Microcomputer Based Laboratory – An effective instructional tool: A review

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Abstract:

Accurate measurement of physical variables is very important in many applications. In modern physics laboratories sensors have more prominence than manual measurements. MBL methodology enables accurate measurements in real time. Programmed computers are interfaced with sensors and actuators that measure physical quantities like position, velocity, force, light intensity, voltage, current, pressure, pH etc. and graph them in real time. The sensor – computer interface enables immediate presentation of collected data in real time.. The MBL methodology with advantages of large volume of accurate measurements in real time and has gained wide acceptance as a medium of interactive classroom learning. This paper attempts to review learning sin this field and suggests practical methods of instruction an effective learning.

Keywords: Micro Computer based laboratory (MBL), sensors, measurements, real time observations,

Microcomputer based laboratories (MBL) have been very effective in improving conceptual understanding of mechanics in students. MBL was first implemented as early as 1994-95 in Högskolan Dalarna in Sweden, using PASCO Science Workshop software and equipment.

In MBL, data generated by student-run experiments is collected through multiple types of sensors directly connected to computers via interface. The main pedagogical advantage of MBL is direct concurrence between experiments and the graphical representations of results. As a result of this, learners can take large number of experimental observations by making changes in experimental conditions, one at a time, during a short period of the experiment and observe the results. Thus the MBL experiment methodology adds capacity and flexibility.

MBL's allow for deeper understanding of concepts by graphically displaying the outcome of the experiment and have thus been noted to be the most effective educational tools for providing students with opportunity to understand scientific concepts [21].

In hands-on MBL experiments (as opposed to simulations), the varying sensors measuring physical parameters, and interfacing with a MBL computer program altogether present a powerful tool to collect, display and analyse the data from the experiment. These computer programs developed for most MBL systems are platform independent and easy to use, allowing for quick collection and display of data. This allows the students to focus on the experiments and examine in a small period, the result of many changes in experimental conditions, also adding capacity and flexibility to the experiments.

Based on these observations, Bernhard and colleagues revised the introductory mechanics course and introduced MBL in the PASCO2 science workshop with VideoPoint3 software in their mechanics II course. This was found to significantly improve student's functional understanding of advanced mechanics concepts. The use of a rotary motion sensor to investigate the non-linear large-amplitude behaviour of pendulums highlighted that the non- linear behaviour is highly correlated with angular velocity and acceleration graphs. The Runge-Kutta method of numerical approximation solution to the pendulum differential equation also supported the experimental data results. The lab also introduced coupled oscillations, symmetric, ant-symmetric, forced oscillations with coupled oscillations and mixed mode oscillations. They used low friction carts from PASCO which are placed on the tracks in the lab, connected together with springs [4].

Jonte Bernhard studied different applications of MBL experiments by instructors in physics classrooms. Conceptual tests used involved Force and Motion Concepts (FMCE), as an instrument for evaluating conceptual understanding of students using MBL in a study with 55 pre-service teachers as sample in 2003. In first case of Mechanics I course for engineering students, MBL-labs were implemented with active involvement mode for a complete "Predict Observe Explain" (POE-cycle).. Additionally, MBL laboratories were implemented for pre-service teacher's course as a basic technological tool alone. Subsequently, the collision laboratory from second case was changed into POE and active participative mode. It was observed that normalized gain <g> of 0.61 was achieved, confirming that MBL must be implemented with sound pedagogy otherwise it is only marginally better than traditional teaching. The study concluded that when MBL is implemented as a mere technological tool, the benefits were very marginal and learning observed was not remarkable and when microcomputer based laboratory is implemented both as a technical and cognitive medium, with discussion and co-operative learning, very good learning results are observed [4,8].

Thus it is advisable and necessary that the development and implementation of MBL based teaching programs must concentrate on the cognitive and technical aspects. This combined with the teachers' understanding of teaching and learning influences their understanding of remedial action required in the curricula and may lead to a significant improvement in the educational pedagogy. Therefore, to exploit MBL's fully requires a change in the laboratory methodology, giving students more opportunity for exploration and self-learning through investigations, hands on experimentation and peer discussion [20].

Research studies have established that MBL experiments enhance retention, develop graph analysis and interpretive skills but do not help improve graphing (graph preparation) skills. These graph preparation skills are best developed by pen and pencil methodology, manually drawing graphs [10]. However, at the same time, it is established that simultaneous graphical representation helped students retain the interpretive results in their long term memory and illustrates the salient features of the graph for deeper understanding. This was vindicated by the fact that the group of students who were shown 20 second delayed graphs, did similarly as the paper and pencil control lab group without access to MBL [5]. This is supported by Nakhleh and Krajcik in their chemistry experiments among K11 students, where they noted the MBL group focused more on interpretation of results due to a reduced need for short-term memory.

