International Journal of Allied Practice, Research and Review

Website: www.ijaprr.com (ISSN 2350-1294)

Understanding Kinematics of Free Fall through MBL based Real-Time Visualization

Lalita V. Rane
Professor, Ramkrishna More A.C.S. College,
Akurdi, Pune, India.

Abstract - Free fall motion is a physical example of straight line motion with constant acceleration in downward direction. It is most basic system studying the principles of kinematics. The primary objective of the study was to analyse student's misunderstandings about free fall and to search for new instruction method to address them. A 15 item diagnostic test on free fall was prepared and a total of 131 and 100 students were tested for pre and post-test performances respectively to study the effect of microcomputer based laboratory on student's conceptual understanding. The tests confirmed the utility of MBL experiments as a method of interactive instruction and also identified several misconceptions students normally have about kinematics.

Keywords - Microcomputer based Laboratory, Diagnostic test, Fergusson Delta, Difficulty index, Pre and post teat,

I. Introduction

Researchers have proved that free fall misconceptions are very common among the students [7]. It is an important concept of physics which can be addressed through kinematics, energy and force. If the graphical representations of the displacement, velocity and acceleration and their changes with time are not understood correctly, students cannot use them for deductive reasoning of related cases scenarios like tossing the ball, projectile motion etc, [9]. Though students understand acceleration vs. time graph correctly in free fall motion, the graph of displacement and velocity as a function of time revealed strong misconceptions both on the physical phenomenon and its inherent mathematical consistency [8]. The MBL methodology has advantages of accurate measurements in real time. The experimental data is immediately available via the sensor – computer interface for immediate presentation. This offers an ideal alternative / complement to traditional lab methods. As the readings are sensor based, least counts can be smaller than in the lab and also highly accurate. Real time collection of data at high speeds and over a long period, even months or years, is possible as data collection is automated. Similarly, data can be simultaneously collected from large number of sensors for different variables. Thus, a very large data repository is available to mine for accurate results. As the results can be shown graphically, the experiment is better controlled and less tedious and without errors.

This can be motivating to students who also find a high tech novelty in the process. **According to Jonte Bernhard1,** Microcomputer Based Laboratory (MBL-lab) students do real experiments, not simulated ones, using different sensors (force, motion, temperature, light, sound, EKG…) connected to a computer via an interface[6].

This will lead to a focus on results and their interpretation, rather than the tedium of slow and laborious data collection. As multiple observations are possible through multiple sensors, the data views make for an integrated understanding of the phenomenon under study. The data collection is also possible under extreme physical conditions and even remotely over the internet e.g. GPRS based data transfer from remote devices. As the data is plentiful, accurate and for multiple views, the researcher/student can focus on the graphical interpretation and even use quantitative methods like regression, correlation to find the underlying relationships trends in behaviour. The large data volumes under controlled conditions may also reduce experimental errors.

It is the objective of this study to investigate the effect of the MBL experiments on student comprehension and understanding of mechanics' Principles in Physics. Compared to simulation which is basically computational modelling, MBL involves actual experimentation and working with equipment. This is nearer to real life laboratory experiments and subject to practical constraints and limitations of the laboratory experiment. Thus, the results are actual measurements and since the student is personally involved in the experiment, the learning can be more definitive and long lasting. **Beichner** considers that MBL methods are effective as they give students interactive environments where they can control the motion event and receive immediate visual feedback[3].

II. Microcomputer based Laboratory (MBL) Experiment

We have designed a microcomputer based interface to study motion of an object. The instrument was validated by conducting experiments on free fall. The aim of MBL was to measure displacement, velocity and acceleration of body moving along straight line and show the graphical representations in real time. This help to explain linear motion qualitatively as well as quantitatively. The system designed, have an instrument was observed. Students could control the direction and speed of motion of the object and could watch the corresponding displacement, velocity and acceleration graphs are displayed simultaneously on the screen in real-time. Students get immediate feedback of the experiment and are free from the task of plotting graphs. This enables them to learn the skill of interpretation of the graphs. The computer analysis helps students to understand the connection between kinematical variables like displacement, velocity and acceleration. An array of IR transmitter-receiver pair to collect data from the moving object is connected to the microcontroller. This array of IR transmitter-receiver pairs can arranged along the path of motion of the object.

