

Using Video Analysis, Microcomputer-Based Laboratories (MBL's) and Educational Simulations as Pedagogical Tools in Revolutionizing Inquiry Science Teaching and Learning

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Introduction

La main á la pâte is an inquiry-based science education programme founded in 1996 by Georges Charpak, Pierre Lena, Yves Quere and the French *Académie des Sciences* with the support of the Ministry of Education. The operation of the program primarily aims to revitalize and expand science teaching and learning in primary education by implementing an inquiry process that combines spontaneous exploration through varied prediction, experimentation, observation and argumentation. As a recognized program of innovation in science, *La main á la pâte* has gained global visibility and transcended across cultural backgrounds. The strength of the program is founded on continuous educational collaboration and innovative projects among pioneering institutions and educators for more than a decade.

The emphasis of "learning by doing" as a principle of inquiry in science is a pedagogical movement since the late 18th century traced to the works of John Locke, Jean-Jacques Rosseau and John Dewey. In their progressive education program, truth and knowledge are out of observation, direct manipulation and concrete experience of objects (Hayes, 2007). The methodology is focused on the child's interests and intrinsic motivation to learn. According to Dewey, a child that is thrown into a passive role of absorbing information results to a waste of that child's education. The role of the teacher therefore is to guide students as individuals and allow learning to unfold naturally (Butts and Cremin, 1953). This educational philosophy set the tone for the "new educational thinking," which provided reforms in many educational institutions around the world. Furthermore, the rise of favoured industries and the age of information and communications technology have somehow influenced the kind of education that institutions offer.

In recent years, educational technology has been used to support teaching and learning in many developed countries. Technology has dramatically transformed the way students acquire information, exchange data and communicate in the classroom using automated hand-held devices such as tablet PCs in different platforms, probewares, data loggers and other pedagogical tools. Other than varied experiments in modern science laboratories, they are exposed to educational softwares, simulations and other interactive models. These developments led many educators to reconsider teaching strategies in general and evaluate ways in which technology has influenced classroom practice and experience in particular. While these new perspectives support educational philosophies and form the basis for the emerging standards in science education, enhancing learning through inquiry using these technologies post a greater challenge. There is no doubt that these tools enrich the students' experience in understanding science and developing their scientific skills. However,

the need to define its role in providing effective links among extended information, ideas and real-life experiences become crucial.

This paper generally focuses on revolutionizing the inquiry-based science education (IBSE) approach using technology-based pedagogical tools at pre-university levels. Since there is no universal model for the IBSE, it is understood that the operation of this program is dependent on the course of study, the teacher, the students' stages of development and the resources available. Nevertheless, the indicative measures and evidences of inquiry teaching and learning in this context will be discussed. Specifically, the first section of this paper discusses the IBSE in detail and presents areas in which technology can be used to potentially enhance teaching and active learning in the "new classroom". The features of well-recognized educational software with the same underlying positions on IBSE will also be given. The second section presents activities that combine technology and inquiry and the inherent issues on assessment. It includes examples of thinking models that students are engaged in during the inquiry operation.

Finally, actions of various kinds have been taken in the hope of bridging the gap between a variety of technology-based resources and the IBSE. Challenges at any point are inevitable but this should not impede continued experience as a process of building the understanding of science through inquiry. Whether or not supported by these resources, the ultimate goal is to develop life-long learners who understand what is involved in learning and take responsibility in managing their own thinking.

Inquiry-Based Science Teaching and Learning

The pebble that drops into a pond is like an idea that sparks inquiry. The concentric circles represent new questions that emerge from the first germ of the idea. The ever-enlarging pattern of ripples refer to the integrated knowledge that is acquired as each question is explored, limited only by the force of the inquirer's enthusiasm for the search. The greater the interest and the more probing the questions, the more encompassing the study, the bigger the ideas that it develops and the deeper and more meaningful the knowledge the inquirer constructs.

- Marian Martinello and Gillian Cook
Interdisciplinary Inquiry in Teaching and Learning (1990)

Inquiry is a way of acquiring knowledge (Hebrank, 2000). In the field of science, it is associated with the role of students as active researchers. In 1996, the U.S. National Research Council (NRC) released the National Science Education Standards (NSES). In its inquiry standards, the NSES states that inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known in light of experimental evidence: using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (p.23).

Inquiry-based science education describes a range of curricular and pedagogical approaches to teaching and learning. It was developed in response to a perceived failure of more traditional forms of instruction where students are required to memorize fact-laden instructional materials (Bruner, 1961). As a form of active learning, it focuses on the students' development of experimental and analytical skills rather than a simple acquisition of knowledge. It is an understanding of students' learning by making sense of the world around them, describing patterns and relationships in their experiences and interaction with others. However, inquiry is more than the ability to use science process skills in solving problems or answering questions. Equally important are the skills of the teacher in planning and organizing activities that engage students in meaningful learning.

Characteristics of IBSE

The key elements and characteristics of IBSE have been the subject of discussions in many conferences since the publication of the U.S. National Science Education Standards in 1996. While there are contradicting views about the importance of inquiry, many educators from different institutions have advocated to continuously work together on clearly defining the recognised features of IBSE, including the roles of the students and teachers. From a number of related literatures, the general characteristics of IBSE are outlined below:

1) It emphasizes constructivist ideas of learning.

Constructivism sees learning as a dynamic and social process in which learners actively construct meaning from their experiences in connection with their prior understandings and the social setting (Driver, Asoko, Leach, Mortimer & Scott, 1994). In the constructivist view of learning, students construct their own models about the natural world from their interactions and experiences. Students become active recipients of new and complex knowledge. They make sense of the content of learning by building connections to their experiences which is one of the goals of the methods of inquiry. This is the result of an active interaction of key cognitive processes (Glynn, Yeany & Britton, 1991).

2) It involves reformation of ideas.

Students do not enter a class as empty vessels. They have developed many ideas from their experiences that may or may not have been verified as absolute truths. Learning starts when they encounter new material and where observations and experimentation reveal new knowledge. However, new knowledge that does not agree with experiences is difficult to reconcile. These ideas or pre-conceived notions are possible "misconceptions" which can be valuable bases for learning and reformation of ideas. The inquiry approach has an important role in this learning context. It allows students to discover new knowledge and make judgments on the basis of evidences observed to correct "false ideas."

3) It focuses on metacognitive learning.

Metacognition refers to a higher order thinking process that involves active control of cognitive processes (Livingston, 1997). It is commonly defined as "thinking about thinking." Students are engaged in metacognitive activities such as planning a learning task, monitoring comprehension and evaluating their own progress in completing the task. In an inquiry-based perspective, students are given the opportunity to examine their thinking processes and learning practices. Students oversee gathering of information, evaluating the relevance of such and deciding on the usefulness of methodology in answering a question or resolving a problem. The idea of self reflection is emphasized as an important aspect of learning.

4) It promotes lifelong learning.

Learning is not confined to the classroom but occurs throughout life and in a range of circumstances. Depending on the favoured industry, schools take responsibility in preparing students to acquire skills necessary to be productive and competitive in any field. While the focus is the development of skills, the inquiry-based approach also aims to emphasize the importance of cultivating curiosity, grappling with problems using multiple approaches and working with others in dealing with challenging situations.

Role of Learners and Educators in IBSE

The inquiry standards are divided into grade levels in order to identify specific tasks set for each stage of learning. This is to set the expectation of the teacher from the students belonging to a grade level. In 2006, the working group on the International Collaboration on

the Evaluation of IBSE programs provided a list of the general roles of students in an inquiry-based classroom setting (Harlen W. et.al. 2006).

- 1) engaged in observation and, where possible, handling and manipulating real objects;
- 2) pursuing questions which they have identified as their own even if introduced by the teacher;
- 3) taking part in planning investigations with appropriate controls to answer specific questions;
- 4) using and developing skills of gathering data directly by observation or measurement and by using secondary sources;
- 5) using and developing skills of organising and interpreting data, reasoning, proposing explanations, making predictions based on what they think or find out;
- 6) working collaboratively with others, communicating their own ideas and considering ideas of others;
- 7) expressing themselves using appropriate scientific terms and representations in writing and speaking;
- 8) engaging in lively public discussions in defence of their work and explanations;
- 9) applying their learning in real-life contexts;
- 10) reflecting self-critically about the processes and outcomes of their inquiries.