Pennington et al. approached the process of understanding a concept in an experimental setting with the student's use of STM and LTM (Short/Long term memory) and working memory. The real time graphical presentation in MBL relieved the demand on the students working memory. The working memory is short term and has limited capacity and the real time and continuous charting of experimental results facilitates the transfer of subconscious learning or intuition into a long-term memory as single unit. It also allows the students to easily correlate the two, making it easier to transfer the understanding of physical phenomenon to long-term memory. Researchers suggest that this temporal alignment is critical for in-depth understanding of kinematic phenomena [13]. The risk, however, is that the data from the computer may not be questioned and is accepted as reported [12].

Beichner further suggested that MBL methods impactfully delivery interactive environments where students can control the kinematic experiment and receive visual feedback via graphs generated in real time. The other important part is the linking of visual with kinaesthetic feedback. He also suggested that the technical environment like the quality and design of the screen presentation is also critical to the interpretive capability [3].

Roth and colleagues also noted that peer learning was enhanced in MBL experiments since students could refer to scientific symbols, diagrams and graphs on the computer as 'visual anchors' and stimulate comparisons and discussion among the group. It was found that the MBL method is effective in small group of 2-3 students, and an increase in numbers caused overcrowding and reduced effectiveness [14]. Beichner et al. also reported that real-time MBL experiments enabled students to visually observe the results in real time and, experience the relationship between the physical variables in the experiment and their graphical representation [3].

Recent research showed that with MBL experiments students grasp the causal relationships between physical events and charted results significantly better [10, 20]. The technique is effective because the data is collected in real time and the graphs produced simultaneously.

Shuell suggested that "Contiguity (the proximity of two events) is a critically important basic variable affecting conventional learning". The students taught via 'Video Graph' performed similar to the traditional Laboratory students, at least after a single lab period exposure; although there was a trend for them to have higher scores [15].

Some researchers attribute the combination of these four factors to the power of learning via MBL [9]: (1) Multimodal reinforcement, (2) Real-time linking of concrete and abstract, (3) Meaningful context, and (4) Elimination of drudgery.

Performing the experiment designed by themselves and receive real-time feedback through MBL, creates an ideal environment for the students to learn and interpret the result graphs. It was observed that if the graph presentation is not real time, but delayed even by 20 seconds, and then the student results using MBL's are significantly negatively impacted. This also has corroborates the studies involving short term and working memory requirements during MBL and traditional experimentation mentioned earlier [17].

MBL has proved effective in improving conceptual understanding. When MBL replaced the conventional group sessions for problem solving for mechanics students at the University of Maryland, it was found that the performance significantly improved compared to traditional methods. It was also found that MBL experiments in combination with peer review and shared experimentation allow students to predict the outcome of the experiments [21].

Physics education researchers have established that using the MBL based techniques provides a definite competitive advantage in the workplace [22].

A number of MBL experiments have been developed recently to cater to the increasing requirement for computer savvy experimental scientists and engineers. However, on the basis of experience, researchers believe that students often denigrate the value of learning computer and sensor based interfacing techniques and can often see them as being less valuable than conventional experiments where they need to do the experiment in the traditional way [8].

To exploit the advantage offered my MBL requires a basic change in the teaching methodology. The traditional laboratory needs to be re-organized where classroom lectures are supplemented by MBL experiments where students explore and learn through investigations, discussions and peer learning. The result is striking and reliable and has now been confirmed at a large number of universities and colleges. This work is often cited as an indication that interactive-engagement MBL activities are highly effective. However, they are necessary but not sufficient to provide a complete solution to robust and functional knowledge for many students. Multiple choice tests qualitatively indicate the direction of change, but cannot be used to determine the extent of comprehensive knowledge developed by the class. This suggests that traditional classroom teaching and experimentation still has a big role in education [11].

Researchers report that introductory physics students' understanding of kinematics and graphical interpretation of kinematic quantities like velocity, displacement, acceleration, etc could be significantly improved using an MBL curriculum they developed. The results are significant while a large fraction of the students could solve only the simplest of the velocity graph questions after traditional instruction and after few hours of the MBL instruction methodology, the error rate dropped significantly on all the questions including then more complex [19].

