The Research Behind the

Solar Learning Lab™

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 March 1, 2005

Introduction

Too often, topics such as Renewable Energy are taught in a dry, factual way. Students are presented with information which they can regurgitate but not apply or visualize impacting their lives in any way. This situation is at times exacerbated by the increasing pressure on students and teachers alike to meet the requirements of standardized testing. The nature of such tests often means that the focus is on the recall of facts rather than the application of knowledge. Students need to be given opportunities to develop higher order skills such as critical thinking, decision making, evaluation and synthesis if they are to succeed in the increasingly information-driven world. There is also an interesting dichotomy about this topic. It is very easy to teach superficially. The concepts dealt with are straightforward and easily grasped. There is little understanding required to develop a working knowledge of energy resources, and it is often the case that teachers present the material in a few easy lessons and then move on, glad of the opportunity to make up lost time. However, it is precisely this ease of delivery and student reception on a superficial level that makes Renewable Energy such an interesting topic into which to integrate a software design. It can be incredibly difficult for both students and teachers to get to the root of the topic, which is filled with problems and ethical issues which require critical thinking and debate and to which there may be no obvious right or wrong answers. In fact, it is not until we delve into these depths of the topic and see for ourselves the impact which Renewable Energy could have on our lives and environment that students can really become engaged. It is becoming increasingly clear that if we are to engage students and enable them to learn the skills they will inevitably need in the future, then “the curriculum taught in school [should] relate to the concerns and experiences that occupy students in their regular lives" (Wiske, 1998, p. 63). All students will eventually have to buy gas for their cars or pay fuel bills for their homes. They have to listen to their parents complain about energy prices. They see headlines about oil supplies and the environment and are keen to know how it affects them. Students can see this topic as "real life science". The topic has impact on their thinking about politics, the environment, their own families' approaches to energy usage in the home and even their own thinking about their personal and national place in the world. Hence, it is a truly large topic at the heart of which lies the ability to think critically, work collaboratively and reflect on one's own learning.

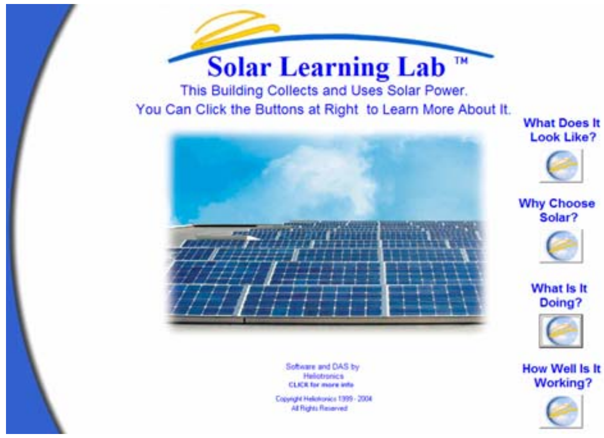
The Company

Heliotronics is a small engineering company that makes educational data monitoring systems for the clean energy industry, focusing on electricity generation by solar and wind power. Their main product is the **Solar Learning Lab™** which includes a working solar electric system with an educational monitoring display, either in the form of a public kiosk or on a computer or network in a lab or classroom. Heliotronics Inc. sees itself as a for-profit organization with non-profit ideals. Their declared mission is "to promote innovative ideas and products that accelerate the adoption of utility grid-connected photovoltaics." and they aim to increase the acceptance of clean energy technologies through public education. They have recently focused more on the educational potential of the **Sun Viewer™** software and are constantly seeking opportunities to get the equipment into schools, museums and science centers. Already, their systems have pride of place at M.I.T. and the Boston Nature Center, as well as being installed in fifty public schools in New York State as part of the *School Power Naturally* program. State level school programs Island have also been completed in Indiana and Rhode Island, making a total of over 90 systems installed around the country.