All of the activities above cannot be practically present in every inquiry-based lesson. They do not occur simultaneously either. If the desire is for the students to acquire these skills over time, the implications for teaching become clear. In order to facilitate learning, it requires that the teacher is primarily involved in the following activities (IAP, 2010):

- 1) providing opportunity for students to encounter materials and phenomena to explore or investigate at first hand;
- 2) asking questions that require reasoning, explanations and reflection, and showing interest in the students' answers;
- 3) arranging for discussion of procedures and outcomes as well as practical investigations in small groups;
- 4) encouraging, through example, tolerance, mutual respect and objectivity in small group and whole class discussion;
- 5) providing access to alternative procedures and ideas through discussion, reference to books, resources such as the Internet and other sources of help;
- 6) setting challenging tasks whilst providing support (scaffolding) so that students can experience operating at a more advanced level;
- 7) teaching the techniques needed for advancing skills, including the safe use of equipment, measuring instruments and procedures;
- 8) encouraging students through comment and questioning to check that their ideas are consistent with the evidence available;
- 9) helping students to record their observations and other information in ways that support systematic working and review, including using conventional representations;
- 10) encouraging critical reflection on how they have learned and how this can be applied in future learning.

Levels of Inquiry-Based Learning

There is a spectrum of inquiry-based teaching methods available. Though educators define inquiry differently, they generally agree that the inquiry cycle involves at least four critical steps: 1-generating hypotheses, 2-collecting data, 3-interpreting evidence and 4-drawing conclusions (Suthers, 1996; Looi, 1998; White and Frederiksen, 1998). As a proponent of a collaborative nature of inquiry approach, a four-phased learning model includes: 1-anchoring and planning, 2- individual inquiry, 3-collaborative inquiry and 4-concluding group's results (Chang, Sung and Lee, 2003).

In 1971, Marshall Heron developed the Herron Scale to evaluate the amount of inquiry within a particular learning task. There have been a number of revisions proposed including an extensive continuum on the levels of pedagogical practice as proposed by Carl J. Wennings (2012) described in the table below:

Discovery Learning	Interactive Demonstration	Inquiry Lesson	Inquiry Lab	Real-World Applications	Hypothetical Inquiry
Low		Intellectual Sophistication			High
Teacher		Locus of Control			Student

A basic hierarchy of inquiry-oriented science teaching practices. The degree of intellectual sophistication and locus of control are different with each approach (Wennings, 2012)

1) Discovery Learning

Discovery learning is a fundamental inquiry approach. The objective is to build concepts and acquire knowledge from experiences. The experience is introduced in order to enhance its relevance and meaning. Students are guided by the teacher who directs questions to the problems thereby allowing the students to draw simple relationships, generalizations or conclusions.

2) Interactive Demonstration

In an interactive demonstration inquiry approach, the teacher is responsible for conducting the demonstration, developing and providing probing questions, eliciting responses by making predictions, soliciting explanations after the demonstration and helping students to arrive at conclusions on the basis of evidence. The teacher's role is important in modelling the process of inquiry at the most fundamental level.

3) Inquiry Lesson

Inquiry lesson involves a more complex form of investigation and experimentation. While the teacher is still in charge of guiding the discussion and leading students to conclusions, guidance is more indirectly using appropriate question strategies. There is more independence as students formulate experimental approaches, identify and control variables.

4) Inquiry Lab

In the inquiry lab, students are independently developing and executing experimental plan. They collect data and analyze them to find useful scientific laws and draw simple relationships. Unlike the traditional lab, the inquiry lab is driven by questions requiring ongoing intellectual engagement using higher order thinking skills (HOTS). Based upon the degree of sophistication and locus of control, Wennings identified three levels of inquiry lab as follows:

- a. Guided inquiry lab is an approach where students follow a series of leading questions in order to achieve the goal of the lab. The procedure for the lab is based on the teacher-identified problem and the multiple leading questions.

- b. Bounded inquiry lab does not provide the benefit of leading questions. Students are required to design and conduct their own experiment and perform dimensional analysis as a means of formulating a logical basis for conducting an experiment. As needed, teachers can assist by asking leading questions but not answers to students questions.
- c. Free inquiry lab requires students to identify the problem to be solved and create an experimental design. It is a science project of gifted or more advanced students during or outside regular class hours.

5) Real-World Applications

This level of inquiry allows students to apply what they have learned through experiences in new situations. Problem solving exercises serve the purpose of mastering manipulation of variables in equations. However, it may not be a good opportunity for students to make connections to more complex problems encountered by scientists and engineers in real life. Therefore, project-based activities will serve as an authentic assessment of what has been learned.

6) Hypothetical Inquiry

Hypothetical inquiry is the most advanced form of inquiry dealing with hypothesis generation and testing. It involves testing the hypothesis to account for certain laws and or observations. It is a research made without taking into account the real-world application. The goal of this inquiry approach is to extend understanding of the laws of nature.

Technology and the IBSE

In this day and age very few real experiments are conducted without employing the latest technology -- sophisticated measurement instruments supplying large amounts of accurate data to a computer for storage, analysis and display (MacKenzie, 1988, p. 13).

New perspectives in learning theories have encouraged researchers and practitioners to design, develop, implement and evaluate inquiry-based instructional models (Hmelo and Williams, 1998). By maximizing the use of available learning technologies, a body of research evidence demonstrates the positive effect of computer supported collaborative learning (Koschmann, 1996; Koschmann, Hall and Miyake, 2001). For the purpose of discussion, emphasis must be given on learning *with* computers and not learning *about* computers. Taylor (1980) described three different modes of computer use: tutor, tool and tutee. When being used as a tool the computer saves the learner time by completing low level tasks quickly and easily, allowing the learner to focus on higher order tasks: "*When students use computers to find, sort, sift and analyse information then the computer becomes a conduit for knowledge construction rather than a communicator of knowledge*" (Duffy & Jonassen, 1992, p. 10).

Grabe and Grabe (2001) enumerated five roles of technology in learning:

- as tools to support construction of knowledge
- as information vehicles for exploring knowledge to support learning-by-constructing
- as a context to support learning by doing
- as a social medium to support learning by conversing
- as an intellectual partner to support learning-by-reflecting

While they vary in specific details, the value of using technological resources in an inquiry-based teaching and learning environment all emphasize exploring ideas, conducting hands-on experiments, engaging in projects, working collaboratively, communicating their ideas

and gaining conceptual understanding. However, the effect of these tools on learning can only be assessed by determining the extent in which they are used by students and teachers in the classroom and the laboratory. Part of the consideration is the realization and belief of teachers and the circumstances that matter in their implementation. It is noted that successful learning can be achieved by an outstanding pedagogy alone, with the appropriate use of technology or both. When the objectives of learning agree with the purpose of technological innovation, they complement each other in effectively managing the teaching and learning environment.

Technology-Based Resources

There is a wide range of technology-based resources available. Since these resources offer different approaches in supporting inquiry-based science, they are generally grouped into categories to primarily give detailed descriptions on how they are implemented in the classroom. Specifically, the discussions will include the role of each category in supporting the inquiry approach.

1) Video Analysis and Analytic Mathematical Modelling

The use of video analysis to study different phenomena such as motion in mechanics is an example of technology used in a science and mathematics class. Recent developments have shown sophistication in the quality of videos produced in order to accurately visualize and analyze such phenomena. Regardless of the software, the principles of video analysis are the same: it allows its users to capture a video as a visual record of the experiment or demonstration, analyze it by frame and perform statistical analysis of graphed data including integrals, tangents, linear and curve fits, margin of errors, among others. The growing interest in this type of technology has led many software developers to design rather inexpensive and accessible tools. Currently gaining interest for use in physics classes are as follows:

- a. **Physics Toolkit v6.0.** Formerly known as World-in-Motion, it is a useful educational tool for lecture, laboratory activities, and student assignments. The software includes video analysis tool covering physics topics such as mechanics, acoustics, electromagnetism and waves. It also includes documents, problem sets and demonstration videos covering common topics in first year algebra and calculus-based physics.
- b. **Measurement in Motion.** Measurement in Motion was designed by Learning in Motion with assistance from the Freudenthal Institute, Utrecht, The Netherlands, and Michael Jay. This video analysis software was compatible for both Mac™ OSX and Windows®. It involves critical activities in mathematics and science. Students produce their own video clips for a number of almost unlimited numbers of analysis possibilities.
- c. **Tracker.** Tracker is a free video analysis and modelling tool built on the Open Source Physics (OSP) Java™ framework designed for physics education. It is a powerful and innovative way of combining videos with computer models. Supported by digital resources, it provides links to tutorials and videos ready for analysis. The tracker also has the capability of creating a line profile tool that measures the brightness of the image pixels it lies on in order to generate spectral line profiles and analyze diffraction and interference patterns. This feature is not currently available in other video analysis programs.
- d. **Data Point.** This is the most basic of all the video analysis software described. It is an inexpensive alternative for performing two-dimensional motion analysis in the classroom. While current features are minimum, DataPoint developer is currently

working for revisions that includes frame zooming, multiple-object tracking and support for other video formats (QuickTime™ and MPEG) and operating systems (Mac™ and Linux™).

