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Theoretical Benefits and Research Findings Underlying the Use of Microcomputer-Based Laboratory in Science Teaching

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ABSTRACT

Theoretical benefits and research findings on the use of Microcomputer-based Laboratory (MBL) are considered for using MBL in a way that will be of benefit to students and teachers, and discussed as a whole for further synthesis, including the formulation of a research agenda for future consensus-based action. Based on the findings obtained from a comprehensive review of the literature, using a systematic approach, the uses of MBL were compared and contrasted for advancing understanding of the teaching and learning processes in science and mathematics. A number of benefits were proposed by MBL developers but not investigated by educational researchers. A few research studies considered the following practical aspects raised by classroom science teachers: technical problems of MBL equipment; inaccuracy or incompleteness of presentation; efficient ways for handling class time with MBL instruction; and development of MBL curriculum materials for their own instruction. This lack of research related to the use of MBL in science classrooms resulted in educational research that was neither respected nor utilized by science teachers.

Setting a research agenda based on the theoretical benefits and research findings is necessary for the effective use of MBL in science classrooms can help to maximize the prospects for successful school improvement projects while minimizing the innovation-related frustrations of individuals.

Key words: Microcomputer-Based Laboratory (MBL), science education, CAI

I. Introduction

Changing societal dynamics along with ever increasing expectations for educational institutions, a better understanding of cognitive processes, and more use of instructional technology have focused on changing how and what educators teach. Computers have proven to be of great value in the classroom as a means of providing instruction to students. Indeed, these positive contributions occur both in the classroom and in the science laboratory. One of the high potential areas for the use of computers is in the laboratory.

An educational use of the microcomputer has been to interface it with probes to serve as

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measurement devices to collect experimental data in science laboratories. This process has been labeled microcomputer-based laboratories or MBL (Tinker, 1983). The data collected in MBL activities can be viewed by the student, stored on disk, or printed for laboratory reports. Computer-interfaced labware allows the student the opportunity to experience the event while simultaneously viewing a graphical representation of the event, thus providing direct connections between concrete qualitative representations and abstract quantitative representations of an event.

The following terms are specifically defined for the purpose of this study: Expected (theory-based) outcome which is the outcome reported by developers of MBL and educational researchers as a result of the use of MBL; Documented (research-based) outcomes, which are the benefits and detriments reported in the research studies in the use of MBL for the teaching and learning of science.

Ⅱ. Research method

The researcher carefully investigated the literature related to the use of MBL and found 161 literature citations directly related to the use of MBL. The main sources have been the databases of the Educational Resources Information Center (ERIC) and Dissertation Abstracts (DAIS). A set of relevant descriptors, microcomputer-based laboratories, MBL, computer interfacing laboratory, probeware, and computer-assisted instruction and science laboratory, have been used to guide the search of reports from 1981 to 2002. The bibliographies for each report identified through these sources have been examined to locate additional reports. The advice of ERIC specialists in the area was obtained and acted upon during the identification and acquisition of MBL related documents. Anything that looked relevant to the use of MBL in the science classroom was considered as the literature base for this research. Once the documents were actually obtained, all information of particular interest was put on a database file which was created to facilitate better understanding of the general status of the MBL use in science teaching and learning.

The initial focus of this research was to find out what researchers and developers of MBL say about the effects of using MBL in science instruction. Theoretical perspectives of the literature on the use of MBL, including position papers, technical reports, and project proposals written by researchers and developers of MBL (N=109), were critically traced from the start of development through to the current state of the use of MBL in order to identify the expected (theory-based) outcomes.

Ⅲ. Results And Discussions

1. Expected (Theory-based) Outcomes Related to the Use of MBL

According to the literature, the use of MBL for science learning has a number of attractive features over other science teaching methods. The theoretical bases of these features are grounded in, a) learning theory and the use of computer in schools, b) laboratory experience for science learning, and c) graphing instruction described in the previous sections.

