoped, will help students to deal with an increasingly scientifically and technologically laden world and make informed decisions regarding science and technology related personal and societal issues, as well as pursue careers in science, math, and technology. Consequently, as was demonstrated in the second section of the present paper, it might make little sense and constitute a cost-ineffective endeavor (both in monetary terms and in terms of the learning accrued) to attempt to integrate IT for the purpose of achieving outdated curricular goals, which largely focus on the memorization of a vast array of facts, principles, and theories in science and math, and feature preoccupation with algorithmic textbook-based problem-solving. Integrating technology into the curriculum invites a reexamination of curricular philosophy and content.

Second, consistent with the curricular goals of current reform efforts is a pedagogical approach based on a constructivist view of learning (von Glasersfeld, 1979, 1989). This view is radically different from more traditional conceptions in which learners are viewed as passive recipients of information, which is disseminated by teachers or other figures or sources of authority. According to constructivism, students learn by active (hands-on, minds-on) involvement with science and math concepts, which allows them to construct their own understandings of the target concepts. This view entails a pedagogy in which there is a decrease in the didactic dissemination of information and drill-and-practice activities in any medium, and an increase in the interaction with a variety of scientific and mathematical concepts and processes. Activities focused on the memorization of facts, and procedural and computational skills are de-emphasized. Instruction that targets conceptual understanding, and process skills, inquiry skills, and metacognitive skills is emphasized (McCoy, 1996; Weller, 1996). Indeed, as explicated in the above sections, IT is mostly used to foster an environment in which students explore phenomena and concepts, generate and test ideas by conjecturing and collecting data to adjudicate between alternative hypotheses, and come to build their own understating while developing essential skills. Under this pedagogical approach, teachers relegate their role as "providers of knowledge" and assume the role of "facilitators of learning." Teachers structure the learning environment and guide students in their efforts to learn. As such, the decision to integrate IT into secondary science and math teaching entails the abandonment of outdated behaviorsitic views of learning, traditional views of learners, and didactic approaches to teaching. Thus, teachers need to re-conceptualize their roles in the classrooms and reexamine their methods of teaching.

This latter point brings forth the third, and probably most crucial, implication of using IT in classrooms, namely, the professional development of science and math teachers. Indeed, despite the "fact" that the teacher is the single most important factor in the success of any attempts to implement IT in classrooms, this factor is often overlooked in efforts to integrate technology in teaching. Such oversight is associated with a "teacher-proof" conception of educational reform, which is based on the belief that if supplied with the appropriate technologies and detailed instructional plans, reasonably experienced teachers will be successful in implementing any desired change. This view is not valid because the teacher *is* the primary intermediary of the curriculum. There has been case after case in which expensive and powerful technologies were purchased only to be left mostly unused or were used in the most ineffective ways in science and math teaching (Fenster, 1998; Usiskin, 1993). Research indicates that several factors influence teachers' ability to meaningfully implement, and success in integrating IT in their classrooms. Among these factors for teachers are (a) having time to thoroughly explore and master the technology for themselves so they could effectively use it with students, (b) developing classroom management skills specific to technology use, (c) having and/or developing positive attitudes toward technology, and a belief in the value of the curricular and pedagogical advantages of using the target technology, (d) valuing and understanding how to implement student-centered inquiry-based science and math teaching using the desired technology, and (e) being actively engaged in all aspects of adopting and implementing IT in their classrooms (Greenberg et al., 1998; Pedretti et al., 1998). All of these factors, it should be noted, can—at least in principle, be addressed through extensive inservice professional development coupled with continuous monitoring and support for teachers involved in the implementation of new technologies in their teaching.

It can thus be seen that the decision to integrate IT into teaching is only a first step in a more engaged process of reexamining curricular goals and pedagogical approaches. Such reexamination entails several necessary aspects for the professional development of science and math teachers, which should be catered for throughout the implementation process.