III. Material and Methodology

Content surveys were conducted on the topic of free fall to design the diagnostic test. There were 15 multiple choice items in the test with four choices each. The reliability index for the test, measured by the KR-21, for diagnostic test on general kinematics concepts is 0.701527. The diagnostic test on free fall motion is a reliable instrument and considered to be sufficient for group measurement. The average difficulty index P_{mean} =0.444346 indicates that the designed test instrument is reasonably difficult. The D_{mean} value for the test is 0.541333, suggesting that the test has good discriminatory power. There was no misreading or misinterpreting the items in the test as indicated by the in-depth interviews with the students.

The Ferguson's delta score of the present test is 0.967723, which is greater than 0.9, suggests that the test offer good discrimination[4].

The test is based on following basic concepts

1. The object's initial velocity is considered zero m/s if it is dropped (not thrown) from a height.

2. When an object is thrown in vertical direction, then speed starts decreasing as it rises upward. The velocity reduces to zero at the instant it reaches the highest point.

3. When an object is thrown in vertically upward direction, then its velocity at any position is equal in magnitude and opposite in direction during upward and downward journey.

4. An object in free fall motion experiences an acceleration of $-9.8\ m/s^2$ throughout the motion.

5. Motion in freefall is independent of mass of the object. Average velocity between two positions in constant acceleration motion is the velocity at mid time.

Subject: A total of 131 and 100 students from First year undergraduate students from colleges affiliated to Pune University. The table 1 show the distribution of sample used for the study on free fall.

Table 1
Sample of diagnostic test on free fall

	Pre			Post		
College	Male	Female	Total	Male	Female	Total
Prof RM College, Pune	44	53	97	38	32	70
AB Telang College, Pune	16	18	34	18	12	30
Total	60	71	131	56	44	100

Research questions on free fall

To obtain data on student's understanding of kinematics, following research questions were set for the study.

Research question 1: Will Students be able to interpret verbal representations on free fall motion?

Research question 2: Will Students be able to use kinematics equations to solve problems on free fall?

Research question 3: Will Students be able to interpret graphical representations on free fall?

Diagnostic test on free fall was in accordance with these research questions. The items of the test are based on interpretation and application of kinematics equations, interpretation of graphical representation and interpretation of verbal representation. Also to check the consistency of conceptual understanding, there is a link between the questions.

Misconceptions were identified after detailed analysis of student's response on each item of the Diagnostic and discussion with the students and subject experts, on the basis of answers given to the questions in pilot test. The wording and the possible answers in the list were modified on the basis of student's feedback in the pre-test.

Assessment of pre-test results

The pre and post tests were carried out in two consecutive academic years for unbiased, verifiable results.

The performance of experimental and control groups was compared in pre-tests. Following table 2 shows the comparison of means of pre-tests for experimental and control groups in the first semester of academic year.

TABLE 2

Assessment of pre-test performance at on Free Fall (Year 1)

Group	Pre-test		t-value (0.01)	*p*
Control	N	44	0.14	0.44
	Mean	38.03%		
	S. D.	11.37		
Experimental	N	43		
	Mean	37.67%		
	S. D.	12.07		

[$t_{critical}$=2.70 at 0.01 level for df = 43]

The t-test was conducted on the pre-test scores for two treatment groups. The mean of the pre-test scores for experimental group students is 37.67% and was not significantly different from the control group (mean = 38.03%), (t = 0.14 at α = 0.01 level). Thus, experimental and control groups were equivalent in the pre-test since their performance was not significantly differentstudents are at same level of understanding of concepts of free fall.

Following Table 3 shows the comparison of means of pre-tests for experimental and control groups in the first semester of next academic year.

TABLE 3

Assessment of pre-test performance on Free Fall(Year 2)

Group	Pre-test		t-value (0.01)	*p*
Control	N	32	0.32	0.3744
	Mean	46.88%		
	S. D.	9.5		
Experimental	N	32		
	Mean	46.04%		
	S. D.	10.62		

[$t_{critical}$=2.66 at 0.01 level for df = 31]

The t-test was conducted on the pre-test scores for two treatment groups. The mean of the pre-test scores for experimental group students is 46.04% and was not significantly different from the control group (mean = 46.88%), (t = 0.32 at α = 0.01 level). Thus the two groups are equivalent in terms of level of understanding of principles of free fall motion. the performance of experimental and control groups in the pre-test was not significantly different.