(1) Impact on students' science conception: The computer can play a vital role because it has the capacity to both motivate learners and focus their attention more effectively on the task at hand (Woerner, Rivers, & Vockell, 1991). MBL activities stimulate high energy discussions among the students about their findings. Students construct their understanding of the world through personal experience and observations (Linn & Songer, 1988; Settlage, 1995).

(2) Impact on students' problem solving skill: Higher-level thinking skills can be encouraged and developed by MBL (Tinker, 1989; Woerner, Rivers, & Vockell, 1991). Computers provide speed and accuracy in the analysis or laboratory data, determining experimental error, and calculating the precision and variance of laboratory instruments. With the advantages of educational technology, students can practice the scientific method that involves selecting a hypothesis, conducting observations, collecting data, testing the hypothesis, and rejecting or accepting the hypothesis. Students can think as scientists think (Linn, Layman, & Nachmias, 1987; Lehman & Campbell, 1991).

The laboratory becomes a place where learners spend time in mental activity, not in routinely collecting and recording data. Students can investigate a wider range of problems more quickly, and at a higher range of sophistication than is usual (Krajcik & Layman, 1993; Mokros & Tinker, 1987; Brasell, 1987). MBL can be useful for exploring topics in depth by allowing the student to acquire data in the laboratory through probes directly connected to the computer (Tinker, 1987; Linn & Songer, 1988; Lorson, 1991).

(3) Impact on students' prior knowledge: Prior knowledge can be quickly and easily challenged and possibly corrected if graphs, such as the kind microcomputers can quickly produce, are displayed immediately for the students' thinking and learning (Brasell, 1987). Thornton (1987) stated that experimentation with MBL allows students the opportunity to verify their intuition and modify their misconceptions.

(4) Effect of real-time graphing: One of the major characteristics of the MBL is the formation of a real-time graph as the experiment is carried out. Students are more likely to view graphs as a representation or a dynamic relationship rather than a static picture because students can see data displayed on their computer screen in an orderly array as they collect it (Mokros & Tinker, 1987). This real-time graphing allows the learner to process the information simultaneously rather than sequentially (Brasell, 1987). In this way, after the MBL experience, graphs are less likely to be seen as static pictures and more likely to be seen as representations of dynamic relationships (Linn, Layman & Nachmias, 1987). MBL links the concrete experience with more abstract and symbolic representations (Woerner, Rivers, & Vockell, 1991).

(5) Effects on students' graphing skills: MBL can help in improving graphing skills that include the ability of students to construct and interpret graphs due to the grounding of the

graphical representation in the concrete action of the students. The inclusion of different modes for expressing the material, and the fast feedback, allow students to immediately relate the graph to the event (Linn, Layman & Nachmias, 1987). Although the actual data acquisition and analysis is done by the computer, the student has the responsibility of changing the sampling rate, the length of time, and the temperature or the range of other variables, and to decide which calculations should be performed. Students can learn to distinguish dependent and independent variables by engaging in the real scientific processes (Mokros & Tinker, 1987).

(6) Impact on relationships between students and teacher: The role of the teacher is that of a facilitator and an organizer of problems for students to study, discuss, and solve. Adding technology supports this philosophy by providing rich resources for students to use as they construct their personal knowledge (Krajcik & Layman, 1993). Teachers can move away from the text toward laboratory experiments that may be more directly related to the world of the student outside the classroom (Woemer, Rivers, & Vockell, 1991).

(7) Effect of computer as a tool: MBL provides a setting which encourages inquiry and allows students more control of their own learning. MBL encourages student collaboration and guided discovery, thus providing an atmosphere conducive to student success. This increase in student success is likely to be accompanied by a positive change in attitude toward science. Since the computer plays a central role in the learning process, there should be parallel changes in attitude toward computers, and the use of computers in learning science (Barrow, 1991).

