Sustainable Education in the Perspective of STEM Education Using Sun Machines (Heliodons)

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Abstract

Sustainability has been gaining strong momentum in our society especially since the World Commission on Environment and Development (WECD) established policies for sustainable development to address the growing concerns of global warming and about the accelerating deterioration of the human environment and natural resources from other causes than climate change. As our society has a strong and necessary relationship with those concerns, it is important to incorporate the concept of sustainability into K-12 education curricula (science and technology curricula) called K-12 sustainability. From the various sustainability strategies and technologies, understanding solar is one of the most important factors because it influences on not only understanding solar geometry and solar design, but also increasing the students' attention and awareness of sustainability in general. Therefore, this study introduces three different types of sun machines (heliodons)of which two were invented by one of authors because the two helidons invented by one of the authors are of a type that are conceptually clear, they are ideal teaching tools for students as well as adults. They are powerful tools for teaching how the sun's motion across the sky can be utilized in building and urban design to achieve the year-round benefits of solar heating in winter, effective shading in summer and quality daylight for the whole year. In addition, this study demonstrates effective teaching strategies to improve the knowledge of sustainability to K-12 students using various heliodons in the perspective of STEM education.

Introduction

Today designers, construction builders, and even public are interested in energy efficient building design. To design buildings that successfully save the potential energy for built environment the building should be constructed by three major principles: (1) successfully collecting winter sun, (2) shading the buildings from the summer sun, and (3) gathering daylight all year. In other words, in solar responsive design, the major goals are to get as much of the winder sun as possible and to avoid the summer sun as much as possible. For accomplishing these principles, the building designer should have a thorough, complete, and permanent understanding of sun mechanics (sun angles). Therefore, they need the fundamental understanding (knowledge of solar geometry and its consequences) for successful design, and since most of them have little time or patience to acquire this technical knowledge, it is imperative that a conceptually clear and powerful teaching tool or method be available (Lechner, 1991).

Due to the need and importance of the teaching tools, one of the authors in this paper has invented two powerful tools for teaching sun mechanics to either technical or non-technical people. In particular, the groups such as architects, homebuilders, planners, developers, interior designers, some manufacturer, and owner builders need a more in-depth understanding of solar design. However, it can be a good integrated course for K-12 students, including earth science, construction technology, and mathematics content.

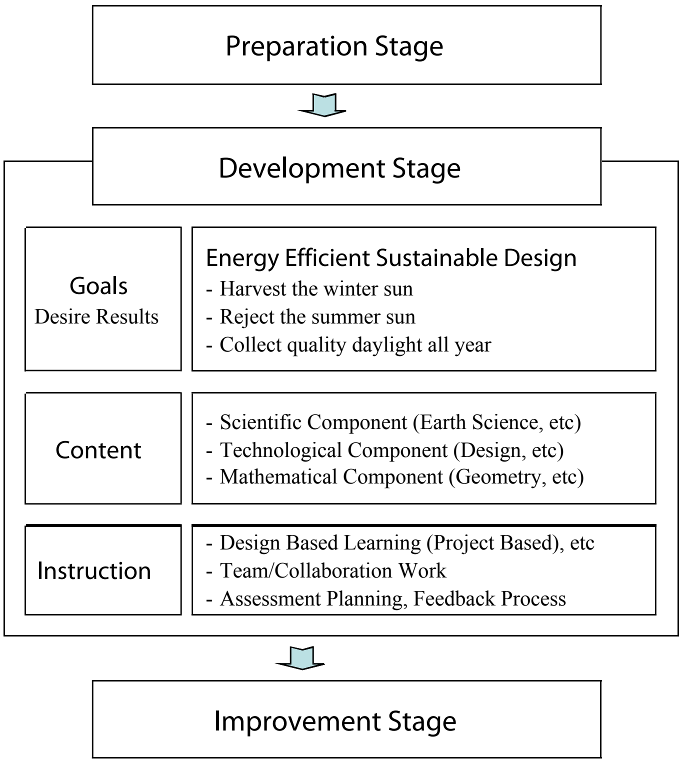
The purpose of this study is to establish a theoretical background for developing an integrated course for K-12 students. To accomplish the purpose, this study employs an in-depth review of relevant literature and a course development strategy. The course development consists of a procedure of preparation, development, and improvement. This study concentrates on the stages of the preparation and development.

A Framework for Course Development

The major goal for using sun machine is to implement solar responsive design (an energy efficient sustainable design for built structures). The specific objectives are to harvest the winter sun, reject the summer sun, and collect quality daylight all year. In this situation, fundamental understanding of sun mechanics is necessary and a heliodon (sun machine) that is easy to use and conceptually clear is employed. In particular, to implement effectively the identified specific objectives in K-12 education environment, there are several ways such as a course development, extra-curricular activity, and science museum or laboratory activity. Lechner (1994) suggested the active usage of sun machine with a hands-on as well as demonstration in the K-12 education environment.