The Solar Learning Lab™

The Solar Learning Lab™ is designed specifically to enable middle and high school students to learn about the effectiveness, efficiency and environmental consequences of renewable energy through investigation and inquiry. Students learn about the physical attributes of the generating and data gathering system and initial reasons for choosing sources such as solar energy before studying how the system is working and providing energy. They may also study the effects of weather conditions and get a feel for how much energy is being produced and what devices that amount of energy may be capable of powering in a typical home or school. A group of students may, for example, choose two days – one sunny and one cloudy – and study how the energy output varies with the intensity of the incident light, and may extend this even further with the real time and stored data by considering what factors affect the efficiency of the PV panels. At the highest level, this may involve detailed interpretation of a series of graphs, hinting at the multidisciplinary nature of the software.

The Solar Learning Lab™ consists of an educational data monitoring package with interactive display software and an operational solar energy system that produces usable electricity. SunViewer™ display software is the most visible part of the data acquisition system. The software is the students' main point of contact with the solar energy system and in addition to presenting a rich graphical interface and introduction to the world of solar energy, it displays the performance of the photovoltaic (PV) array and describes the different parts of the PV array. The software is structured so that students can work at their own levels in terms of age or ability, with the opportunity to progress from simple to complex concepts and displays. SunViewer™ is designed to operate on standalone machines or on a school network, enabling a large number of students to access the software and manipulate data at one time.



One further tool is available which broadens both the scope and potential of the Solar Learning Lab™ in the classroom. SunViewer.net™ is a powerful, interactive web-based tool that enables students and educators to access data from the school's solar system over the internet, thus allowing projects to be completed at home or in a local library. There is also the potential for schools to access data remotely from other solar generating systems which may be much larger or located in areas which experience considerably different weather conditions. For example, with the New York State program, schools in Buffalo can compare their energy production and weather data with schools in New York City. Buffalo typically gets significantly more snow than New York City, making this an interesting and valuable exercise for students in both regions. In addition to displaying data in both numerical and graphical form, SunViewer.net™ allows students and educators to download data in a spreadsheet compatible format for further analysis and study.

The Research behind the Solar Learning Lab™

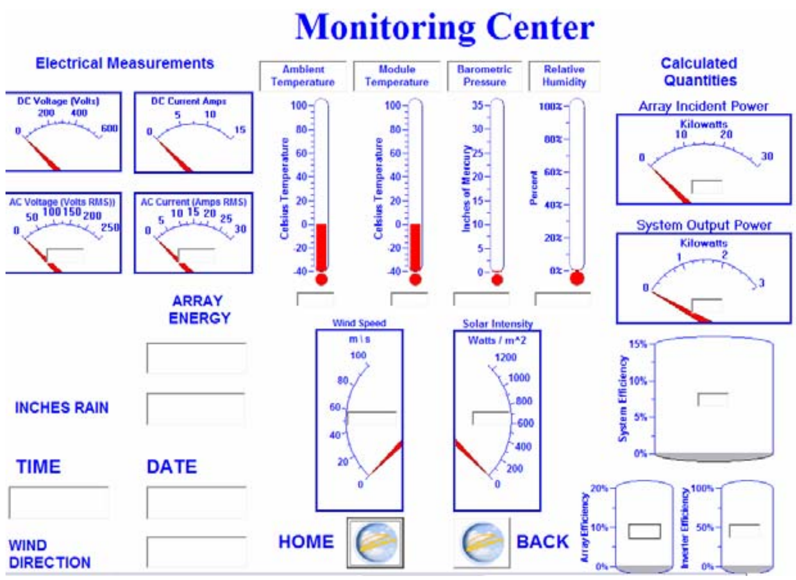
The Solar Learning Lab™ is designed to support learning, and therefore it is an essential part of the design to ensure that the approach is educationally sound and grounded in research. The research behind The Solar Learning Lab™ is best described in the form of a series of broad statements which express how the facets of the design will help to engage students and allow them to make progress in their learning:

- *Technology-enhanced student learning environments can support learning.*
- *Inquiry-based activities enable learners to understand and apply scientific concepts*
- *Computers and multimedia can be used to develop critical thinking*
- *Interactive multimedia can promote achievement*
- *Microcomputer-based Laboratories increase students' ability to interpret graphs*

The remainder of this paper will deal with each of these facets in turn.