Using the computer as a tool not only increases teacher and student productivity, but also serves as an analytic tool to ask "what if" questions of all kinds of science phenomena (Tinker, 1987). The computer can save time by serving as a tool to perform onerous and distracting tasks and, as a result, students can reinvest this time in more active and productive learning (Woemer, Rivers, & Vockell, 1991). This feature can influence the attitudes of students and teachers concerning computers (Tinker, 1987).

Tinker (1987) advocated the use of MBL because of the ease of student control, the fast response of the instrument, and the ease and flexibility of data display. More traditional scientific tools, such as oscilloscopes, are difficult to use, and not easily understood by students (Thornton, 1987).

(8) Learning environments: MBL can make it possible to create learning environments in which students can be engaged in activities that they find interesting and exciting for their personal reasons. By eliminating some of the trivial and boring aspects of the traditional science class, teachers lecture less, and students become more involved in the active quest for information. This will necessarily cause a change in the classroom environment, including the objectives taught (more process-oriented skills), the teacher's role, and the methods of evaluating students. This environment can help put the fun back in science (Woerner, Rivers, & Vockell, 1991; Redish, Saul, & Steinberg, 2000).

(9) Impact on traditionally underrepresented groups: Many students, especially females and those from traditionally underrepresented ethnic or socioeconomic groups, have had negative

experiences with science, resulting in science anxiety. Complicated calculations and difficult data interpretation required by many traditional laboratory programs often aggravate this problem (Thornton, 1987). Reducing the obstacles by the use of MBL can increase participation of the underrepresented groups.

(10) Impact on different levels of student ability and experience: Underprepared, disadvantaged students are especially helped by MBL. Probeware emphasizes experiment-based science. Access to science is increased for learning-disabled students and others who do not have highly developed verbal skills (Tinker, 1987). Computer probes make it easy for students to gather data without the stumbling blocks of language, reading, tedious calculation, and graphing. Concrete physical action is directly linked to display of data on a screen (Lehman & Campbell, 1991).

A number of features more attractive than in other science teaching methods have been indicated in the use of MBL instructional approach to science learning.

2. The Research Findings on the Use of MBL

Among the 161 literature citations related to the use of MBL in science teaching, 38 were defined as research studies, including eight non-experimental studies. The findings from quantitative and qualitative research on the use of MBL have been critically investigated to identify the documented outcomes. The following review is based on the statistical information and anecdotal data rather than interpretations, abstractions, and generalizations of previous research. The following literature review will serve to identify the discrepancies between the theoretical and documented outcomes, so as to help in "sorting out truths and realities" (Tabachnick, Popkewitz, & Zeichner, 1980).

(1) Impact on students' science conception: There have been several studies on the impact of MBL on students' science conception. The MBL methods produced better results for general knowledge concepts (Brasell, 1987; Lorson, 1991; Nakhleh and Krajcik, 1994; Settlage, 1995; Russell, 1999; Hart, 2000). Pre-service science teachers used MBL also showed a positive influence on their achievement relative to motion, heat, and temperature, and also showed better confidence in interpreting physical relationships in science by providing a framework which allows them to refine their explanations and interpretations of concepts and by encouraging them to articulate and elaborate on their own personal conceptions (Barrow, 1991; Berg & Smith, 1994; Alessi & Pena, 1999).

Nakhleh and Krajcik (1994) investigated how knowledge and the type of thought processes of high school students changed while they engaged in performing the treatment tasks for the chemistry topics of acids, bases, and pH. These understandings and thought processes were followed as a function of three levels of information presented by the technology: low level as represented by the use of chemical indicator solutions, intermediate level as represented by the use of a pH meter, and high level as represented by the use of a microcomputer-interfaced electronic pH probe. They show qualitative evidence that MBL appears to help students develop deeper understanding of acids, bases, and pH concepts, as indicated by the concept maps showing more detailed differentiation and integration.