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Table 1.1

Illustrative Examples of Science CAI and Problem-Solving Software

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Natural Selection Peppered Moths	Newbyte Educational software http://www.newbyte.com/uk	9 - 12	Biology: Evolution, natural selection, selective pressures, prey-predator relationships	In this game, students assume the role of birds and eat moths from forest trees to develop an understanding of the impact of environmental changes on the survival and appearance of individuals in a population. PC system requirements: Windows 3.1
ChemIt	Bob Gibbons http://www.chemit.at/	8 - 12	Chemistry: Periodic table, mole concept, atomic mass and weight, chemical conversions	Helps beginning chemistry students to practice conversions. An interactive periodic table houses all information students might need about each element.
Planetwatch 2.2	Raben Software and Graphics http://ourworld.compuserve.com/homepages/galen_raben/	7 - 12	Astronomy: Solar system, and motion, relative positions, and attributes of planets	A multimedia atlas of the solar system that helps students to learn about each planet's motion, atmospheres, geology and internal structure. Provides colorful photographs, animated maps, and data from Voyager,

				Galileo, and other space probes. PC system requirements: Windows 95+
Chemical Formula Tutor	ChemWare http://webnz.com/chemware/	9 - 12	Chemistry: Elements, compounds, chemical reactions, and stoichiometry	A drill-and-practice software that allows the generation of tests to help students assess their knowledge of concepts related to stoichiometry. Tests are scored immediately and a running list of scores is retained for reference and competitions. PC system requirements: Windows 95+

Table 1.1 (continued)

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
The Bungee Egg Challenge	SEEDS Software http://www.bungee@seeds2learn.com/	9 - 12	Physics: Damping, forces, elasticity, and kinetic and potential energy	A simulation of the design of an egg drop project. The relevant physics concepts are described, and tools for interactive exploration of these concepts are provided in the program. PC system requirements: Windows 95/98/00, 8-16 MB RAM, Win 3.1 requires win 32 addition
Sky Map	Sky Map Software http://Sales@skymap.com/	7 - 12	Astronomy: Basic astronomical concepts, night sky	A comprehensive planetarium and sky mapping software. Helps students to learn about the night sky by locating various astronomical objects and making projections as to the positions of astronomical objects in the night sky, as well as the dates of future astronomical events, such as eclipses. PC system requirements: Windows 95/98

Table 1.2

Illustrative Examples of Science Simulations and Microworlds

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Model ChemLab 2.0	Model Science Software http://modelscience.com/	9 - 12	General chemistry: Acid/base reactions, electrochemistry equilibrium, fractional crystallization and distillation, gravimetric analysis, kinetics, redox reactions, stoichiometry, thermal chemistry, volumetric analysis, and water quality	Covers the core topics of general chemistry. Provides pre-defined lab simulations, and has an optional Lab Wizard that allows the creation of custom simulations of a range of chemical processes, including titration, decanting, filtering, heating, hot and cold water baths, mixing, collecting gases, using indicators, and measuring temperature, weight, and pH. PC system requirements: Windows 95/98/ME/NT, 8 MB RAM, VGA+
The Bungee Egg Challenge	SEEDS Software http://www.bungee@seeds2learn.com/	9 - 12	Physics: Damping, forces, elasticity, and kinetic and potential energy	A simulation of the design of an egg drop project. The relevant physics concepts are described, and tools for interactive exploration of these concepts are provided in the program.
Interactive Physics	MSC.Software http://www.vndesktop.com/products/ip.html	9 - 12	Physics: A wide range of concepts in Newtonian mechanics	A simulation tool that emphasizes developing inquiry skills and physics knowledge. Provides opportunities for students to repeat investigations while varying different variables. Allows modeling, simulating, and exploring a wide variety of

phenomena related to Newtonian mechanics: Students can alter friction and elasticity, change or turn gravity off, and control almost any physical characteristic of an object.

PC system requirements: Windows 95/98, 8 MB RAM, VGA+

Table 1.2 (continued)

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Model It: Model Builder	Center for Highly Interactive Computing in Education http://hi-ce.eecs.umich.edu/	5 - 12	General: Model Builder does not include any pre-determined content. It provides a mechanism for students to create their own models. Any phenomenon that involves cause and effect relationships may be used (e.g., acid rain, stream ecology, photosynthetic rate). Background information concerning the phenomena being modeled should be provided to the student. It allows students to develop inquiry and experimentation skills (e.g., predicting, controlling variables)	A modeling tool that enables students to make qualitative models of cause and effect relationships. Students are able to associate objects found in the environment with measurable, variable factors, and define relationships between these factors. Students can then "run" their model and visualize it as a whole. As students become more sophisticated in their modeling, additional features of the program can be utilized to increase complexity. PC system requirements: Windows 95+
Pea Plant Genetics	Newbyte Educational Software http://www.newbyte.com/uk/	9 - 12	Biology: Mendelian genetics; independent assortment; single, double, and triple gene inheritance; codominance and complete dominance inheritance	Allows teaching Mendelian genetics by simulating breeding experiments using pea plants and observing offspring characteristics. Can display up to six genotype modes; allows unlimited generations and unlimited number of plants in each generation. Student involvement is increased by simulating the physical removal of plants to examine them and use them in the next set of crossovers. PC system requirements: Windows