1. Technology-enhanced student learning environments can support learning.

It is not the case that merely introducing a computer (or any other form of technology) into a classroom will automatically raise the standards of teaching and learning. In fact, there are many occasions when poorly designed and implemented technology may act to the detriment of the students concerned and the learning they are expected to achieve. The success of computers in the classroom is highly dependent on the pedagogy in which it is embedded, and it has become clear that constructivist approaches in the classroom, which place an emphasis on student centered learning as opposed to teacher-centered content delivery, sit most comfortably with the affordances of computers in the classroom (Jonassen, 2000, p. 1-19). The Solar Learning Lab™ is designed to be used in such an environment, where students work together in groups, collaborating with each other and where the teacher acts more as a facilitator and guide. There is strong research to support the fact that the use of technology can both encourage the development of constructivist environments in the classroom and support learning once that atmosphere has been established. “Technology enhanced student learning environments create contexts within which knowledge and skill are authentically anchored….They afford opportunities to seek rather than comply, to experiment rather than accept, to evaluate rather than accumulate, and to interpret rather than to adopt” (Hannafin & Land, 1997, p. 9). Using this type of computer software provides the opportunity to prompt and guide students into thinking for themselves in ways which would be difficult to conceive in the non-computer based classroom. As students work with the Solar Learning Lab™, they are not merely presented with a series of facts in a detached situation. Clear, colorful displays represent authentic data in real time coming from the solar panels. As they interpret these displays, visual aids are given to ground them in the students' experiences, thus helping them to gain a solid grasp of what the displays show. Students must then think deeply not only about the relationship between these readings and the real world, but also about what they tell us about the effectiveness and efficiency of the system. There are many paths they can follow in their investigations, and once again, students are aided by rich and flexible graphing capabilities within the Sun Viewer™ software.



The main data display screen in Sun Viewer™

2. Inquiry-based activities enable learners to better understand and apply scientific concepts

The notion of *inquiry-based learning* sits comfortably alongside constructivist educational theory and according to Edelson, Gordin & Pea, is based on the premise, advocated by Dewey (1964a, 1964b) that students should learn science in the classroom the way that science is 'done' in the real world. This process is led by questions and is often open-ended (1999). As with many educational terms, many overlapping and complimentary definitions of *inquiry-based learning*, both as a way and philosophy of learning, exist. In this context, a useful definition has been provided by Grabe & Grabe in their study of how the Internet afforded this type of learning; "Inquiry involves finding sources of information appropriate to a task, working to understand the information resources and how they relate to the task, and then, in the cases for which some action is expected, applying this understanding in a productive way" (2000). Research has consistently shown that students reap considerable benefits when the teaching and learning of science takes place in this manner, not only in the area of understanding scientific concepts but also in acquiring scientific skills. Students who search for and encounter scientific concepts in an authentic and meaningful context gain an improved understanding of those concepts. It has been shown that students who learn science by inquiry methods have the opportunity to develop and build a range of investigative and thinking skills such as posing research questions, analyzing and communicating (Edelson, Gordin & Pea, 1999, p. 393-394). Perhaps most striking are the contributions which computer and networking technologies can make to the success and effectiveness of inquiry-based learning. Six such contributions have been identified;

- Enhancing interest and motivation.
- Providing access to information.
- Allowing active, manipulable representations.
- Structuring the process with tactical and strategic support.
- Diagnosing and correcting errors.
- Managing complexity and aiding production. (Blumenfeld et al, 1991; Owens, Hester & Teale, 2002)