5.11.2 Pre-test-Post-test comparison on the basis of normalized gain

(1) Pre-test-Post-test comparison

By using pre-test and post-test scores of each student the normalized gain was calculated for each student. Class average normalized gain with its standard deviation was obtained for control and experimental groups. These average gains were evaluated by applying t-test at the 0.01 significance level.

Following Table 4 shows the comparison of average normalized gains in the first academic year

TABLE 4

Comparison of pre-test and post-test performance on Free Fall

(Year 1)

Group		Pre-test	post-test	<g> (s.d.)	*t* -value (0.01)	*p*
Control	N	44	44	0.1757	6.32 (Significant)	6.29*10^(-8)
	Mean	38.03%	49.24%	0.128		
	S. D.	11.37	10.49			
Experimental	N	43	43	0.4131		
	Mean	37.67%	64.65%	0.205		
	S. D.	12.07	9.92			

[$t_{critical}$=2.70 at 0.01 level for df = 43]   For <g>0.3 the treatment is effective

Table 4 shows that the <g> value for experimental was found to be 0.4131 and for control group it was 0.1757.The class average normalized gain for experimental group was significantly more than class average normalized gain for control group. This difference was significant at 0.01 α levels (t = 6.32). The average normalized gains showed that the teaching of free fall with microcomputer based laboratory experiments in the classroom is more than 0.3 times more as effective as traditional teaching method in promoting conceptual understanding.

Following Table 5 shows the comparison of average normalized gains in the academic year 2.

TABLE 5

Assessment of pre-test and post-test performance on Free Fall

(Year 2)

	Pre-test	post-test	<g> (s.d.)	*t* -value (0.01)	*p*
N	32	32	0.1386	10.54 (Significant)	4.48*10^(-12)
Mean	46.88%	54.58%	0.131		
S. D.	9.5	9.03			
N	32	32	0.503		
Mean	46.04%	73.75%	0.137		
S. D.	10.62	6.97			

[$t_{critical}$=2.74 at 0.01 level for df = 31]   For <g>0.3 the treatment is effective

Table 5 shows that the average normalized gain for experimental group was found to be <g> = 0.503 and for control group it was <g> = 0.1386. The t-test was conducted on normalized gains of both the groups. The class average normalized gain for experimental group was significantly high as compared to class average normalized gain for control group. The difference was significant at 0.01 α levels (t =10.54). The average normalized gains showed that the teaching of free fall with microcomputer based laboratory experiments in the classroom is more than 0.3 times more as effective as traditional teaching method in promoting conceptual understanding.

Student's performance on various representations and conceptual understanding in free fall was obtained on the basis of research questions which were set for the study in the academic years 1 and 2. For that purpose the items in the diagnostic test on free fall were grouped according to the criterion set on the basis of research questions.

These groups are given below.

1. **Research question 1:**

Will Student be able to interpret verbal representations on free fall motion?

Items: 3, 4, 6, 7, 10, 15

2. **Research question 2:**

Will Student be able to use kinematics equations to solve problems on free fall?

Items: 1, 2, 8, 9

3. **Research question 3:**

Will Student be able to interpret graphical representations on free fall?

Items: 5, 11, 12, 13, 14

Table 6 shows students' performance on various representations and conceptual understanding of free fall..

TABLE 6

Comparison of performance on conceptual understanding on Free Fall

(Year 1)

Research Question	Control group <g>	Experimental group <g>	t-Value (0.01)	p
Research Question 1	0.1216	0.3895	4.99 (Significant)	5.28*10^(-6)
Research Question 2	0.2405	0.3915	2.35 (Not Significant)	0.01161
Research Question 3	0.1958	0.4674	4.26 (Significant)	5.49*10^(-5)

[Change in experimental group performance in comparison with control group]