	3.1/3.11/95/98, 8 MB RAM, 256 colors+

Table 1.3

Illustrative Examples of Science Microcomputer-Based-Laboratory Software and Hardware

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
LoggerPro	Vernier http://www.vernier.com/	6 - 12	Vernier furnishes a large number of probes or sensors that could be used to cover a large number of high school science concepts in biology, chemistry, physics, and earth science. These sensors include: Accelerometers, Barometer, CO_2 Gas Sensor, Colorimeter, Conductivity Probe, Current and Voltage Probes, Digital Control Unit, Dissolved Oxygen Probe, EKG Sensor, Exercise Heart Rate Monitor, Flow Rate Sensor, Force Sensors, Gas Pressure Sensor, Instrumentation Amplifier, Ion-Selective Electrodes, Light Sensor, Magnetic Field Sensor, Microphone, Motion Detector, O_2 Gas Sensor, pH Sensor, Pressure Sensor, Radiation Monitors, Relative Humidity Sensor, Respiration Monitor Belt, Rotary Motion Sensor,	The Vernier microcomputer-based-laboratory is the single most utilized MBL and most versatile. The system comprises a software package (*LoggerPro*), probes or sensors, and an interface box that links the probes to a microcomputer. The probes could also be linked to graphing calculators. Meaningful operation requires a set per group of students (2 to 3 members). The system could be used to engage students in a wide range of phenomena in the physical, chemical, and biological sciences, and help to learn a large number of related concepts, as well as develop their inquiry and higher order thinking skills. This MBL system has the added advantage of allowing students to perform several hands-on (versus virtual) experiments that are not possible to perform using traditional laboratory equipment. PC system requirements: Windows 3.1, 95+ (preferred)

		Sound Level Meter, Temperature Probes, Turbidity Sensor, Vernier Photogate, and Voltage Probe. A large number of experiments in the biological, physical, and chemical sciences are built into the accompanying *LoggerPro* software.

Table 1.4

Illustrative Examples of Interactive Videodiscs, Multimedia, and Hypermedia in Science Teaching

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Force and Motion CD-ROM	Fable Multimedia http://ww.fable.co.uk/	9 - 12	Physics: Linear, circular, and parabolic motion; collisions and conservation of momentum	Students can model the physical processes involved in collisions, vector addition, circular motion, motion time graphs, terminal velocity, projectile motion, satellite orbits and space flight. PC system requirements: Windows 95+
Digital Frog 2	Digital Frog International http://www.digitalfrog.com/	8 - 12	Biology: Anatomy, frog dissection and anatomy, vertebrate anatomy, and ecology	Students can virtually dissect a frog using this CD-ROM multimedia environment, which uses the full spectrum of full motion video, animation, sounds, narration, in depth text, and still images. PC system requirements: Windows 95+, 4xCD ROM, 8 MB RAM
GeoMedia 2	Intergraph Mapping and GIS Solutions http://www.intergraph.com/geomedia/	6 - 9	Earth science: Carbon cycle, greenhouse effect, and environmental change	An interactive multimedia CD ROM on global environmental change; provides a multi-sensory introduction to several earth science concepts using images, animation, and narration in an interactive environment. PC system requirements: 4xCD ROM

Redshift Multimedia Astronomy	Marius Multimedia Ltd. http://www.mariusmedia.com/	10 - 12	Astronomy: Astronomical bodies, and astronomical positions and motions	Provides a versatile planetarium program, a hypermedia astronomy dictionary, planetary surface location maps, and astronomical photographs and video clips. Provides guided tours and free navigation. PC system requirements: Windows 95+, 4xCD ROM

Table 1.4 (continued)

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Concept in Chemistry	Media Design Associates http://www.indra.com/mediades/	8 - 12	Chemistry: Atoms, chemical elements, compounds and mixtures, chemical reactions, acids and bases, and oxidation and reduction reaction	A videodisc that provides a huge library of images related to general topics in chemistry. Teachers can select certain images to produce series of connected presentations related to a certain topic. Students can also use the videodisc to prepare reports and presentations.
Physics: Cinema Classics 3	Ztek Co. http://www.ztek.com/	7 - 12	Physics: The greater majority of high school physics concepts	A compilation of 245 "classic" physics experiments from over one hundred sources on three double-sided videodiscs. Provides all the videos needed for most high school physical science. Includes a CD-ROM with a 2,000-page teacher's guide including lessons and activities. Software for accessing the videos is included
Interactive Biology: Mollusks	Tangent Scientific Supply http://www.tangentscientific.com/	9 - 12	Biology: Taxonomy, and mollusks classification, anatomy, and physiology	Photographs and 3-D images reveal the detailed biology of the mollusks. Detailed animations show a variety of relevant processes as they really occur. Covers unique evolutionary adaptations of the four major subclasses and presents an in depth examination of unifying organ and body structures.