- e. **VideoPoint®.** VideoPoint® Physics Fundamentals is supported by the American Association of Physics Teachers (AAPT). It is designed to teach fundamental laws and principles of physics using video-based motion analysis. It is targeted primarily to assist in the teaching of introductory physics to high school students. Videopoint® includes some notable features that are not available in other video analysis software. It has the capability to translate and rotate the coordinate system and to display multiple graphs in separate windows. The program is available in Mac™ and Windows®.
- f. **Logger Pro.** Logger *Pro* is a program developed by Vernier Software and Technology (1981) for Windows®, Mac™ and Linux™. It supports a wide variety of sensors and devices for data collection and analysis. One of the notable features of this video analysis tool is the advanced real time graphing capabilities and powerful statistical tools. It allows its users to model data with user-adjustable functions, use time of day and date stamps for graphing, a GPS support, and manual configuration mode for IB courses, among others. With its recent development, it is capable of allowing multi-touch and advanced networking and exporting of graphed data.

2) Microcomputer-Based Lab (MBL)

The effect of microcomputer-based laboratories (MBL) upon student learning and development in undergraduate physics has been collaboratively studied by pioneering educators of Tufts University and Dickinson College (Laws, 1989; Thorton, 1989; Thorton and Sokoloff, 1990). There are other research studies which examined the various aspects and characteristics of MBL's implementation in science laboratories. A list of key desirable cognitive characteristics of MBL as enumerated by Tinker (1984a) shows the functional simplicity of the program, provision of immediate feedback, and focus on direct experience where there is control and ease of data transformation.

There are two-fold advantages inherent in the use of MBL technology in the science laboratory (Amend et al., 1989):

- MBLs allow students to do the steps in the experimental process faster, more thoroughly and more accurately; and,
- MBLs involve the student in more of the scientific process.

The traditional laboratory activities consider time constraint as a challenge in the ability to repeat experiments that involve a collection of data. As a result, important phases of the laboratory experience such as errors in measurement, instrumental effects (calibration, accuracy, error of quantification, resolution, scaling) and control of extraneous variables are not treated. The MBL increases the number of data where meaningful examination and analysis can be done instantaneously. Since simultaneous measurements of data are easily displayed, more time is spent postulating relationships, controlling experimental variables and redesigning the experiment if necessary. MBL technology has the ability to free the user from the drudgery of quantification and graphical analysis and allow active investigation (Amend et al., 1989).

There are a number of inexpensive data collection sensors available that can easily be connected to a microcomputer. Examples include force, temperature, pressure, electric voltage and current, light intensity, dissolved oxygen, and pH among others. Two companies that provide innovative tools for MBL are described below:

- a. **PASPORT Probeware.** This is a collection of different sensors developed by PASCO Scientific. Each digital sensor has a computing device of its own complete with digital chip on board. Students collect data with computers, without computers and wirelessly to a computer. PASCO's Spark Science Learning System is a revolutionary device that integrates the capability of probeware with inquiry-based approach and assessment. It is a small, fingertip-touch navigation device complete with data collection and analysis capabilities. Recent engineering development introduced MultiMeasure sensors (2012), a new line of multiple sensors in the convenience of one unit of sensor.
- b. **Vernier Sensors.** Vernier probeware is a set of rugged, classroom-proven sensors developed by Vernier Software and Technology. The sensors provide reliable, consistent and high quality results when used with compatible interfaces. The interface translates sensor data for graphing and analysis software on a computer or handheld device. The intuitive touch-based colored interface, built-in graphing and analysis, stopwatch, notes, activities and scientific calculators are among the key features of Vernier interface. New software developments include compatibility with Mac™, wireless connectivity with Wi- Fi and Bluetooth and its fast data collection capability with 100,000 samples per second.

3) Interactive Educational Simulation

The use of interactive educational simulation has been popular over the years with the absence of an actual experimentation of physical phenomena. While the purpose of an educational simulation is to motivate the learner to engage in problem solving, hypothesis testing, experiential learning, schema construction, and development of mental models (Winn & Snyder, 1996; Duffy & Cunningham, 1996), it relies heavily on scaffolding (Duffy & Cunningham, 1996), coaching, and feedback (Alessi & Trollip, 2001) to facilitate learning.

- a. *Physics Education Technology (PhET).* The Physics Education Technology (PhET) is an interactive research-based set of educational simulations developed by a group of researchers, software engineers, K-12 specialists and teachers from the University of Colorado at Boulder. The goal of the project is to incorporate the findings of their research in developing a technology that simulates real-life phenomena. The research on both use and design of these interactive simulations was done in order to gain insights on specific characteristics that make these tools effective and to understand how students engage and interact with the tools in a variety of learning environments (PhET Research).

With the knowledge of simulation design principles based on how students learn and think-aloud interviews, the PhET research team was provided with data sources that are helpful in interface design and continuous software development. Specifically, the team outlined their immediate interests in the project as follows:

- *Use of analogy to construct understanding:* Students use analogies in simulations to make sense of unfamiliar phenomena. Representations play a key role in student use of analogy.
- *Simulations as tools for changing classroom norms:* Sims are shaped by sociocultural norms of science, but can also be used to change the traditional norms of how students engage in the classroom.
- *Specific features of simulations that promote learning and engaged exploration:* Our design principles identify key characteristics of simulations

that make them productive tools for student engagement. Now we wish to study in detail how each feature impacts student understanding.

- *Integrating simulations into homework:* Simulations have unique features that are not available in most learning tools (interactivity, animation, and dynamic feedback allow for productive exploration).
 - *Effectiveness of Chemistry simulations:* We have just begun investigating the envelope of where and how chemistry simulations can be effective learning tools.
- b. *Open Source Physics Simulations.* The Open Source Physics (OSP) simulations is a collection of Easy Java Simulation (EJS) applets developed by Loo Kang Lawrence Wee, an educational technology officer at the Ministry of Education in Singapore. The objective of his work is to research and develop ICT-enabled pedagogies and implement principles for sustainable and scalable applications. It is aimed at promoting a culture of active experimentation and reflective practices on innovative use of ICT in education (Wee, 2012). His computer models for physics education can be downloaded from Digital Libraries on the NTNU Virtual Physics Laboratory and the Open Source Physics (OSP).

Using Technology Resources in Inquiry-Based Science Teaching and Learning

Physics classes consist of students with a variety of interests, abilities and motivation. Therefore, identifying specific learning preferences and appropriate teaching strategies are crucial considerations when designing activities. In teaching an introductory physics topic such as projectile motion, a variety of innovative instructional methods can be employed to ensure a worthwhile learning experience. Depending on the objectives of learning, each level of pedagogical practice as described by Wennings (2012) can be used.

One of the issues in the implementation of an inquiry approach is the time spent in the whole authentic inquiry process. With some constraints, teachers resort to lecture-discussion to deliver content which is sometimes inevitable if the goal is to cover as much of a topic as possible. As imperative to an inquiry-based curriculum, it is important to note the benefits of allowing the students to explore before they explain in the context of "Activity Before Concept" (ABC) at least whenever a new topic is introduced. Specifically, the following outlines a typical inquiry process which can be considered when designing activities:

- a. The skill of the students in using any technological resources such as video analysis, microcomputer-based laboratories (MBL) and educational simulations are well in place. There is always an assumption that the teacher will not teach how to use the tool during the course of the experiment. This approach allows more time for gathering and analysis of data.
- b. Learning is collaborative. Students can work in pairs or by group with a minimum of three members and maximum of four members depending on the dynamics of the class and the availability of resources. Groups with five or more members increase the probability of having a member who is most likely to free-load. To ensure that all students are on task, small group work and discussions are usually productive.
- c. An inquiry lesson usually begins with predictions. These are dependent on the objectives of the lesson but are usually limited to the context of checking what students know about the lesson being introduced. It does not include higher level thinking models that could be derived from a thorough analysis of data that students are about to collect. To be conscious of their pace in discussing and arriving at common predictions, a time limit is usually given.