The Solar Learning Lab™ is designed to encourage and support inquiry-based learning in a way consistent with this research. The nature of the activities made possible by the software and the clear and graphically rich user interface will help to improve and sustain student engagement. The data acquisition system and Sun Viewer.net™ web utility offer unprecedented access to data of this kind – the data and access to it would not be available to students from any other source (not least of all as a result of the complexity of the data acquisition process), allowing them the opportunity to investigate renewable energy, establish quantitative and qualitative relationships and present conclusions in a way never before possible. The structure of the user environment, the breadth of data available from the sensors and the multiplicity of ways of analyzing and manipulating the data both inside and outside the Sun Viewer™ software, allow teachers and students to pose a range of interesting and valid research questions which may then be investigated in depth. The focus of the Solar Learning Lab™ means that teachers can give students a certain degree of freedom in deciding, for example, what factors to investigate in relation to the energy output from a solar generating system, while remaining confident that such investigations will tie in closely with curriculum targets (unlike Internet research, which can sometimes lead students down vague and unrelated learning side-roads!). The ability to export data to a standard spreadsheet gives any investigation or inquiry the possibility of being truly open-ended, limited only by the imagination and ability of the students and, perhaps more realistically, the class time available. Hence, the Solar Learning Lab™ gives students the opportunity to improve their grasp of the scientific concepts which are central to an understanding of solar energy as well as their investigative and research skills as they learn by inquiry in a contextually rich environment.

3. Computers and multimedia can be used to support critical thinking.

Before considering how addressing the issue of renewable energy through data-based software encourages critical thinking, it is useful to take time to focus on what we the notion of *critical thinking* actually means. There have been many overlapping definitions and descriptions of critical thinking and *higher order thinking skills*, but in the context of The Solar Learning Lab™, what exactly are we seeking to achieve with students? A model which is particularly useful in focusing goals for students in this respect is the Integrated Thinking Model (Iowa Department of Education, 1989). According to this model, critical thinking involves three general skills – *evaluating*, *analyzing* and *connecting*. The process of *evaluation* includes the ability to assess information, determine criteria and prioritize. *Analyzing* incorporates the identifying of main ideas and assumptions. *Connecting* refers to the skills of comparing/contrasting, logical thinking, deductive and inductive referral as well as identifying causal relationships. As they discuss the pros and cons of various energy resources and take a quantitative look at a working solar energy system students will have the opportunity to engage their minds and practice these skills.

In their paper "Developing Critical Thinking Skills in a technology Related Class", Thoms and Junaid assert that in technology-related classrooms, students tend to be considered as thinkers rather than vessels to be filled with 'knowledge' (1997, p. 4). This is exactly what the Solar Learning Lab™ is trying to achieve. It is possible to present students with a list of advantages and disadvantages of different energy resources, and to explain to them why we need to begin the move away from total dependence on oil and how this will be a good thing for mankind in general. However, when students are allowed to reach some of these conclusions for themselves and actually get the opportunity to investigate for themselves the effectiveness of a particular system, as well as to apply graphing and numerical skills to a real-life situation, they are much more likely to develop and retain their own valid and supported conclusions. Always bearing in mind the context in which the software is used, research shows that a major affordance of computers is to promote *higher order* thinking skills (as opposed to lower order, content-based skills) such as critical thinking. The use of well designed software tools helps students to learn to deepen their engagement with information, particularly in the area of analysis and scientific inquiry (Roschelle et al, 2000). Jonassen coins the term "Mindtools" to describe pieces of software which are effective for this purpose, recognizing that such computer applications "require students to think in meaningful ways in order to use the application to represent what they know" (2000, p. 4). In this respect, the Solar Learning Lab™ is indeed a "Mindtool." As students begin to collect and ascribe real-time data from the system and progress to interpreting and manipulating data using spreadsheets or databases, they will necessarily engage the very higher order skills the software is designed to develop. Within Sun Viewer™, students will *evaluate* the usefulness of solar energy as they *analyze* the data and its relationship to various external factors and *connect* this information together as they work through their projects.