This study focuses on developing an integrative course emphasizing an energy efficient sustainable building design. The topic in this study can be a perfect example to implement an integrated course among Science, Technology/ Engineering, and Mathematics (STEM) subjects and has an integrative characteristic.
Course development using the systematic approach is the objective of this research. For more systematic research, the researchers establish the stages of the course development through reviewing systematic curriculum development theories. The most important decision for course development should be the establishment of course goals or objectives (Tyler, 1949; Wiggins & McTighe, 2006). The course development is divided into three major stages of preparation, development, and improvement (Mager & Beach, 1967). Wiggins and McTighe (2006) suggested "backward design" with three components, "identify desired results – determine acceptable evidence – plan learning experiences and instruction", in the course development stage. During the preparation stage, an in-depth review of relevant literature is conducted in order to achieve the major goal using the sun machine. The literature consists of prior studies using sun machine, K-12 education national standards, and course or curriculum development theory. The developmental procedure is presented in Figure 1.

Figure 1. A Framework for Course Development



Preparation Stage

Due to the complex characteristic of the major topic in this study, a through preparation stage is necessary to set the theoretical background. Sun machines (heliodons) are powerful tools for teaching how the sun's motion across the sky can be utilized in building design to achieve the year round benefits of solar heating in winter, effective shading in summer, and quality daylighting for the whole year. Lechner (1993) pointed out the drawbacks of tradition sun machines and invented "Sun Emulator". The major benefits are the conceptual clarity and ease of use it presents to the user. It will be a meaningful and practical teaching tool for students of architecture and building technology schools as well as K-12 grade level (e.g. science museum). This study expands Lechner' idea and focuses on K-12 grade level. Also, a review of relevant literature regarding sun machines is necessary and a manual handbook and textbook written by the inventor provides a good resource for using sun machines.

3-D Tool

Since sun angles are a complicated 3-D problem, it is reasonable to assume that 3-D teaching tools might be best. The heliocentric model can be easily and effectively demonstrated by a globe carried around a central light source. A planetarium could be effectively used to illustrate the sun's path across the sky.

Sun Path Models

A miniature version of the sky dome is used in the Sun Path Model. Pipe cleaners rather than a string of lamps are used to define the location of the sun at different times of day and year. For simplicity, only the extreme sun paths for the summer and winter solstices and the mid point sun paths for the equinoxes are shown. The sun paths for the intermediate months can be inferred. The simplicity, low cost and small size all makes this tool very useful. It takes less than 15 minutes and less than $1.00 in materials to make one.

Sun Machines (Heliodons)

The "sun emulator" helidon was developed by one of the authors for those schools that do not have room or the resources to build their own sun simulator. The Sun Emulator consists of 7 lights mounted on 7 rotating rings so that the sun angles on the 21st of each month can be simulated. Like the Sun Simulator, it has seven rather than 12 rings because of the symmetry that places the sun in essentially in the same place on May 21 as on July 21, on April 21 as on August 21, etc. The rings rotate from east to west to simulate time of day. The harness holding the rings rotate to simulate the changes due to latitude. The main advantages of the Sun Emulator are modest size, reasonable cost, flexibility, ease of use, and conceptual clarity (Norbert 1993). Although sun machines are primarily testing or analysis tools, they are also very useful in teaching sun angles. In the integrating Sun Machines a separate light indicates the direction of the sun for each hours of the 21st day of each month (about 130 lamps). Each lamp can be switched on independently or an automatic sequencing mechanism can simulate the changing sun directions. Because all lamps are visible at all times, it is immediately clear what the earth/sun relationship is for the whole year for any particular latitude. Ordinary sun machines which have only one lamp are not so conceptually clear. In the integrating sun machine, latitude adjustments are made by tilting the table.

There are several types of sun machines such as the sun simulator heliodon, the sun emulator and sundials. Sun machines are primarily testing or analysis tools which can simulate shade, shadows, sun penetration, and solar access on a scaled model. In addition, sun machines are also very useful in teaching sun angles (Lechner, 1991a&b).
The sun simulator (heliodon) was developed by one of the authors at Auburn University in Alabama, the United States. It is a tree-dimensional model of the solar window, with each month's sun path represented by an arch. From watching the sun simulator including seven the ground plane, arches and 130 bulbs, it is possible to teach solar geometry because the sun simulator is conceptually clear (Lechner, 2009). As the ground plane located in the middle of the sun simulator is horizontal, the sun simulator helidon can simulate our everyday experience of the sun revolving over a building site. According to Lechner (2009) said that "The simulator heliodon make solar geometry so simple that even a child can understand it because of this clarity." In addition, the sun simulator has seven arches which represent twelve months because of the annual symmetry. The sun simulator also has one light for each hours of the day (total 130 bulbs) that can be conveniently switched on to make model testing very easy. However, the sun simulator requires large space with is expensive and difficult to build.