- d. Predictions should be communicated. In order to encourage reasoning as part of any science laboratory practice, three or more pairs of students will be asked to simultaneously sketch their predictions on the chalkboard. Each pair discusses with the class the basis of their predictions. The role of the teacher is to come up with a common prediction using the class' judgment on what prediction they think is "most reasonable." Furthermore, the teacher should encourage the thinking that all predictions are treated as not necessarily correct nor incorrect.
- e. Students conduct the experiment using a set of parameters provided by the teacher. It may include the objectives, materials needed and the procedure. The prediction sheets will be collected, checked for compliance and returned since part of the proceeding tasks is a comparison of predictions and actual observations.
- f. During the analysis, students are encouraged to brainstorm with their partners. The locus of control should gradually shift from the teacher providing leading questions written on the worksheet to the students discussing and analyzing the physical meaning of the data gathered. The teacher moves around the room to observe how students progress in the analysis. Teachers should not provide answers to questions when students ask rather, a leading question should be thrown back to the student which allows them to manage their own thinking.
- g. A teacher-facilitated discussion will give students the opportunity to state their arguments, justify their answers, provide visual representations, create their own models, and pose intriguing questions, among others.

Logger Pro Video Analysis

Below is a sample activity using *Logger Pro* video analysis software in introducing non-horizontally- launched projectile motion. The distinction between a guided inquiry lab and the free inquiry lab depends on the abilities of students. AP students can work on free inquiry labs considering a strong mathematical physics foundation.

In an exclusive school for boys like the Ateneo de Manila High School in the Philippines, students' active involvement in sports activities beyond the school's physical education program is a good opportunity for lesson integration. The description of the entire inquiry experience in teaching non-horizontally-launched projectile using basketball free throw is outlined below. A guided inquiry lab approach was the focus of the lesson development. However, some parts include discovery and inquiry lesson approaches.

The session begins by asking students to make predictions using a problem presented by the teacher. For example, "You are standing on a free-throw line of a basketball court that is approximately 15 ft away from the ring. Doing a "set shot", you release the basketball freezing your hand at the topmost part of your follow through. Your partner observes the motion of the basketball as it goes through the basket. In the next ten minutes, discuss and predict, 1) the shape of the graph of the ball's horizontal and vertical position as a function of time; 2) the shape of the graph of the ball's horizontal and vertical velocity as a function of time; 3) the shape of the graph of the ball's horizontal and vertical acceleration as a function of time; 4) Which graph(s) will show a linear relationship? Quadratic relationship?

The video analysis software can be used to draw predictions as shown by the sample position versus time graph screenshots below.

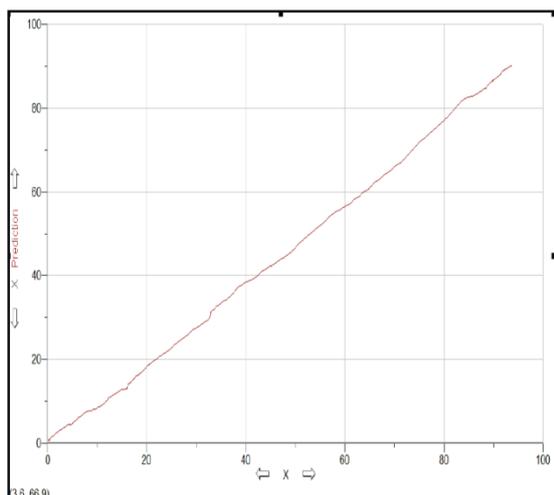


Figure 1. Prediction for the graph of horizontal position of the basketball as a function of time.

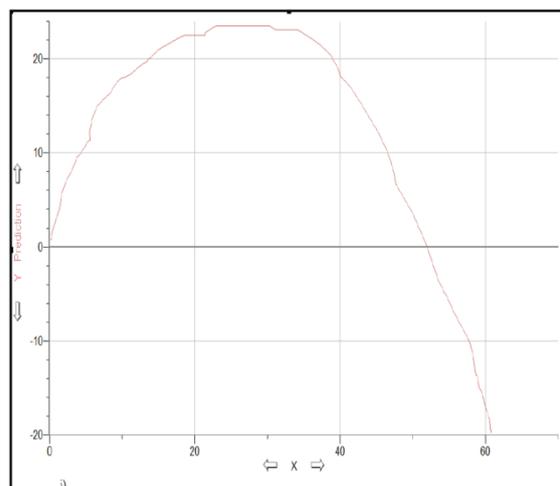


Figure 2. Prediction for the graph of vertical position of the basketball as a function of time.

There is an assumption that students know how to use Logger Pro at this point. The key elements necessary for a video to be valid for analysis such as a visible scale marker and use of a still camera will no longer be included in the instruction. Only those procedures needed to come up with the same experimental set-up for all student pairs will be included. The videos will be saved on a flash drive or an SD card for the video analysis. Students analyze the basketball free throw video using Logger Pro. They define the origin of the basketball's motion, add appropriate scale and manually mark the successive positions of the basketball in each frame. At the same time, the x and y graphs of motion such as position versus time and velocity versus time are automatically created. The video analysis software is capable of providing statistical details of the graphs such as linear and curve fitting, mean, median, mode, correlation value and the root-mean-square error (RMSE). Below is a screenshot of a working window of Logger Pro:

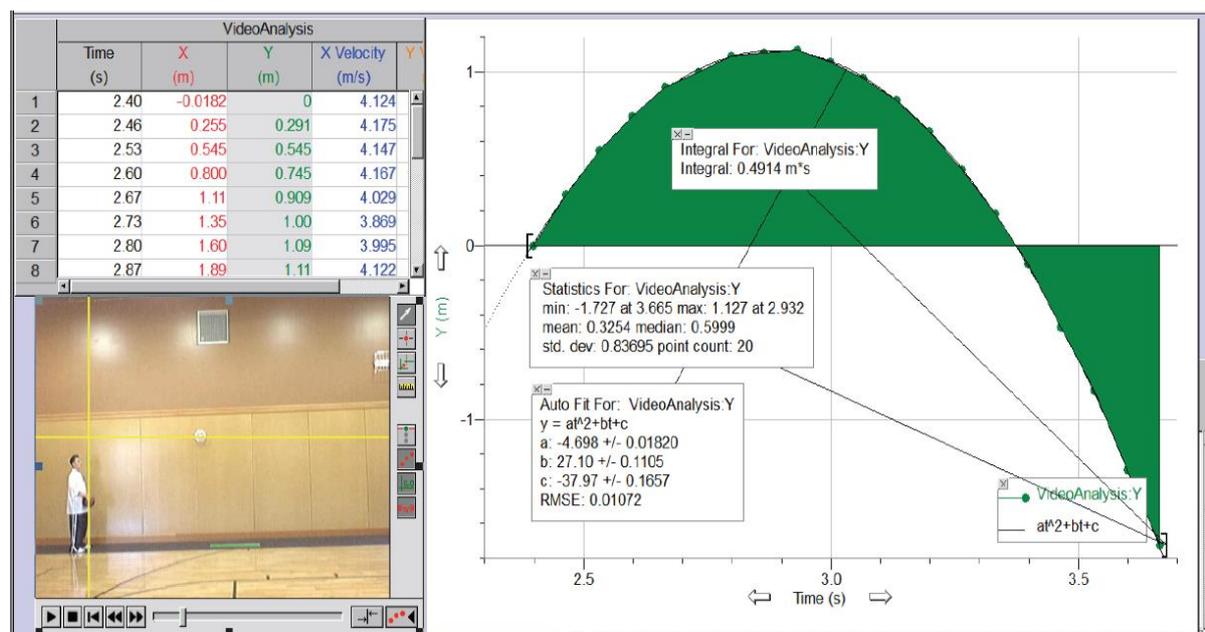


Figure 3. Window of Logger Pro video analysis

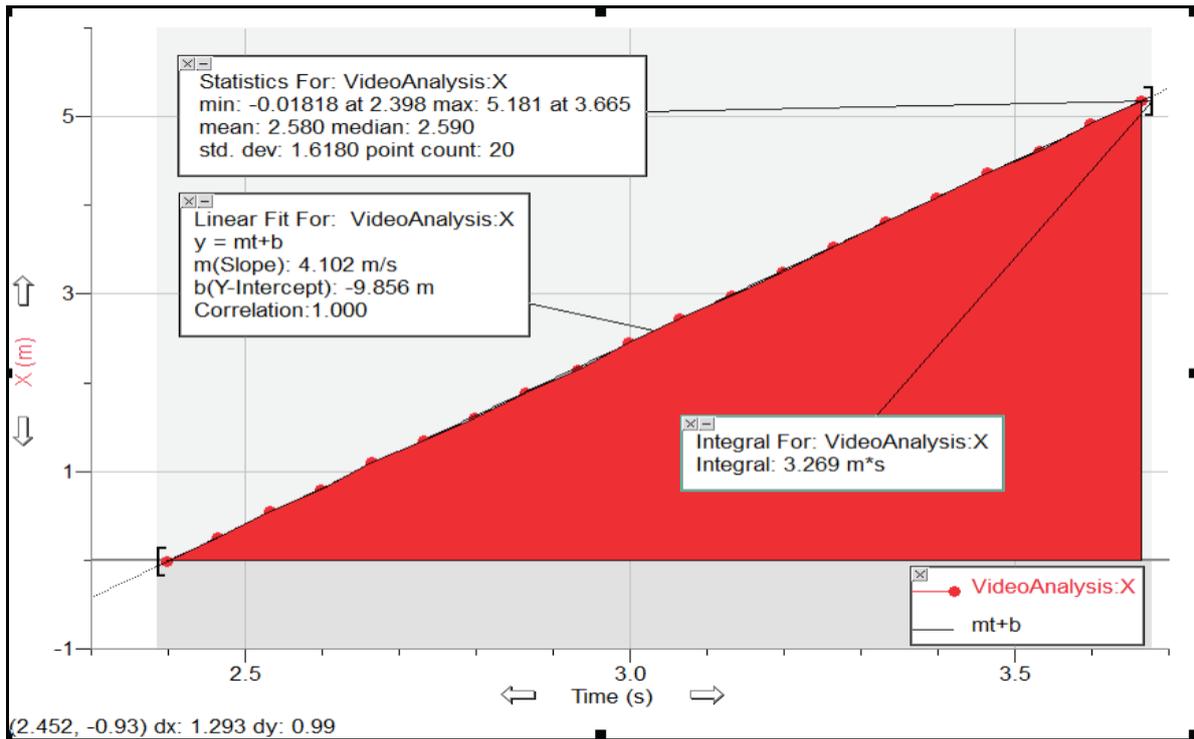


Figure 4. The graph of horizontal position of the basketball as a function of time.

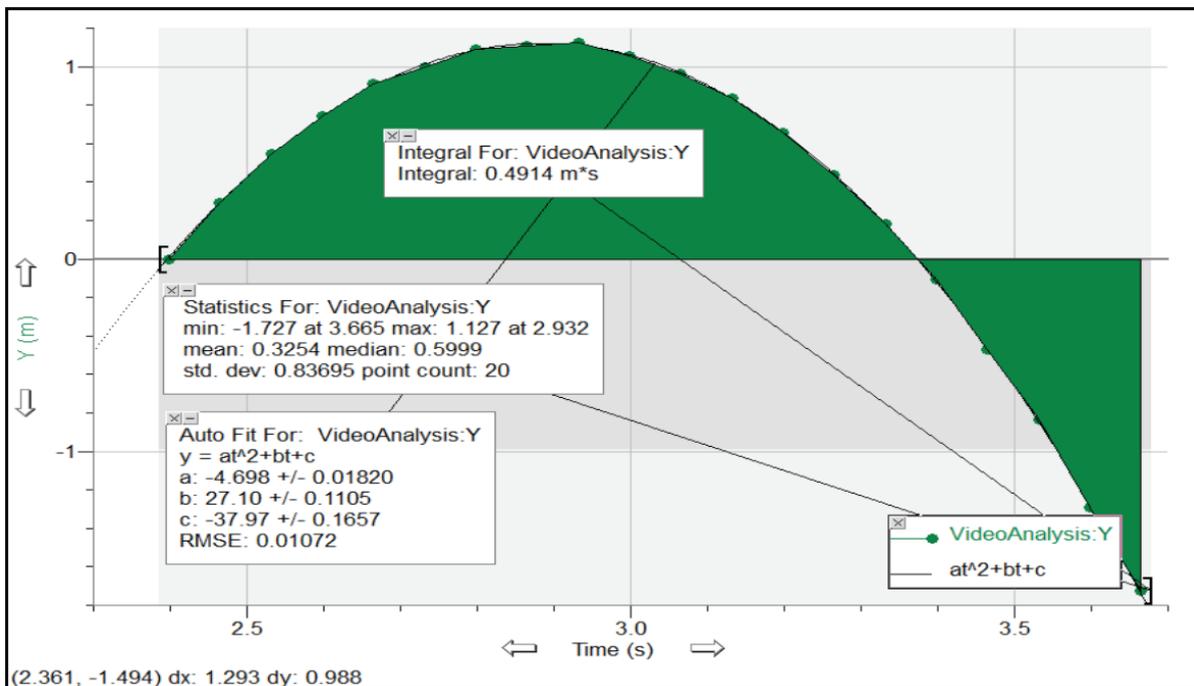


Figure 5. The graph of vertical position of the basketball as a function of time.

Students will be asked to go back to the prediction sheet and answer the same set of questions but this time, guided by the graphs generated by Logger Pro. The equations of the line or curve with other statistical values on their computer screen should be included in the graph. The discussion is not strictly guided by the questions on the laboratory activity

sheet. The discussion should be free-flowing allowing students to commit mistakes and correct themselves at the same time in the process of analyzing the data. Below are sample questions on the video analysis activity:

- Analyze the upward and the downward motion of the basketball by examining the displacements along the horizontal axis. What do you notice on the distance between the two adjacent points when the ball is moving upward? Is it the same as when the ball is moving downward? Follow up questions: What does it imply? Is the ball accelerating along the x-axis? Why or why not? What type of relationship does the x versus t graph show?
- At what initial velocity and projection angle should a person of your height release a basketball in order to make a successful free throw?
- If you increase the projection angle of the basketball, do you need to increase, or decrease the initial velocity of the basketball in order to shoot the ball into the basket?

Building up the concepts and principles involved is the key. Analysis questions on the worksheet starts with simple relationships and progresses to higher order thinking skills. Sample student responses are given below.

"From the data points in the graph, we observed that the distances between the adjacent points during the entire motion of the basketball are equal. This means that the horizontal velocity of the basketball is constant and therefore, the acceleration becomes zero. There is a linear relationship between the horizontal position and time expressed mathematically in the form $y = mt + b$. The slope of the graph represents the average horizontal velocity of the basketball."

"It was also observed that the distances between the adjacent points (in the graph of y position versus time) during the entire motion of the basketball are equal and the trajectory forms a parabola. This means that the vertical velocity of the ball is changing and therefore, the acceleration is not zero."

"There is a quadratic relationship between the vertical position and time expressed mathematically in the format $y = at^2 + bt + c$. The slope represents the acceleration. We found out that this is similar to the kinematic equation $d = 1/2at^2 + v_i t + d_i$. In which case, the value of a in the graph should be close to $1/2$ of -9.8 m/s^2 which is -4.9 m/s^2 "

"When the graph was examined, the x and y velocity values on the data table at the point of release were noted. The angle of release was calculated using the inverse tangent function of the ratio of the y velocity to the x velocity. If the angle of projection is increased, the basketball might not hit the basket. Therefore, we need to increase the initial velocity."

It is highly recommended to further the discussion on how the velocity changes as the ball moves upward, reaches the peak and moves downwards. The symmetry in the graph provides key concepts on the magnitude of velocity at two symmetrical points in the graph or relationship between the time it takes the ball to move upward and the time it takes the ball to move downward. There was little analysis about the comparison on the value of b in the equation of the graph versus manually calculating the initial velocity at that point. Only a few groups of students explained that the video analysis is not capable of treating the point of release of the basketball as when $t = 0 \text{ s}$ thus, resulting in a discrepancy when initial velocity is calculated manually. The idea that the correlation and RMSE values measure the experimental error is enough but all of the students should account for the sources of these errors. As teachers led students to introduce encountered errors in using the software, they are also teaching the value of controlling variables. Students identified three major errors in this experiment:

- "Marking the points." Although each frame is precisely timed by digital recording, the exact position of the basketball at different time intervals is dependent on the marking skill of the student.
- "Scaling." Scaling is important so that the software can make adjustments on actual distance measurements during the analysis. If the scale is too short, the values of velocity and acceleration will be too large and vice versa.
- "Video quality." An object moving too fast can blur making it extremely challenging for students to determine its center of mass. Though a high speed camera is not necessary, some advanced experiments can take advantage of this.