4. Interactive multimedia can promote achievement.

There is convincing evidence to suggest that the use of interactive multimedia simulations (in this case, student involvement with appropriate mixtures of text, images, and real-time data) has a positive effect on student engagement and improves student learning and retention. Although the content and structure of any piece of software is of course key, the importance of the student-computer interface and context and their influence on student learning cannot be underestimated.

In 1996, a study was performed at a mid-western university to examine the effect of interactive multimedia on student grades and higher level thinking skills (Frear & Hirschbull, 1999). The research employed a "quasi-experimental approach" and involved 152 students who were pre and post tested. A control group of 113 students were taught a course in environmental science using traditional lecture-type methods. A second group of 39 students were taught the course using interactive multimedia. Quantitative data from the research was obtained in the form of GALT scores and statistical analysis, in addition to the more anecdotal evidence provided by those involved in the project. The results and conclusions of the research team are striking, and in each of the analyses performed it was found that the students in the 'treatment' group performed considerably better than those in the control group. Although they acknowledged the need for continued research, Frear and Hirschbull concluded that the study "validated the effectiveness of the use of interactive multimedia" in education (1999).

Other studies have directly compared instruction which has been supported by some form of computer-based multimedia enhancement with text-only instruction. In each case, there is considerable evidence to suggest that the use of multimedia instruction leads to a noticeable improvement in knowledge retention among students, particularly those initially with “low-knowledge” (Mayer et al, 1995; Mayer & Gallini, 1990). It is clear that the visual nature of Sun Viewer™ will allow students who may struggle with text-only environments to engage in a more meaningful way with the concepts being studied and reach a deeper understanding of solar energy and its potential. The clear grounding of the numerical data in real-world phenomena such as cloud cover and light intensity, and the ability to easily view the data in graphical form, provide a lucid contextual basis for learning and can only help to improve student achievement.

5. Microcomputer-based laboratories increase students' ability to interpret graphs

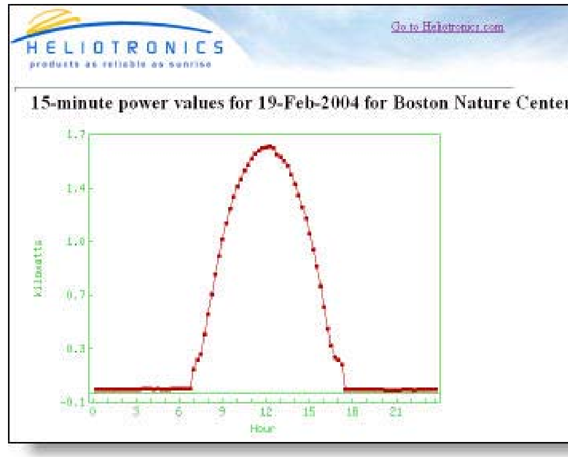
The Solar Learning Lab™ transforms the science laboratory into an excellent example of what has been termed a "microcomputer-based laboratory", or MBL. Although often associated with the collection of data from motion sensors, MBL instruction can broadly be considered to be instruction which involves the measurement of a physical quantity by a probe or sensor attached to a computer. MBLs enable that physical quantity to be studied, plotted or analyzed in some way and it has been consistently shown that such instruction can significantly improve students' ability to understand and interpret graphs (e.g. Linn, Layman & Nachmias, 1987; Adams & Shrum, 1990; Svec, 1995). According to Thornton & Sokoloff (1990), there are several aspects which such instructional approaches have in common and which appear to be significant in aiding student learning;

1. The tools allow student-directed exploration but free students from most of the time-consuming drudgery associated with data collection and display.
2. The data can be plotted in graphical form in real-time, so that students get immediate feedback and see the data in an understandable form.
3. Because data are quickly taken and displayed, students can easily examine the consequences of a large number of changes in experimental conditions….The students spend a large portion of their laboratory time observing physical phenomena and interpreting, discussing and analyzing data