	PC system requirements: Windows 95/98/NT 486 MHz+, 16 MB RAM, 2 MB HD, 4xCD ROM, sound card, QuickTime

Appendix B

Illustrative Examples of Secondary Mathematics Teaching Software and Tools

Table 2.1

Illustrative Examples of Mathematics CAI and Problem-Solving Software

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
DollarSkills **(Set 2)**	Merit Software http://www.meritsoftware.com/software/dollarskills/	7 - 9	Algebra: Percents, fractions, decimals, ratios and proportions	Helps students improve their math problem-solving skills, and provides strategies for solving word problems by showing individual steps. Students track their progress through session scores, which are kept in a management system that provides teachers with measurable results. PC system requirements: Windows 95+
MathXpert: **Pre-Calculus Assistant**	MathXpert http://www.mathpert.com/	9 - 12	Pre-calculus: Advanced algebra, trigonometry, logs, exponentials, complex numbers, trigonometric functions, and matrices	Helps students build proficiency as they direct the step-by-step solution to pre-calculus problems. Provides a total of 4,500 problems to solve. PC system requirements: Windows 95+
Spiro Math	Hufnagel Software http://www.hufsoft.com/software/	6 - 9	Basic arithmetic	A game-like program that helps students to develop basic arithmetical skills (multiplication, addition, division, and subtraction)

				by setting target values to reach. If stuck, the software provides hints toward the correct solution. Students are rewarded for getting the "right" answer. PC system requirements: Windows 95+
MathKal	Educational Software Ltd. http://www.mathkal.co.il/	7 - 9	Algebra (word problems, probability), analytic geometry, trigonometry, calculus, and linear programming	Furnishes problems for students to solve along with corrective feedback. PC system requirements: Windows 95+

Table 2.1 (continued)

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Interactive Past Papers	Computer Aided Learning in Mathematics http://www.calm.hw.ac.uk/	9 - 12	Trigonometry, analytic geometry, algebra, basic probability	An exam simulator and personal tutor. Math topics or problems are randomly selected to generate exams. Student responses are marked immediately. The software can be used in study mode (with on-screen assistance) or in exam mode. PC system requirements: Windows 95
Galactic Geometry 3D	Curry Kenworthy Software http://www.kagi.com/curry/	6 - 9	Geometry: Basic coordinate and three-dimensional graphing	A game-like software in which students get into the pilot seat and learn about volume and surface area while blasting away space debris! PC system requirements: Windows 95/98
Math Concepts Step-by-Step	Siboney Learning Group http://www.gamco.com/	6 – 9	Geometry, graphing, integers, and percent	A tutorial-driven series that helps students understand key math concepts. Students work step-by-step through a comprehensive selection of interactive tutorials with many problem-solving opportunities. Information and instruction are delivered in chunks so that students are able to progress at their own pace. PC system requirements: Windows 95/98

Table 2.2

Illustrative Examples of Mathematics Simulations and Microworlds[1]

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Blocks	Thompson (1992)	4 - 6	Numerals, decimals, basic arithmetic operations	Uses diagrams of base ten blocks to model operations with decimals. It allows for parallel and dynamic representations of blocks (concrete representations) and numerals (iconic representations), such that any change in one representation is immediately reflected in the other. PC system requirements: Windows 3.1
Motions	Johnson-Gentile, Clements, and Battista (1994)	5 - 6	Motion geometry, Cartesian coordinates	Students manipulate the motions of figures and shapes on the screen through a combination of keystrokes and simplified line commands. Allows students to make conjectures about anticipated motions and immediately test them in the microworld.
Turtle Paths	Clements, Battista, Meredith, Swaminathan, and McMillen (1994)	3 - 5	Length measurement	Students construct their own concepts of length and length measurement through the motions of a "turtle." Motion can be induced without the need to be familiar with the Logo programming language.
Dots and Rules	Zehavi (1988)	6 - 8	Graphing, Cartesian coordinates	The microworld dynamically links multiple representations (numeric, arithmetic, and

		graphic) allowing students to explore relationships between these representations and infer generalizations regarding graph construction

1Note. Very few, if any, math microworlds are commercially available. So far, these software have been mainly developed by individual math educators using the Logo programming language for research purposes. Moreover, math microworlds have been mostly used with elementary students. However, these software have strong potential for use with middle school students (grades 6 – 9), especially if their graphics and interfaces are enhanced.