The graphical representation of the above data is shown in the Figure1

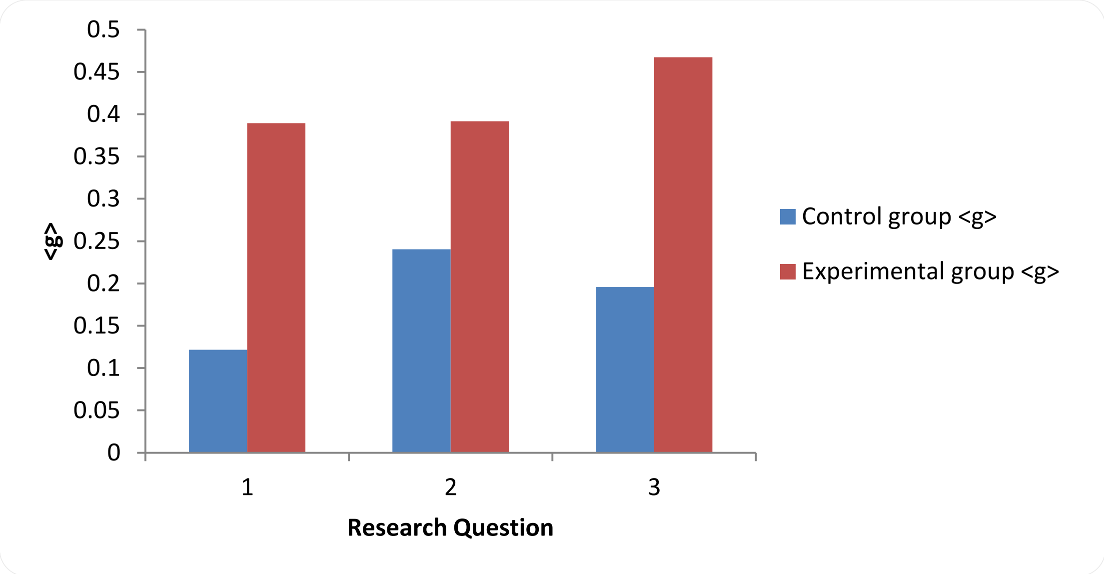

Figure 1 Performance on conceptual understanding on Free Fall (2012-13)

Table 7 shows students performance on various representations and conceptual understanding of free fall at first year undergraduate level in the academic year 2.

TABLE 7

Assessment of performance on conceptual understanding on Free Fall

(Year 2)

Research Question	Control group <g>	Experimental group <g>	t-Value (0.01)	p
Research Question 1	0.0818	0.529	6.29 (Significant)	2.71*10^(-7)
Research Question 2	0.2292	0.406	1.92 (Not Significant)	0.0321
Research Question 3	0.1438	0.532	6.47 (Significant)	1.61*10^(-7)

[Change in experimental group performance in comparison with control group]

The graphical representation of the above data is shown in the Figure 2

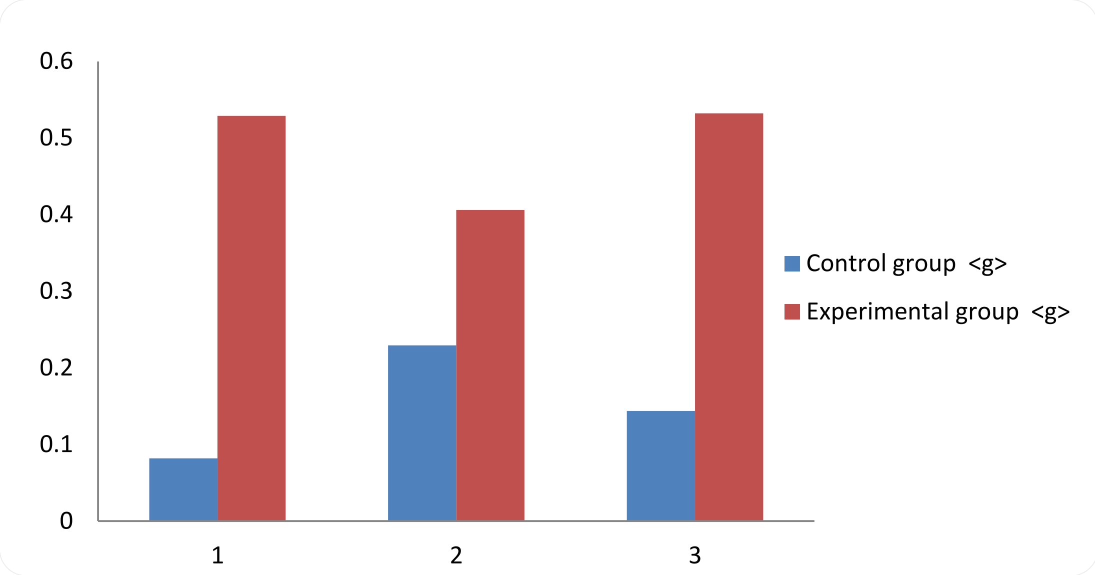

Figure 2: Performance on conceptual understanding of free fall year 2

The graphs in Figures 1 and 2 shows that the normalized gains, in first and third category of conceptual understanding for experimental group is more as compared to the normalized gain for control group. The average normalized gain for experimental group is greater than 0.3 thus the treatment used for experimental group is interactive and produces significant change in the conceptual understanding of students in first and third category. In second category the change is not significant because it is based on the understanding of kinematics equations, which students are already good at.