(2) Impact on students' problem-solving skills: Students show higher confidence in MBL as a problem-solving tool since they do not feel the need to monitor the data collection process (Kreuger & Rawls, 1998), and they consider MBL as the final authority in resolving any conflicting opinions, and they consider MBL as a desirable alternative to the traditional laboratory exercises performed in physical science (Barrow, 1991; MacIsaac, 1995; Durick, 2001). Several researchers have mentioned that the use of MBL improved science process skills, problem-solving, and developed higher level thinking skills, however, most of these reports are either anecdotal, descriptive in nature, or researchers' intuitions.

(3) Impact on students' prior knowledge: Students often have graphical misconceptions about how graphs are related to the concrete event. The commonly held misconceptions of graph as a picture and slope as a change of height (Clement, Mokros & Schultz, 1986) were significantly remediated through the use of MBL (Mokros & Tinker, 1987). Chiu's item analysis (1990) revealed that after using MBL, students had difficulties in remedying their misconceptions of the graph-as-picture, in particular, when the test items dealt with an object moving vertically instead of horizontally.

Barclay (1986) found that MBL instructional approaches do help in improving graphing skills, and attributes of the MBL science laboratories that seem important in this regard include: the grounding of the graphical representation in the concrete action of the students; the inclusion of different ways of experiencing the material (visual, kinesthetic, and analytic); and the fast feedback that allows students to immediately relate the graph to the event.

(4) Effect of real-time graphing: Brasell (1987) reveals the effect of real-time graphing by comparing the effect of real-time laboratory graphing (standard-MBL) and delayed-time graphic representation (delayed-MBL). The real-time MBL approach shows a graph immediately after the action is completed, while the delayed-MBL approach stores experimental data in computer memory for about twenty seconds before the graph is displayed. Students in the real-time MBL group outperformed the students in the delayed-MBL group. The researcher concludes that immediate graphing is better than delayed, and attributes the difference to the effects of real-time graphing that allows learners to process information about the event and the graph simultaneously (in parallel), rather than sequentially.

Barrow (1991) notes that MBL has a significant positive influence on students' achievement relative to motion, heat, and temperature (p=.003). He concluded in his experimental study that MBL provides students with a graphical representation of velocity as the rate of change of distance, establishes the foundation for understanding instantaneous velocity, prepares them to sketch the distance and velocity graphs of a moving object, emphasizes that all motion graphs must be drawn with respect to some pre-specified origin, and provides a visual representation of how an object can have a constant acceleration while its velocity is constantly changing.

(5) Effects on students' graphing skills: The descriptive study done by Mokros (1985)

described the impact of MBL on middle school students' understanding of graphs of distance and velocity, where they were challenged to construct different kinds of graphs via their own movements and the movements of a toy cart. After having experience with MBL, students could accurately match complex graphs of physical phenomena with written descriptions of these graphs. Chiu (1990), and Stuessy and Rowland (1989) also report that MBL provides significant increases in graphing skills. Adams (1988) found that the students experiencing MBL exercises outperformed the students who used paper and pencil in their graph interpretation tasks. Students experiencing conventional laboratory exercises outperformed the experimental students on graph construction tasks.

However, in a series of 'Computer as Lab Partner' project reports, Nachmias and Linn (1988) found that students using MBL are likely to accept wrong information when presented in a computer-generated graph. They reported that students had the ability to correctly attribute inaccurate graphs to incorrect scaling of the axes, incorrect location of the temperature probe, or incorrect probe calibration. There was no improvement in diagnosing computer graph errors due to technical problems, such as a lack of probe insensitivity and experimental variation.

Lower performance of MBL group on graphical translation from one graph (i.e., a distance-time graph) into another corresponding graph (i.e., a velocity-time graph), and interpretation of erroneous graphs, was also observed by Chiu (1990). In a study funded through a grant project called STEPS (Student and Teachers Electronic Productivity System) to Better Science, Lehman and Campbell (1991) sought to broaden the knowledge base by examining MBL use by teachers and students in a variety of science classrooms. Quantitative results obtained from classroom observations of the use of MBL and student graphing performance, show no evidence of an impact of the use of MBL on either student graphing skills or student attitudes toward computers (Lehman & Campbell, 1991; Nakhkeh, 1994).