Vernier Motion Sensor and Inquiry Science Teaching and Learning

Teaching about using motion graphs is generally complicated when the connection between the visual representation and the actual experience of motion in a specific direction is not established. With the teacher providing the lecture, sketches and some word descriptions of motion, the tendency is for the students to find simple patterns and memorize them. As a result, students who are given new situations to interpret in a graph will not be able to accurately provide the representation. The use of a motion detector is not new but the way it was used has evolved in the past few years. The basic design principles involve detecting the position of the object at some linear and radial distance and interpreting the changes in position with respect to time in terms of velocity and acceleration. The design of activities using a motion detector can vary from guided inquiry lab to free inquiry lab. Below are brief descriptions of actual experiments in a pre-university physics class.

The variation in the process of the laboratory experience is necessary so that students' interests are peaked without the notion that activities are "predictable." While making predictions is a useful strategy, breaking the monotony of the process should be done. In this motion sensor activity, students are given set graphs of position as a function of time as shown below. The task of the students is to describe the motion of the person walking in front of the sensor based on the shape of the graphs.

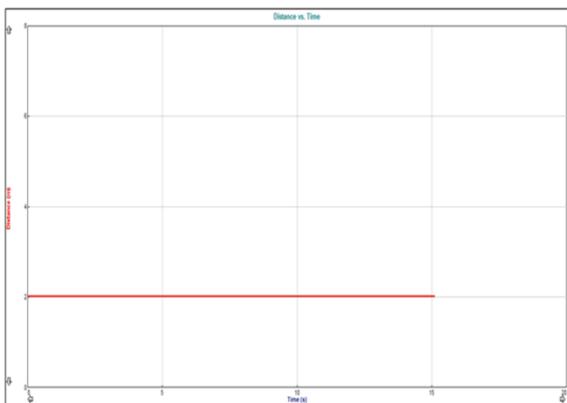


Figure 6. "A person is not moving and is standing 2 m in front of the motion sensor for about 15 s."

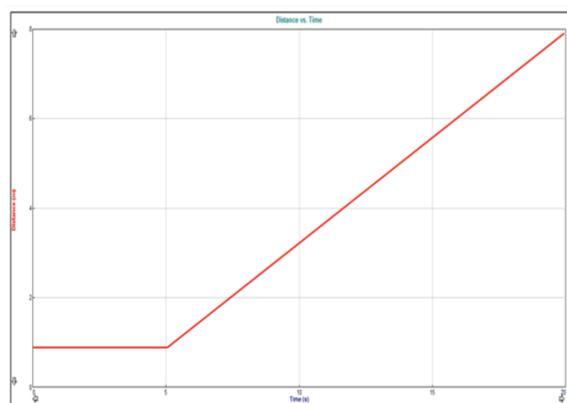


Figure 7. "A person is at rest approximately 1 m in front of the motion sensor for 5 s then moves away from the sensor at a constant speed."

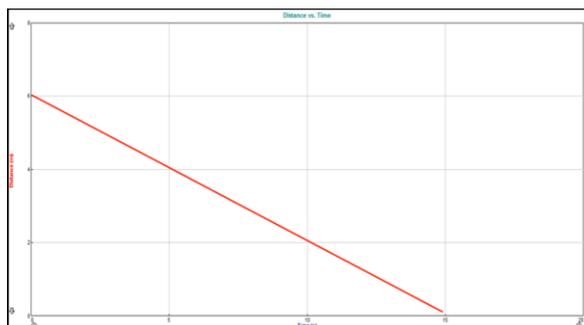


Figure 8. "Person stands 6 m in front of the sensor, he then moves towards the sensor at a constant speed."

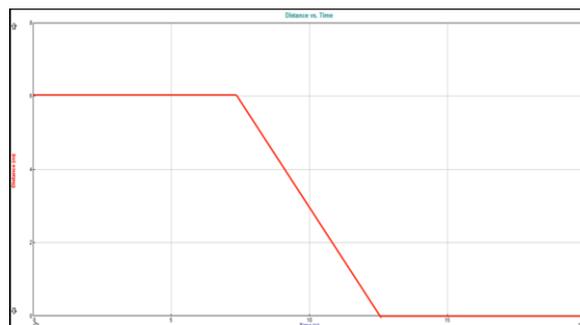


Figure 9. "A person is at rest 6 m away from the sensor then moves towards the sensor decreasing his speed and finally come to rest."

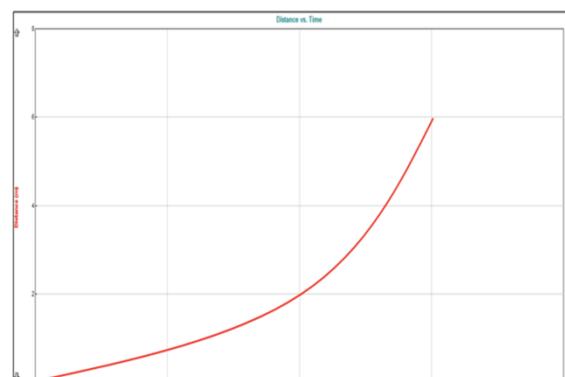


Figure 10. "A person moves away from the sensor and is accelerating."

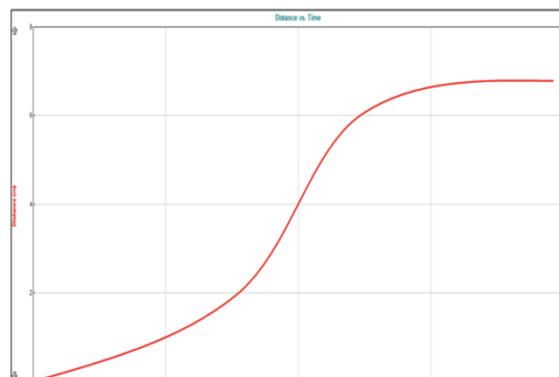


Figure 11. "A person speeds up as he moves away from the sensor then he slows down until he finally rest."

The descriptions provided in each of the figures above are actual students' responses which serve the purpose of "predictions." Before the experimentation, students are engaged in meaningful discussions as they share their interpretations for each motion graph. The way students describe the graphs is limitless but most of the students used the terms "speed" and "acceleration" instead of focusing on position as a function of time. These responses were accepted as they are.

The Vernier motion sensor is connected to an interface then to the computer unit. The default Logger Pro screen shows the graph of position as a function of time and the graph of velocity as a function of time. However, it is better to start with position as a function of time and translate them to velocity as a function of time later. The subject positions himself in front of the sensor while another member captures the data in Logger Pro. Part of the experimental design is to determine the minimum and maximum distance that can be detected by the device.

An alternative motion sensor activity uses dynamics track and magnetic carts. The motion sensor is placed at one end of the track and is defined as the origin. The cart is allowed to move away or toward the sensor. This motion is automatically translated to a graph of position as a function of time. However, the challenge in this activity is to determine the amount of push needed by the cart in order to keep or vary its speed. In an interactive demonstration inquiry, students are tasked to observe and create models based on the evidences gathered. In a guided inquiry lab, the worksheet can be provided and students conduct the experiment on their own. Likewise, a free inquiry gives students the opportunity to design their own experiment given the materials.

The set-up for this activity is shown below.

Example 1: The cart moves away from the origin along a horizontal track at a constant rate.