Studies at NCSU on video motion analysis establish that students performed better when video analysis was integrated into their kinematics study as compared to traditional instruction. The best results were obtained when laboratory demonstrations were combined with peer discussions and review. Students consistently had difficulty in interpretation of kinematical graphs of vector quantities like position, velocity and acceleration w.r.t time. Students interpret graphs as paths of motion rather than behaviour of kinematic variables with time. Generation of graphs in real time with the lab experiments help students cognitively recognize the relationship between various cognitive variables of motion. As these tools depict motion in real time, the experiment could be repeated, discussed and analyzed in the class facilitating collaborative learning. Several example situations like an athlete's motion and movement during basketball, diving, soccer, table tennis and amusement park rides and other sporting events were videotaped and their kinematics discussed in the class. It was found that students who were taught using MBL tools of real time generation of graphs were able to identify and analyse the situations correctly. The TUG-K was used as a measure of students' improvement. The analysis also clearly indicated that students' learning was directly impacted by the number and variety of different examples discussed in the class [2].

Research study was carried out to study how school children (seventh and eighth grade) thought about graphs. Discussions with the students indicated two major types of mistakes [10].

1. Students were confused between the path of motion and their respective displacement and velocity graphs. They take graphs as pictures.
2. They were confused between slope and height of the graph.

Motion sensors were used to study the body movement of sixth grade students in 1987. In the study, students were required to plot the graphs of their body movements and motion of toy cars and asked to predict the graphs. The experiment was carried out over a period of five days and their discussions, interactions and use of the equipment was recorded. They were asked to draw displacement-time, velocity-time graphs.

The results showed that students demonstrated sound understanding of displacement and velocity time graph. They understood the graphs showing positive and negative velocity directions and change. The study was extended for among students from 7th and 8th grade who experimented with MBL using different types of sensors. While teaching the concept of heat and temperature, students used temperature sensors and heated water using immersion rods. Statistical analysis of observations obtained from their pre / post test results was used to gauge their understanding of graphs. The questions in the test did not have figures and diagrams. Students were tested on a battery of objective type question to select the correct graph and asked to speak on making hypothesis, observing phenomenon, interpreting graphs and drawing conclusions. The results of sixteen graphing items showed significant change in their understanding and interpretation of graphs ($P<<0.001$) between pre and post tests results. The children scored the least in questions related to situations when the ball was coming down the hill and velocity time graph was rising up. They scored the most when rise and all of velocity time graph matched with their mental picture.

Researchers have suggested the most frequent errors indicated in the above study cannot be considered as misconceptions since they remained with one third of the students even after using MBL for three months [10].

While describing the famous MBL studies two major questions were raised:

1. How one class with the use of MBL for physics students from schools can improve their understanding of velocity and displacement time graph as compared to graphing with paper and pencil?
2. What are the advantages of simultaneous graphing as compared to delayed time graphing of the data.

Morkos and Tinker suggested that real time charting of the graph as the experiment progresses has the advantage of cognitive memory association linking of two events. Brasell was also of the opinion that when both the events happen simultaneously, students can very easily transfer them as one unit to their long term memory [9].

To test this hypothesis, another study was carried out which experimented with real time and delayed time graphing. A sonic distance finder sensor was used to study and measure human motion away from and towards the sensor. The data was displayed in the form of displacement v/s time and velocity v/s time graphs. 75 students from physics were chosen for this study, had prior knowledge of kinematics concepts. They were required to predict the graphical behaviours for different constant velocity motions and or more complicated motions. For real-time MBL group, graphs were displaced for 20 seconds in real time. For delayed time MBL group, the kinematic graphs were displayed point by point after the event. The third group carried out only paper and pencil activity for the motion. The fourth group gave only pre and post test. The pre and post test questions related to verbal descriptions for their respective graphs.

The results showed that there was a remarkable improvement in the graphing skills of normal MBL group while the delayed MBL group performed little better than the paper pencil group. Researchers believe that delay in the display of graphs on the monitor restrict student's graphing skills because the instantaneous depiction of graphical representation of events reinforces the relationship between the variables in the student's mind [9].

Brasell et al suggested that the reasons for this could be a lack of inspiration, limitation of temporary memory or the student had no knowledge of the need to reflect on observations. As such, the delayed group students were found to be indifferently engaged and disinterested in the experiment or conceptual understand, and more engaged in the process instead. These studies highlighted that in order to analyse the pros and cons of multiple representation learning environment, care should be taken so that the experiments are useful and productively integrate with teaching curriculum.

The use of technological tools has become a powerful and essential element of science education. The integration of computer-based tools in a constructive manner during the teaching process to improve the understanding of concepts is not easy [1], despite the excess of tools available [7]. It is therefore critical to adopt an effective methodology.