(6) Impact on relationship between students and teacher: Most research on MBL seems to assume that teachers and students can easily articulate their thoughts and feelings about the impact of MBL through questionnaires, one-shot interviews, or tests. However, according to Turkle (1984), they are often not articulated at all, but manifest themselves in the expression of ideas through action. It is important to understand ideas that are reflective -those which the individual uses to think and work through their own situation. There is little information provided about the ways in which teachers and students use MBL in the classroom. What are also not apparent from any of these studies are the roles of the teacher and students in teaching and learning science with MBL. As Berger (1987) has emphasized, a major prerequisite for the classroom use of MBL is the understanding by teachers that MBL may provide a rich environment, and that MBL may help students understand some of the more difficult science concepts.

(7) Effect of computer as a tool: Educators often cite improved attitudes toward the computer as evidence that their students have been prepared for a world in which computers are ubiquitous. Lehman and Campbell (1991) examined the use of MBL in real world science

classrooms through triangulation of several data sources, such as student and teacher attitudes toward the use of MBL, classroom observations of the use of MBL, and student graphing performance. Quantitative results from the use of MBL show no evidence of an impact of the use of MBL on either student graphing skills or student attitudes toward computers. However, the attitudes of the participating teachers were overwhelmingly positive. MBL with pre-service physical science teachers (Barrow, 1991; Svec & Others, 1995; Preyer, 1996), and secondary science teachers (Heck, 1990) results in a positive change in attitudes toward the use of computers in learning science.

While helpful in many respects, the prior research revealed a number of problems related to the use of MBL in the school science classroom. Woerner, Rivers, and Vockell (1991) note that many educators have been slow to exploit MBL because of their lack of understanding of interfacing and computer equipment. Several researchers (Wiske, Niguidula, & Shepard, 1988; Sneider, 1987) indicated technical problems as a significant barrier in the use of MBL. Probe and equipment failures during laboratory experiments discourage students and teachers. Science teachers using MBL have been faced with the lack of suitable and standard interfaces, and the lack of transferability of the experiment from school to school (MacKenzie, 1986). Students and teachers view the computer and interfacing equipment as black box devices that tend to make science and mathematics more mysterious.

(8) Learning environments: The reviewed studies discussed learning environments in which many students engaged in MBL activities. Most of these reports are either anecdotal, descriptive in nature, or researchers' intuitions. Students described these science activities as interesting, exciting, and practical. The laboratory became a place where students spend time in active mental activity, not in routinely collecting and recording data (Albergotti, 1994). In contrast to traditional laboratories, where students spend much of their time with menial activities like recording the temperature or the value of some other dependent variable at predetermined time intervals, with the result that they often have very little time left at the end of the laboratory for data analysis (Redish, Saul, & Steinberg, 2000). In addition, the traditional lab often permitted the collection of only one set of data, and students were often sent home to analyze that data as homework, without the benefit of dialogue with other students or with the teacher. This situation discouraged the teacher and the student from taking seriously either the concept development or the problem-solving aspect of science laboratories. On the other hand, the role of the teacher in MBL class was revealed as a facilitator and organizer of problems for students to study, discuss, and solve. The technology supported this philosophy by providing rich resources for students to use as they construct their personal knowledge (Krajcik & Layman, 1993).

(9) Impact on traditionally underrepresented groups: Research shows that MBL experiences help females and underrepresented student groups feel more in control of their learning, more comfortable, more interested, and less anxious (Lehman & Campbell, 1991). Brasell's study (1987) was specifically designed to examine the differences between females and males in both performance on graphing tasks and on their attitudes related to graphs and graph-based activities.