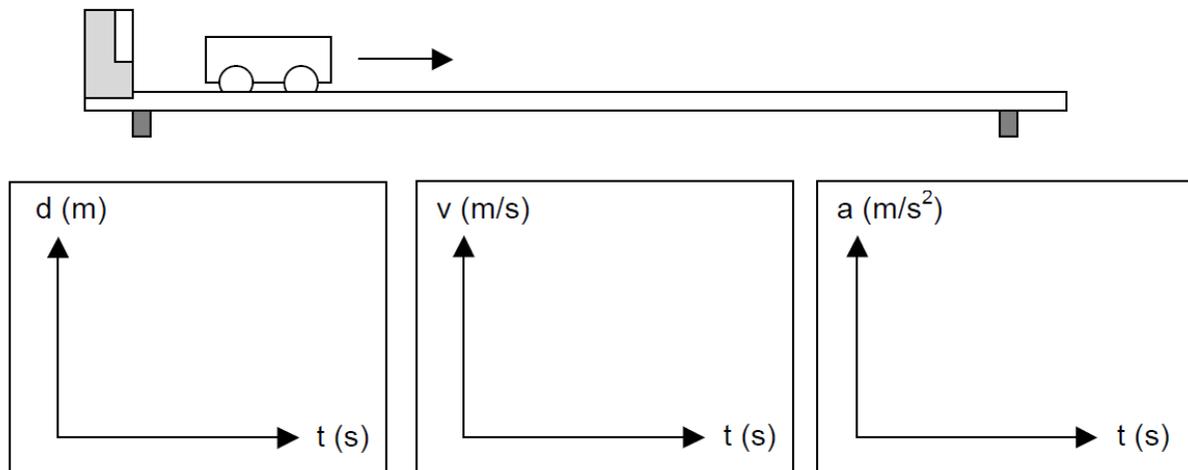


Figure 12. Dynamics track and magnetic cart set-up with motion sensor.

Example 2: The cart moves down the inclined plane away from the origin

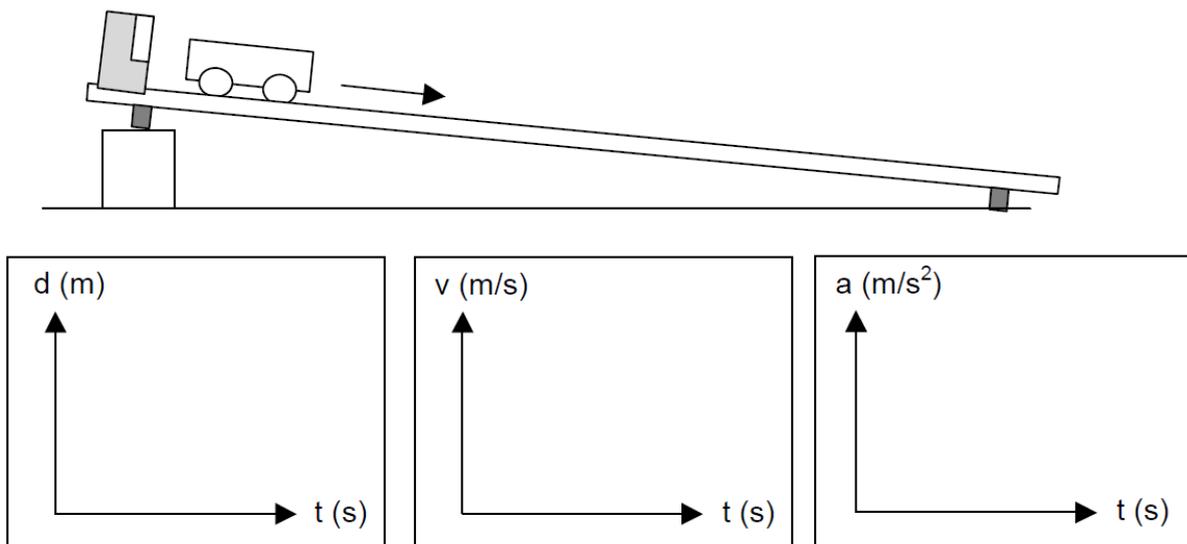


Figure 13. Inclined dynamics track and magnetic cart set-up with motion sensor

Like the video analysis, the graphs generated by the motion detector can be analyzed to accurately determine the position of the person at specific time intervals. There were several problems encountered and a common observation is erratic readings registered in Logger Pro. During the discussions, students identified the following sources of error:

- *the point in the person's body where motion is being detected (should be made of a smooth plane surface)*
- *the sensors and interfaces are old*
- *the working space is small and the sensor reads anything at a certain lateral angle*
- *system delays are also present*

PhET Simulations and Inquiry Science Teaching and Learning

A simulation is a software that allows users to modify or set parameters to model a physical phenomenon. The “messiness” of actual experiments is refined in order to conduct comparative analysis of data. The ability to turn off gravity, air resistance and friction and observing its effect on the phenomenon being observed are some examples. It supports real-world situations which are sometimes impossible to do in an actual experimentation thus, an extension of the physical world that is otherwise inaccessible at the moment. The visualization of moving charges and electric field lines are some representations that are made accessible through simulations.

With increasing interests in the use of simulations in facilitating learning, a variety of educational simulations are being developed. Recent movement in software design gives prevalence to multiple-linked representations. The idea is to study how students learn in using the tools and to have representations in different modalities such as photos, graphs, and so on. The differences among these simulations lie on the complexity of the underlying model, the principle of use and the degree of connection to the curriculum. Exploring use of simulations in the classroom does not require close supervision of teachers. The interactivity and design is highly motivating thus keeping the students’ engagement a little longer. With few instructions, students can independently work beyond the set objectives for exploration. This overwhelming response must be taken with caution though. Parameters are still important in order to direct accomplishment of tasks.

The PhET simulation is a collection of free interactive simulations that can be downloaded and operated without the need for internet connection. Each simulation is accompanied by suggested student worksheets and teacher references downloaded as word files. With permission from the authors, these can be modified for contextual classroom experience. A guided inquiry approach is usually employed in using simulations. A worksheet is provided and students are led to record observations and conclude. One example is the exploration of the concept of “charge” where the interactions between matter in the electrical, chemical and atomic level are observed. In this activity, students are guided to discover the behaviour of charges, how charging occurs and the concept of electric fields.

In the first activity, John Travoltage’s foot is scuffed on the carpet. This picks up charges from the carpet that flow from his foot to his fingertip and eventually being discharged to the doorknob. In the second activity, students explore why balloons stick to a sweater. A balloon is rubbed on the sweater, and then released. It flies over and sticks to the sweater. Representations of the charges in the sweater, balloon and the wall can be viewed.

Sample activities are shown below.

A. John Travoltage

1. *Open the PhET Simulation. On the homepage, click the Electricity, Magnets and Circuits option then find the John Travoltage activity.*
2. *Scuff John Travoltage’s shoe across the carpet. What happens? What do the blue circles represent? What do you think explains your observations?*

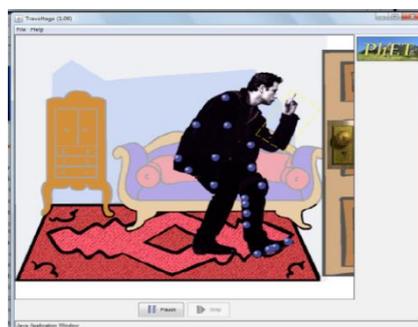


Figure 14. Sample working window for PhET simulations.

3. Bring John Travoltage's hand near the doorknob. What happens? What explains your observations?
-
-

B. Balloons and Static Cling

1. On the homepage, click the Electricity, Magnets and Circuits option then find Balloons and Static Electricity activity.
2. Make sure that the following settings are checked: **Show All Charges, Ignore Initial Balloon Charge, and Wall.**
3. Rub the balloon against the wool sweater. What happens? What do you think explains your observations?

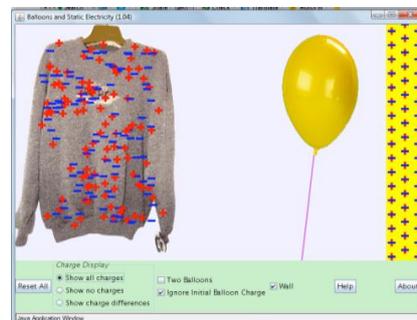


Figure 15. Sample working window for PhET simulations.

4. Bring the charged balloon near the wall. Move it up and down the wall. What happens to the charges on the wall? What explains this?
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Challenges in Inquiry Assessment

The nature of inquiry science raises many issues on how learning is evaluated. Since it involves "process skills" such as hands-on experimentation, problem solving, investigation, thinking, reasoning and argumentation, educators encounter difficulty in detecting evidences that learning has improved. Furthermore, such assessments are likely to include several components such as the ability to use correct methods, draw valid conclusions, state correct assumptions among others which are highly subjective and will require thorough observations on the part of the teacher. It also includes identifying the standard to be achieved and the criteria for accomplishing the tasks. Although it may seem to be difficult at first, there are useful means to measure students' competence in scientific inquiry. While traditional assessment methods involve paper and pencil multiple choice tests to assess knowledge of content, teachers can use alternative strategies such as performance tasks, rubrics, concept maps, structured interviews and self evaluation to measure competence in inquiry (Llewellyn, 2005).