Table 2.3

Illustrative Examples of Computer Algebra Tools

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Mathematica	Wolfarm Research http://www.wolfram.com/products/mathematica/	9 - 12	Numerical calculations; symbolic calculations in algebra and calculus; differential equations; graphing; and programming	A fully integrated technical computing system, combining interactive calculation (both numeric and symbolic), graphing and visualization tools, a complete programming environment, hypertext capabilities, and the ability to communicate and share data with other programs (e.g., Excel, C, C++, and Fortran programs) PC systems requirements: 486+, Windows 95/98/ME, 80 MB HD, 32 MB RAM
Maple	Waterloo Maple http://www.maplesoft.com/	8 - 12	Calculus, linear algebra, equation solving, functions, differential equations, number theory, and graph theory	An advanced computational system with symbolic, algorithmic, and numeric interfaces. Includes spreadsheets, word-processing and hyper-linking capabilities, and several programming languages. PC system requirements: Pentium +, 60 MB HD, 32 MB RAM, Windows 95/98/00/ME/NT 4.0
Live Math	Live Math http://www.livemath.com/maker/	8 - 12	Linear algebra, numeric and symbolic equation solving, functions, graphing, and	Creates symbolic “notebooks,” which could be shared on the Web. The math created is dynamic: A change in one value will ripple throughout the calculations.

		calculus	Allows for algebraic, numerical, and graphical experimentation. PC system requirements: 486+, 16 MB RAM, Windows 95/98

Table 2.3 (continued)

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
MathCad	Math Soft http://www.mathcad.com/	9 -12	Calculus, linear algebra, equation solving, functions, differential equations, and number and graph theory	Allows for equation entry and editing; automatically updates results without recalculation revealing links between algebraic functions. Allows integrating math and associated graphics into a single worksheet to easily illustrate and visualize performed calculations. PC system requirements: Pentium +, 60 MB HD, 32 MB RAM, Windows 95/98/00/ME

Table 2.4

Illustrative Examples of Computer Geometry Tools

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
The Geometric Supposer	Center for Educational Technology http://www.cet.ac.il/math-international/	5 - 12	Basic Euclidean geometry	A laboratory for inquiry into Euclidean geometry: "Ready made" and images constructed using a straightedge and compass could be built and linked together. Any movement of one image or a component of that image affects other linked figures including geometrical relations and measurements PC system requirements*: 486+, 66 MHz, Windows 95/98/NT, 8 Mb RAM, 4xCD-ROM, 256 colors
The Geometer's Sketchpad	Key Curriculum Press http://www.keypress.com/sketchpad/	6 - 12	Exploration and modeling of Euclidean geometry, analytic and transformational geometry, (also allows exploring algebra, trigonometry, and calculus)	Allows for: Euclidean constructions; translation, rotation, and dilation by fixed, computed, and dynamic quantities; measuring properties of sketches and working in rectangular or polar coordinate systems; creating animations PC system requirements: 486+, 4MB RAM, Windows 95/98
KaleidoMania! Interactive Symmetry	Key Curriculum Press http://www.keypress.com/KaleidoMania	6 - 9	Transformational geometry	Allows for dynamic creation, analysis, and animation of symmetric patterns and designs. Helps developing visualization skills essential

for understanding transformational geometry.

PC system requirements: 486+, 4MB RAM, Windows 95/98

Table 2.4 (continued)

Software	Developer / Supplier	Grade(s)	Topic(s)	Notes
Cabri: The Interactive Geometry Notebook	Texas Instruments http://education.ti.com/product/software/cabri/	8 - 12	Euclidean geometry; transformational and analytic geometry; advanced concepts in projective and hyperbolic geometry	Allows for Euclidean constructions (e.g., points, lines, triangles, polygons, circles, conics, ellipses, hyperbolas). Includes Cartesian and polar coordinates. Allows for geometric property checking, which confirms hypotheses based on Euclid's five postulates. PC system requirements: 386+, MS-DOS 3.3, 2 MB RAM, EGA, VGA, or SVGA video adapter Can be used with TI-89, TI-92+