Sundials

Sundials, like sun machines, are most useful when used to test and analyze a built model for shading, solar access, and daylighting. Even though sundials are abstract tools for teaching sun angles, their simplicity of construction and low cost makes them useful nevertheless. To test a model, the sundial is need to be rotated and tilted until the desired analysis time and date are achieved from the actual position of the sun at the time of testing. Sundials have important benefits and challenges in regard to testing physical models. When one uses the sun as a source of light great accuracy can be achieved in modeling shadows and sunbeams (Lecher 2009). However, this mode of testing is limited to daytime on sunny days, which are not common in some climates and some times of the year. A slightly less accurate but sometimes more practical use of the sundials is in conjunction with an electric light source, such as a slide projector at the end of a corridor.

Development Stage

Setting Goals (Desire Results)

The major goal of this course is to design a greater energy efficient sustainable building through improved daylighting, shading, and solar heating. The target for this course will be high school students as a general education. This study needs more specific course objectives for developing relevant content, instructional strategies, and assessment plan. The description of the objectives is based on supporting the environment using a variety of sun machines and hands-on activities as Table 1.

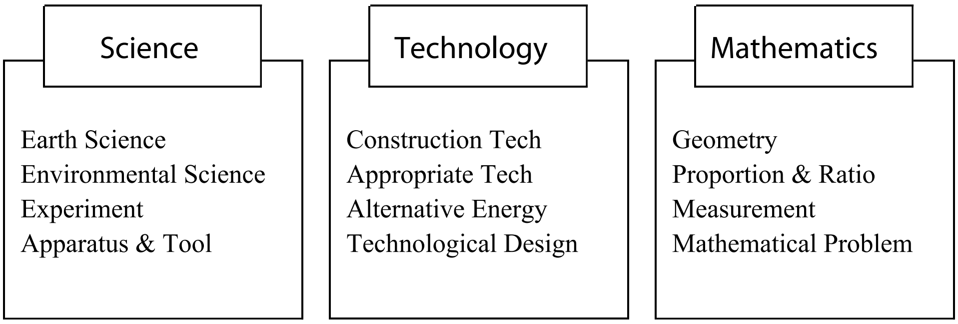
Table 1. Specification of Course Objectives

Categories	**Course Objectives**
Knowledge Component	Students can describe the following issues: - The reason that it is cold in the winter and warm in the summer - The reason that the sun rises and sets due east and west only 2 days each year. - The solar window of the sky and which part is the summer and which part is the winter of the window. - How the sun circulates the north or south pole. How it is possible to have 24 hours of sunrise or sunset. - How sundials work. - Knowledge regarding scientific fact, building construction (modeling, layout planning, drawing, design, etc), mathematical principles, and sustainable design
Hands-on Component	Students can conduct the following activities: - Construction of the building model according to the sustainable principles - How buildings and cities could use far less energy by being solar oriented: street layout, location of buildings and trees, building orientation, building shape, the importance of tilt and orientation, skylights, etc)

Integrative Components

There are a lot of concepts based on earth science, technology, and mathematics education for high school students. To support this course development the national standards of science, technology, and mathematics for high school students are reviewed in the perspective of integrative STEM education. The enduring concepts by each subject for this course development are presented in Figure 2.

Figure 2. Enduring Concepts for an Integrative STEM course (An Energy Efficient Sustainable Design Activity)



The national standards of science, technology, and mathematics supporting "A course development for sustainable building design" are presented in Table 2.

Table 2. National Standards of Science, Technology, and Mathematics Education

Discipline	**Publication**	**Standard (Grades)**
Science	The National Science Education Standards (1996)	Science and Technology - Abilities of technological design Earth and Space Science - Changes in earth and sky - Earth in the solar system - Energy in the earth system
Technology	Standards for technological literacy: Content for the study of technology(2000)	Connections between Technology and Other Subjects Social, economic, and environmental effects of technology Attributes of Design & Engineering Design - There is no perfect design/Requirements - Brainstorming Apply the Design Process - Identify criteria and constraints - Model a solution to a problem - Test and evaluate Construction Technologies - The design of structures includes a number of requirements. Energy and Power Technologies
Mathematics	Principles and standards for school mathematics (2000)	Geometry - Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life Measurement - Solve problems involving scale factors, using ratio and proportion Connections - Recognize and apply mathematics in context outside of mathematics

Future Study

This study provides a theoretical background for developing an integrative STEM course, *"An Energy Efficient Sustainable Building Design."* This course should be organized into students' activities (Design Based Learning, Collaborative Learning, and Integrative Approach). The next step for this study should be the planning of instruction and assessment. To implement this course effectively, an in-depth development procedure with multiple experts (earth science education, technology education, architecture, mathematics education, and etc) and several pilot study are necessary.

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