Results based on a pretest of the participating secondary level students revealed that about one-fifth of the students were seriously restricted in their ability to understand graphs by an inadequate graph schema. Females who had poor graph schema appeared to have been constrained by their comparatively low ability, whereas the males were more likely to have been constrained by lack of interest. After controlling for differences in ability, some sex differences in performance on graphing tasks remained. Females had lower scores for items involving speed or velocity graphs, but not for a variety of graphs involving less abstract properties such as distance. The females who participated in the MBL treatment gained significantly more on a post test in interpretation of distance graphs, than the males did, while the reverse was true for velocity items. There were no sex differences for students in the control treatment.

(10) Impact on different levels of student ability and experience: The MBL treatment works equally well for students with differing levels of ability on graphing skills (construction, interpretation, and application) and concept (distance) understanding and regardless of the scores on the pre-test, honor students had higher scores than standard students on overall performance (Chiu, 1990; Trumper & Gelbman, 2000).

According to several studies investigating the relationship between student variables (e.g., ability, motivation, and achievement) and the effectiveness of MBL, there is increasing evidence of an inverse relationship between student ability and instructional method. Standard students are often found to profit from instructional methods that mirror the teacher-centered instruction. Honor students, on the other hand, are often found to ignore the directional instruction by teachers in favor of their own idiosyncratic learning strategies, or to profit more from "less" direct instruction. Zuman and Weinberg (1988) found that even special needs students can benefit greatly from the use of MBL, both in cognitive and affective ways. Results from a quasi-experimental study of MBL by Mokros and Tinker (1987) reveal that the teacher's approach to using MBL was most flexible with the honors students, and most structured with the special needs students. In that case, all classes except the special needs students made significant gains in mathematics skills and understanding of scientific concepts. The results also show that students who have the greatest flexibility to use software tools to conduct their own investigations are the students who benefit the most from MBL tools. Nichols (1992) examined the relationship between mathematics background and performance on graph-related problems in physics, before and after instruction on the graphical analysis of motion and several MBL experiences. Students identified as either having or not having a graphing technology-enhanced precalculus mathematics background were further categorized into one of four groups according to mathematics placement at the university.

Ⅳ. Conclusions and Recommendations

Many of the expected benefits are common to the research-based benefits, however, the following benefits were expected but not investigated by researchers: development of higher level thinking skills, increased speed and accuracy, fewer lecturing by teachers, wider range of problems explored, increased student control, increased asking "what if" questions, changes in teaching objectives taught (more process-oriented skills), changes in teachers' role, changes in evaluation of students, and less dependence upon the text. While MBL proved helpful in many respects, the research also reveals a number of detriments related to the use of MBL in school science classroom. In order to use MBL in a way that will be of benefit to students and teachers, theoretical benefits and research-based outcomes are considered and discussed as a whole for further synthesis, including the formulation of a research agenda for future consensus-based action. A number of benefits were proposed by MBL developers but not investigated by the educational researcher. A few research studies considered the following practical aspects raised by the classroom science teachers: technical problems of MBL equipment; inaccuracy or incompleteness of presentation; lack of efficient ways for class time handling with MBL instruction; and the need for development of MBL curriculum materials for their own instruction. This lack of studies related to use of MBL in science classroom resulted in educational research that was neither respected nor utilized by science teachers.

Setting a research agenda based on the theoretical benefits and research findings that is necessary for the effective use of MBL in science classrooms can help to maximize the prospects for successful school improvement projects while minimizing the innovation-related frustrations of individuals.

The last decade was a time of experimentation and learning for teachers wanting to integrate the use of MBL in science teaching. Teachers using microcomputer-based laboratories as part of their teaching tried a variety of approaches, some of which have been successful, others much less so. Many continued to use MBL, while others gave up. As yet, there are no standards of what constitutes effective instructional practices, and therefore trainers and teachers are having to learn to use the hardware and software, as well as develop classroom strategies. Knowledge about the effects of MBL use in science classrooms and associated variables are essential for effective implementing and refining of this educational use of the computer.

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