Researchers have perfected decision rules for methodical analysis experiments to evaluate the capability of software and hardware tools. This helps identify specific competencies or experiments most effective for demonstrating a physical phenomenon. This analysis method will simplify the switchover to technologically rich teaching/learning environments using available computer-based modelling and simulation tools [23].

Students have consistent difficulties with the interpretation of graphs of kinematical variables like graphs of position, velocity or acceleration. The most frequent graphing misconceptions seem to be:

1. Confusion due to the tendency to connect the graph with the picture rather than as a symbolic visual representation of information
2. Meaning of the areas under graphed curves and
3. The slope and magnitude items charted.

The understanding of graphs can be effective if MBL activities are used [10]. In this study a 'go motion' was used in conjunction with a computer. A go motion allows immediate collection of data and representation of this data graphically and is not complicated. It is fast and dynamic and provides genuine scientific experiences that could motivate and encourage students [2]. Learners have the opportunity to test and modify their own hypotheses, test other hypotheses and present the observations simultaneously. In addition, learners have more time to analyse and interpret data and for problem solving, critical thinking and reflection [19]. The objective of the research was to evaluate the influence of the go motion on the understanding of kinematic graphs. Reason for study is that there is a constant debate if "old school" lab techniques (e.g., ticker tape timers, graphing by hand, etc) and "new school" lab techniques (e.g., motion detectors, graphing by computer, etc.) have the best effect on student understanding and achievement. An argument in favour of the old school is that seeing the data as physical dots makes the motion much easier to understand and the graphs then have something physical to compare to.

Conclusion: the advantages of MBL technology:

In the United States of America many university science education centres i.e. TERC were doing extensive research on MBLs which led to stronger acceptance of the technology. These centres were working with school education centres. The major part of the research on MBL during the earlier time was carried out in United States.

The advantages of the use of MBL Technology were identified by researchers from UK and the US [6]. These advantages are listed below:

Pedagogical gains:

1. Improvised graphing skills and graph interpretation.
2. Data is represented in multiple ways. Visual representation of kinematics graphs of displacement, velocity and acceleration and see the object moving.
3. It allows students to repeat the experiment and change the physical parameters, control the experiment and investigate it.
4. Peer learning is supported. Graphs could be connected with the experiment in real time.

Physical advantage of using computers

1. High speed of data capture.
2. Storage memory is high.
3. Process and display of date in real time.
4. Data can be captured over large range of time from micro-seconds to man days.
5. Data can be captured by multiple sensors simultaneously.
6. Large range of experiments are feasible and under variable environmental condition.

Advantage of change in attitude of students

1. Motivating.
2. The ease with which experiments can be performed with much better accuracy improves confidence of the students.
3. Reduces drudgery of data collection and processing within time.

Researchers find the use of MBL in laboratory gives direct experience of physical phenomenon and new methods to find out basic principles of physics relevant to the experiment. This helps students remove their misconceptions which is not possible with traditional teaching methods.

The physical benefits of MBL tools are unique only to MBLs as compared to other techniques used in laboratory like simulations and EP, etc. Of all the advantages, most of the authors discussed only the improvement in interpretation of graphing in the research.

Science teachers involved in MBL development have often published instructions to make simple MBL tools and their experience with the use of these tools. It was found that the idea of saving time in recording data attracted students more towards MBL and the laboratory work was successful and students utilized their spare time in analyzing the conditions and they were more interested in trying new conditions for performing experiments [24].

In the field of Biology, implementation of MBL as a collaborative effort was extremely effective, reinforcing the idea of team effort spread into chemistry and physics departments.

With the development of this technology and its increasing implementation, educators started expecting that students understand the concepts better and learn more as they do the experiments. Researchers in these initial studies with MBL used interviews and observations to quantify the change in understanding of concepts by carrying out statistical analysis of pre / post-test observations. Experiments with movement and temperature sensors are very popular due to the easy availability of sensors and their relation to the concepts taught in initial years of higher education. Interviews and tests were related to the understanding of construction and interpretation of graphs.

For measurement of velocity of a moving object many counters have been designed. In a counter designed at Delhi University College a hollow tube was used as drop tower of length 1 meter with eight LED-LDR pairs arranged along the length of the tube at a distance of 10 cm from each other. All the LED-LDR pairs are kept well inside the tube to avoid stray light stray light to cause false triggering of the circuit. As the object moves through the tube it cuts the light falling on LDR and consequently its resistance increases. This variation of resistance is converted into voltage pulses. This voltage is transferred to the opamp comparator circuit. This variable voltage so set to a value between V_L and V_H and output of LM741 opamp is between +12 V and -12 V. 8085 microprocessor kit is used to run the clock from the negative edge of one input signal to that of second input signals negative edge. The microprocessor stores the counters count in its memory and thus restarts the count. The counts are converted to time in seconds. As the object falls under the action of the gravitational force it accelerates. The velocity of the object can be measured accurately by using two sensors [25].