4. Students are able to focus on the investigation of many different physical phenomena without spending a large amount of time learning to use complicated tools.
5. The tools dictate neither the phenomena to be investigated, the steps of the investigation, nor the level or sophistication of the curriculum. Thus, a wide range of students from elementary school to university level are able to use this same set of tools to investigate the physical world. (p. 859)

Carrying out a quantitative study of solar energy without the affordances of the Solar Learning Lab™ would, of course, be a long and complicated process. Even with the aid of equipment such as light sensors, the process of collecting, graphing and analyzing the data would be time consuming and likely to obscure the aims of such a study. Almost at the touch of a button, students can select a range of data to be plotted, and can even compare current data sets with those obtained during a previous lesson, something which is thought to be critical to the success of such instruction (Brasell, 1987a, 1987b). Central to all this is the link that students are encouraged to establish between the real world and the data obtained – connecting visual or kinesthetic experience to abstract thought. In the case of collecting and analyzing data from the sensors in the Solar Learning Lab™, the students are, for example, able to relate the decreasing incident power with the gathering clouds outside, or the decreasing current from the cells as the sun begins to set on a winter's afternoon. The web-based Sun Viewer.net™ also enables data from different locations to be studied and compared, providing the possibility for collaboration with other schools or organizations.

Unlike many other MBLs, the Solar Learning Lab™ is, of course, a permanent installation with a set of specific functions. However, rather than limiting its usefulness, the permanent nature of the system actually has many advantages over more kit-based interfaces and probes. First of all, students spend very little time constructing, arranging and troubleshooting apparatus, ensuring that time in class is spent on the main tasks, such as observing, analyzing and interpreting data, rather than on set-up. Secondly, in the absence of detailed set-up, only a shallow learning curve exists for the software itself, which is both clear and intuitive. The Solar Learning Lab™ is specifically designed to allow students and teachers maximum learning time with minimum distraction. Despite being focused on a single learning topic, the path followed by a particular student or class through the software is by no means inflexible. The wide variety of data which the system is capable of collecting, together with the range of graphing options and even the ability to export data to an external spreadsheet, means that differentiation in terms of age, ability or focus is a key feature of the Solar Learning Lab™, making it an accessible and useful educational tool at all levels.



Summary

The purpose of this paper has been to show, through the consideration of the research foundation on which it is built, how the design of the Solar Learning lab™ will contribute to student learning in the classroom. The system contributes to the establishment of a technologically enhanced student learning environment, supporting student learning by placing an emphasis on student-centered activity and collaboration, anchoring learning to student experience. It provides the opportunity for inquiry-based teaching and learning, thus increasing student motivation and engagement, improving students' understanding of the key scientific concepts in the study of renewable energy as well as encouraging the development of investigative and research skills. The interactive multimedia approach of the Solar Learning Lab™ has been shown to encourage the development of higher order thinking skills such as critical thinking, and there is even strong evidence to suggest that presenting material in this way will enable students to achieve more than if they were taught about these aspects of solar energy using text-based resources. A major feature which gives the Solar Learning Lab™ importance across disciplines in any school curriculum is its focus on presenting data in graphical form. As a prime example of a modern microcomputer-based laboratory, the Solar Learning Lab™ supports instruction which involves the measurement of physical quantities such as light intensity by sensors attached to a computer, enabling that physical quantity to be studied, plotted and analyzed in real time. Such instruction can significantly improve students' ability to understand and interpret graphs, and the use of this software will have a positive effect on graphing across the school curriculum. Hence the use of the Solar Learning Lab™ in the classroom will make a valuable and unique contribution to the education of a group of students, not only in the context of renewable energy and the affordances of solar energy, but also in the broader context of higher order skills which will overflow into other subjects and into the students' later lives.

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