Findings on the basis of Research Questions

Research question 1:

Will students be able to interpret verbal representations on free fall motion?

As the diagnostic test contained questions mostly of qualitative nature and had many questions on verbal representation or verbal interpretation was required in free fall. As shown in Table 6, the normalized gain for the experimental group (<g> = 0.3895) was significantly higher than that of control group (<g> = 0.1216). The normalized gain for exposed group was 3.2 times that of control group in the year 1

As shown in Table7, the normalized gain for the experimental group (<g> = 0.529) was significantly higher than that of control group (<g> = 0.0818). The normalized gain for experimental group was 6.47 times that of control group in the year 2.The exposed group students were observed to be better in interpreting the graphical representation in comparison to the control group students.

Research question 2:

Will Student be able to use kinematics equations to solve problems on free fall?

As the diagnostic test also contained questions of quantitative nature and had many questions on application of kinematics equations was required in free fall. As shown in Table 6, the normalized gain <g> for the experimental group (<g> =0.3915) was not significantly higher than that of control group (<g> =0.2405). The normalized gain for experimental group was 1.62 times that of control group in the year 1.

As shown in Table 7, the normalized gain <g> for the experimental group (<g> =0.406) was not significantly higher than that of control group (<g>= 0.2292). The normalized gain for experimental group was 1.77 times that of control group in the year 2.The experimental group students were observed to be little better in application of kinematics equations as compared to the control group students.

Research question 3:

Will students be able to interpret graphical representations on free fall motion?

As the diagnostic test contained questions mostly of qualitative nature and had many questions on graphical representation and graphical interpretation was required in free fall. As shown in Table 6, the normalized gain <g> for the experimental group (<g>=0.4674) was significantly higher than that of control group (<g> =0.1958). The normalized gain for experimental group was 2.38 times that of control group in the year 1.

As shown in Table 7, the normalized gain <g> for the experimental group (<g> = 0.532) was significantly higher than that of control group (<g> = 0.1438). The normalized gain for experimental group was 3.7 times that of control group in the year 2.The experimental group students were observed to be better in interpreting the graphical representation or graphical interpretation as compared to the control group students.

IV. Results

The mean scores of the pre-test for experimental and control groups were not significantly different for both the years for study. (refer Table 5.16 and Table 2)

The class average normalized gain <g> =0.4131 for experimental group was significantly higher than class average normalized gain for control group<g> = 0.1757 at 0.01 α levels (t =6.32) in the year 2012-13 (Table 3)

The class average normalized gain <g> = 0.503 for experimental group was significantly higher than class average normalized gain for control group<g> = 0.1386 at 0.01 α levels (t =10.54) in the year 2013-14 (Table 4)

The average normalized gains showed that the teaching of free fall with microcomputer based laboratory experiments in the classroom is more than 0.3 times more as effective as traditional teaching method in promoting conceptual understanding in both the years [5].

The study seeks to test the hypothesis of about effectiveness of Microcomputer based laboratory instrument in students understanding of free fall concepts. Results of post-test data analysis were compared with the $t_{critical}$ values at 0.01 level of significance and the hypotheses were tested.

The results of data analysis of pre-test and post-test scores on the basis of normalized gain for experimental and control groups for two successive years for free fall showed that
There is significant difference in the achievement of students and change in outlook towards physics after using microcomputer-based laboratory interface tools in the classroom.

At the pre-test it was observed that most of the students were unable to relate graphical and visual representations with verbal description or vice versa.

At the post-test it was observed on the basis of normalized gains of experimental group control group that the experimental group students were better placed in terms of relating graphical and visual representations with verbal description or vice versa in kinematics. (Table 6 and 7)

At the pre-test it was observed that most of the students were unable to use kinematics equations to solve the problems on free fall.