References:

1) Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts Visualization. Theory and Practice in Science Education,vol3In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), (Berlin: Springer) : 191–208
2) Beichner, R. (1996). Impact of video motion analysis on kinematics graph interpretation skills. American Journal of Physics, 64(10): 1272-1277.
3) Beichner, R. J. (1990). The effect of simultaneous motion presentation and graph generation in a kinematics lab. Journal of research in science teaching, 27(8): 803-815.
4) Bernhard, J. (1999). Hands-on experiments in advanced mechanics courses. In G. Born, et. al., Proceedings of the ICPE/GIREP International Conference "Hands-on Experiments on Physics Education", (175-177), Duisburg: University of Duisburg, Germany.
5) Brasell, H. (1987). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. Journal of research in science teaching, 24: 385-395.
6) Linn, M. C. & Songer, N.B. (1988). Cognitive research and instruction: Incorporating technology into science curriculum. Paper presented at the American Educational Research Association Meeting, New Orleans, LA.
7) Melissa H. D. and Beichner, R. (2006). Impact of animation on assessment of conceptual understanding in physics. Phys. Rev. ST Phys. Educ. Res., 2(1): 010104-1- 010104-7.
8) Martinez, G. et al. (2011). Comparative study of the effectiveness of three learning environments: Hyper-realistic virtual simulations, traditional schematic simulations and traditional laboratory. Physical Review Special Topics - Physics Education Research, 7(2): 020111.
9) Mokros, J., & Tinker, R., (1987). The Impact of microcomputer-based labs on children's ability to interpret graphs. Journal of Research in Science Teaching, 24(4): 369-383.
10) Mevarech, Z.R., & Kramarsky, B. (1997). From verbal descriptions to graphic representations: Stability and change in students' alternative conceptions. Educational Studies in Mathematics, 32(3): 229-263.
11) Podolefsky, S., Katherine K. Perkins, and Wendy K. A., (2010). Factors promoting engaged exploration with computer simulations. Phys. Rev. ST Phys. Educ. Res., 6(2): 020117(1-11).DOI: 10.1103/PhysRevSTPER.6.020117
12) Papert, Seymour, Mindstorms: Children, Computers and Powerful Ideas, New York, NY: Basic Books, Inc., (1980).
13) Pennington et. al., (1996). Executive functions and working memory: Theoretical and measurement issues.In G. R. & N. A. Krasnegor (Eds.), Attention, memory and executive function (327-348). Baltimore, MD brookes
14) Roth et al. (1995). Affordances and constraints of computers in science education. Journal of research in science teaching, 32(4):329-347.
15) Shuell, T. J. (1986). Cognitive conceptions of learning. Review of educational research, 56(4): 411-436..

16) Sharp et al. (2007). Computer based learning in an undergraduate physics laboratory: interfacing and instrument control using Matlab. European journal of physics, 28(3): S1-S12.
17) Slykhuis, D. & Park, J. C. (2006). The efficacy of online MBL activities. Journal of Interactive Online Learning, 5(1): 14-31.
18) Teruaki, I. (2009). Walking Motion Analysis Using Small Acceleration Sensors. International Journal of Simulation Systems, Science & Technology, (Elsevier: Scopus), 10(3):65—71.
19) Thornton, R. K., Sokoloff, D. R., (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. American Journal of Physics, 58(9): 858,-867.
406–427.
20) Tinker, R. (1996). Microcomputer-based labs: educational research and standards, New York: Springer-Verlag.
21) " Redish, E. F., Saul, J. M. &Steinberg, R. N. (1997). On the effectiveness of active-engagement microcomputer-based laboratories. American Journal of Physics, 65:45-54.
22) Wellem, T. (2012). A Microcontroller based Room Temperature Monitoring system. International Journal of Computer Applications (0975-8887), 53(1): 7-10.
23) Papdouris, N. & Constantinos, P. (2009). A methodology for integrating computer-based learning tools in science curricula. Journal of Curriculum Studies, 41(4) 521-538.
24) Jesberg, R.O., & Dowden, E. (1986). Microchip measuring. The Science Teacher, 53(7): 34-37.
25) Garg, M., Kalimullah, Arun, P. and Lima, F. M. S. (2007). Accurate measurement of the position and velocity of a falling object. American Association of Physics Teachers, 75 (3): 254-258.