Without specific measurement tools for inquiry assessment, the U.S. National Research Council (2001) suggested that teachers should employ multiple assessment measures to monitor students' progress and interactions. Multiple assessments are standards-driven assessment not relying on a single type of test. A wide range of assessment alternatives can help teachers in gaining better insights on how much a student has achieved in the curricular program. This includes diagnostic tests, formative assessments and summative assessments. Three of these authentic (formative) assessment methods as enumerated by Llewellyn (2005) are briefly describe below.

a. Performance Tasks

In this type of assessment, students review a range of information sources and construct a model based on the evidence gathered. This can be in the form of structured task or open-ended type of investigations which can be done in a few days. As an example,

physics students at the Ateneo de Manila High School spend days in planning, designing and constructing balloon-powered cars. This is in conjunction with the lesson on Newton's laws. They investigate the type of materials to use and their implication on the speed and distance covered by the car guided by the parameters set by the teacher. Once constructed, students conduct trials and record speed and distance measurements. They are also expected to come up with a written report.

b. Rubric

Rubrics are scoring guides used in performance tasks or projects. This is done by modelling an exemplary work in order to communicate a means for achieving a high standard of work. The rubric includes descriptors and criteria at different levels of competence such as the ability to collaborate with a team in accomplishing tasks, observance of safety in using laboratory equipment, design and construct correct and logical procedures, record the data accurately and concisely and so on. This is usually found in the "behavioural" component of most lab activity scoring guides. This can be used to provide feedback on performance tasks or capstone projects described below.

c. Capstone Projects

Capstone projects are research investigations conducted on a long-term basis such as the entire school year. This gives students a unique opportunity to integrate knowledge of science and process skills in carrying out a plan and doing actual investigations. This project emphasizes inquiry and requires students to communicate progress reports through oral presentations with the teacher as a mentor. Similar to a science investigative project, it includes scoring rubric for every part of the task. The final report is submitted at the end of the school year.

There is no doubt that an assessment method at some point needs significant standardization but the uniqueness of individual inquiry is inevitable. In various practical tasks such as sports, music and the arts, the goals to be achieved are outlined but individual variation in achieving these goals are allowed within a permissible range set by the teacher. Likewise, the achievement of the science process skills varies from one person to another. It is expected that the way they acquire these skills and the level of achievement will also vary. Since there is little empirical evidence on how these skills develop over time, other forms of assessment and administrative monitoring should be in place. If other forms of assessment mirror what the goals of instruction and curriculum are at a certain domain, then it is considered appropriate.

Conclusion

Technological resources are dynamic and the ability of the teachers to use them effectively in the classroom should be of equal importance to having a student-centered learning environment. There is a need to invest in professional development to equip teachers with the necessary skills both in implementing and assessing inquiry learning. This paper suggests that an inquiry approach is supported by technology in many ways. The power and flexibility of these resources continuously expand and education should take advantage of them. Nonetheless, technology is as good as the way it is used. Beyond technology and curricular goals is the teacher who is responsible for promoting and creating an environment of critical thinkers and innovators.



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References

- Alessi S. M. & Trollip, S.R. (2001). *Multimedia for Learning: Methods and Development* (3rd Ed.). (214, 254-257). Boston: Allyn & Bacon.
- Bryan, J. (2004). *Video Analysis Software and the Investigation of the Conservation of Mechanical Energy. Contemporary Issues in Technology and Teacher Education* 4 (3): 284-298. www.citejournal.org/vol4/iss3/science/article1.cfm.
- Butts, F. R. & Cremin, L.A.(year) *A History of Education in American Culture*. New York: Henry Hold and Co.
- Carlson, G. A. (2003). *DataPoint* (Win32 Version 0.62) [Computer program]. Saint Peters, MO: Xannah Applied Science and Engineering. <http://www.xannah.org/datapoint>
- Chang, K, Sung, Y., & Lee, C. (2003). *Web-based Collaborative Inquiry Learning. Journal of Computer Assisted Learning*, 19, 56-69.
- Dewey, John. (1897). My Pedagogical Creed. *School Journal*. 54. pp. 77–80. (December 4, 2012) <<http://dewey.pragmatism.org/creed.htm>>
- Duffy, T. & Cunningham, D. (1996). Constructivism: Implications for the Design and Delivery of Instruction. In D. Jonassen (Ed.), *Handbook of research on educational communications and technology*. New York: Simon & Schuster.
- Duffy, T. M.& Jonassen, D. (Eds.) (1992). *Constructivism and the Technology of Instruction: A Conversation*. New Jersey: Lawrence Erlbaum Associates.
- Grabe, M. & Grabe, C. (2001). *Integrating Technology for Meaningful Learning*. Boston: Houghton Mifflin Company.
- Hayes, William. (2007). *Progressive Education Movement: Is it Still a Factor in Today's Schools?* Lanham: Rowman & Littlefield Education.
- Hmelo, C., & Williams, S.M. (Eds.). (1998). Learning through problem solving. *The Journal of the Learning Sciences*, 7, special issue.
- Koschmann, T. (Eds.). (1996). *CSCL: Theory and Practice of an Emerging Paradigm*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Koschmann T., Hall, R., & Miyake, N. (Eds.). (2001). *CSCL 2. Carrying Forward the Conversation*. Mahwah, NJ: Lawrence Erlbaum Associates.

Laws, P. W. (1988). Workshop Physics: Replacing Lectures with Real Experience. The Conference on Computers in Physics Instruction Proceedings, (pp. 22-32). New York: Addison-Wesley.

Livingston, J. A. (1996). *Effects of Metacognitive Instruction on Strategy Use of College Students*. Unpublished manuscript, State University of New York at Buffalo
<<http://gse.buffalo.edu/fas/shuell/cep564/metacog.htm>>

Looi, C.K. (1998). Interactive Learning Environments for Promoting Inquiry Learning. *Journal of Educational Technology Systems*, 27(1), 3–22.

Llewellyn, D. (2005). *Teaching High School Science Through Inquiry*. California: Corwin Press and NSTA Press.

Orleans, A. V. (2004). The State of Secondary School Physics Education in the Philippines: Recent Developments and Remaining Challenges for Substantive Improvements. Unpublished Doctoral Thesis, Hiroshima University, Japan

Rubin, A. (1996). Published in paper from "Technology Infusion and School Change," TERC. Hebrank 2000 Duke University. viewed September 4, 2012
<www.biology.duke.edu/cibl/index.htm>

So, W. (2002). *Constructivist Teaching in Primary Science*. Asia-Pacific Forum on Science Learning and Teaching, Volume 3, Issue 1, Article 1(June, 2002) viewed October 20, 2012
<http://www.ied.edu.hk/apfslt/v3_issue1/sowm/sowm3.htm>

Suthers, D. (1996). Distributed Tools for Collaborative Learning and Coached Apprenticeship Approaches to Critical Inquiry. Proceedings of the *ITS'96*, Montreal.

Taylor, R. P. (1980). Introduction. In Taylor, R. P. (ed.) *The Computer in the School: Tutor, Tool, Tutee*, p. 1-10. New York: Teachers College Press.

Thornton, R.K., & Sokoloff, D.R. (1990). *Learning Motion Concepts Using Real-Time Microcomputerbased Laboratory Tools*. *American Journal of Physics*, 58, 858-866.

Tinker, R. (1984a). *Microcomputers in the Lab: Techniques and Applications*. Cambridge MA: Technical Education Research Center.

Wenning, C.J. (2005a). Levels of inquiry: Hierarchies of Pedagogical Practices and Inquiry Processes. *Journal of Physics Teacher Education Online*, 2(3), February 2005, pp. 3-11. viewed November 4, 2012.
<http://www.phy.ilstu.edu/pte/publications/levels_of_inquiry.pdf>

White, B.Y., & Frederiksen, J.R. (1998). *Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students*. *Cognition and Instruction*, 16, 3– 118.

Winn, W. & Synder, D. (1996). Cognitive Perspectives in Psychology. In D. Jonassen (Ed.), *Handbook of Research on Educational Communications and Technology*. New York: Simon & Schuster