At the post-test it was observed that the normalized gain of experimental group was more than the control group *i.e.* experimental group students were better placed in terms of application of kinematics equations to solve problems on free fall (Table 5 and 6). Though there was more increase in average normalized gain of experimental group as compared to control group but the difference was not significant because the MBL method is effective in teaching concepts in kinematics not in use of kinematics equations.

At the pre-test it was observed that most of the students were unable to conceptualize or calculate the first integral quantities like position and velocity from velocity and acceleration graphs respectively using area under the curve.

At the post-test it was observed that the normalized gain of experimental group students is more than the control group students' *i.e*. experimental group students were better placed in terms conceptualizing or calculating the first integral quantities like position and velocity from velocity from acceleration graphs respectively using area under the curve. (Table 6 and 7)

V. Conclusion

The concepts of kinematics and especially free fall, probed in the study were among the most basic concepts of physics and are taught when formal education of physics starts. Students were assumed to have good understanding of these concepts as they studied these topics in their previous classes also. After analysis of data on pre-test it was found that students had many conceptual and problem solving difficulties. When data of qualitative items was analyzed it was observed that students' qualitative understanding of concepts had serious deficiencies despite of giving correct answers to corresponding quantitative questions. These difficulties are discussed in the previous chapters. The root cause of these difficulties is the traditional teaching method.

The experimental group and control group students were at the same level of basic knowledge and understanding of concepts in kinematics at the pre-test. After the analysis of content survey, students difficulties in kinematics were identified and the microcomputer based experiments were designed using ARM-7 microcontroller. The experimental group was revised kinematics using MBL and control group students were taught kinematics by traditional classroom instruction method. Learning performance of students was determined by administering post-test to both the groups. The control and experimental groups were studied and show a marked positive correlation between MBL experiments with improvements in test scores. The results of the test are indicative of a lack of conceptual mastery amongst undergraduate students of basic and familiar kinematics concepts, particularly kinematics graphical interpretation and free fall. It is necessary to use interactive teaching methods for proper understanding of these concepts. Microcomputer based laboratory (MBL), Computer simulations, animations and demonstrations may be useful in these respects. Physics educators should use these tools for interactive learning. It appears that interpretation of graphs as taught in mathematics classes in schools is not adequate for students to apply in real life to understand physics [2].

It is an observation (external to this study) of the researchers that the MBL group discusses any physics problem better qualitatively in class and their test scores are also significantly improved. However, we feel that this quality is not yet fully translated into scores – suggesting more MBL and training is required. This can be a scope for further research. A prudent combination of teaching methods, teaching material, laboratory tools and tests could significantly improve student understanding even within the ambit of existing syllabi.

The student response to the method was extremely encouraging and positive. They felt that the method was technologically advanced, mentally challenging, helped collaborative learning and encouraged discussion and easy repetition in case of misunderstanding. It was also a personally a fulfilling and rewarding experience for us.

VI. References

1. [3] Barsell,H. (1987).The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. Journal of research in science teaching, 24(4), 369-383.

2. 13 Berg, C. A., & Smith, P. (1994). Assessing students' abilities to construct and interpret line graphs: Disparities between multiple-choice and free-response instruments. Science Education, 78: 527-554.

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. Ding, L., Chabay, R., Sherwood, B., &Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. Physical Review Special Topics-Physics Education Research, 2: (010105), 1-7.

5. Hake, R. R. (1998). Interactive engagement vs. traditional methods: A six-thousand-student data of mechanics test data for introductory courses. American Journal of Physics, 66(1): 64- 74.

6. (9A) Jonte Bernhard1, August, 1998, Experiments in Physics Education", Duisburg, Germany, 23–28.HANDS-ON EXPERIMENTS IN ADVANCED MECHANICS COURSES.Dep. of Physics, Högskolan Dalarna, S-781 88 Borlänge, Sweden

7. 55 Katherine et. al, (2006). PhET: Interactive Simulations for Teaching and Learning Physics. The Physics Teacher, 44: 18-23.

8. 75 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.

9. 9. 116 Weller, H. G. (1996). "Assessing the Impact of Computer-Based Learning in Science." Journal of Research on Computing in Education, 28(4):461-85.

10. 56Kavanagh, C., &Sneider, C. (2006). Learning about gravity I. Free fall: A guide for teachers and curriculum developers. Astronomy Education Review, 5(2): 21-52