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Jerry Streichler, Founding Editor and Publisher from 1977-2006

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A Case Study in CAD Design Automation

Andrew G. Lowe and Nathan W. Hartman

Abstract

Computer-aided design (CAD) software and other product life-cycle management (PLM) tools have become ubiquitous in industry during the past 20 years. Over this time they have continuously evolved, becoming programs with enormous capabilities, but the companies that use them have not evolved their design practices at the same rate. Due to the constant pressure of bringing new products to market, commercial businesses are not able to dedicate the resources necessary to tap into the more advanced capabilities of their design tools that have the potential to significantly reduce both time-to-market and quality of their products. Taking advantage of these advanced capabilities would require little time and out-of-pocket expense, since the companies already own the licenses to the software. This article details the work of a small research team working in conjunction with a major turbine engine manufacturer endeavoring to make better use of the underutilized capabilities of their design software. By using the scripting language built into their CAD package for design automation, knowledge-based engineering applications, and efficient movement of data between design packages, the company was able to significantly reduce design time for turbine design, increase the number of feasible design iterations, increase benefits from relational modeling techniques, and increase the overall quality of their design processes.

The design of turbine engines involves creating, modeling, and documenting the development of airfoil geometry for turbine, impeller, and compressor blades. This process is highly iterative due to the circular revisions made between design and analysis groups chasing the optimal airfoil shape and performance. Airfoil blades are a crucial component within a turbine engine, and their design covers many engineering disciplines such as thermodynamics and statics. For both analysis and manufacturing, these airfoils are modeled in a CAD system. However, the complex shapes of airfoils make this difficult. They are typically modeled using b-splines or NURBS, and the development of methods to do this has been ongoing for decades (Corral, Roque, Pastor, & Guillermo, 2004; Korakianitis & Pantazopoulos, 1993)). After revisions are made, geometric data are often re-engineered and recreated within the CAD system. This process ranges from hours to days because the current methods of creating the airfoil models in the CAD system are not parametric, (i.e., the geometry is not associated with the engineering definition of the airfoil after the model is created). A turbine engine can contain as many as of 20 different airfoils, so any improvement in the time for one design iteration will have a beneficial effect on the total design process. In addition, additional benefits can be realized depending on whether a turbine, compressor, or fan blade is being designed, as the geometric complexity of each part varies from relatively simple to highly complex.

According to O'Brien et al. (2006), the knowledge-based engineering (KBE) techniques can make a substantial impact in the design of engineering products. It is gaining prominence as a major tool to speed up product development by capturing knowledge from engineers and designers and embedding that into software configuration (Bermell & Fan, 2002; Prasad, 2005; Rosenfeld, 1995). This knowledge is then used to assist designers while they create products within the CAD system (Hunter, Rios, Perez, & Vizan, 2005). KBE systems are used to automatically create objects (Clark, 2001; Sekiya, Tsumaya, & Tomiyama, 1998), assist designers while they create objects (Carleton, 2005), and compare the cost versus efficiency of created objects (Susca, Mandorli, & Rizzi, 2000).

The industrial research partner in this project does its CAD design in Siemens PLM NX and ports their models into assorted versions of ANSYS and various other in-house applications for analysis. At the beginning of the project the design process was almost totally manual – aerodynamics engineers would pass point cloud data representing turbine airfoils to modelers who would spend one or more full workdays constructing a CAD model from the data. This time encompasses only the airfoil itself and not any of the turbine wheel attachment points or internal cooling geometry. There were no standards in place, so each modeler created their airfoils in their own way which complicated and unnecessarily extended the time required for design changes and additional design iterations. Altering a turbine model would either require adding the task to the queue of the original modeler, each of whom works on several projects concurrently, or enlisting an available modeler to decipher the original modelers techniques and make the necessary adjustments. Even in ideal circumstances, the time to make a design change would be roughly equal to the time required to make the original model.

The company was interested in the capabilities of Knowledge Fusion (KF), a scripting language built into the NX CAD package to automate, standardize, and streamline this process. It had several objectives in mind for the prospective KF application. The first was to reduce the overall design process time by automating the repeated tasks involved in creating the initial airfoil CAD model from the aero engineer's point cloud data. The second was to reduce the time required for design changes and design iterations. By building on objectives one and two, it hoped to standardize the process, both to reduce the likelihood of costly errors in the existing fully manual process and to have consistent models suited to more efficient or automated importation and meshing in analysis software.

Initial requirements were for a KF application capable of reading the raw point cloud data provided by the aero engineers and automatically generating a solid model to which a modeler could add the necessary geometry for attachment points and internal cooling. Ideally the application would be user friendly enough that the aero engineers, who have no CAD training, would be able to generate the initial airfoil model themselves and verify that the solid model conforms to their design intent before passing the model off for final modeling, analysis, and production, a capability they did not currently have. If the application proved robust in generating the initial airfoil solid, additional capability would be added to the application allowing for automation of additional features, including framework for internal cooling geometry, representations of thermal coatings, and NX-specific settings to conform to company design policy and to make the final modeler's job easier.

Project Background

Knowledge Fusion (KF) is a procedural, object-oriented scripting language built into the NX CAD package. Generic Windows-style menus and dialog boxes can be created and tied into KF applications with UI Styler, a user interface design tool also built into NX. KF applications run from simple text files, so they do not need to be compiled on each computer they are to be used with. This makes distribution of the applications throughout a corporation a simpler matter, and it also gives a company the ability to store the application files on a server to which employees can point their copy of NX and run the application without having to download the files.

KF offers most of the basic capabilities one would expect from a programming language – conditional logic, looping, file input/output, basic math, text parsing and string manipulation. The language's vast function library allows the user to call virtually every action available in NX's traditional graphical user interface. With basic programming architecture and the large library of geometry-related functions, a KF application can create automatically almost any model a trained human could design by hand (Golkar, 2006).

Program Capabilities

The automated turbine design application was developed in stages by a series of small research teams and individuals, each building upon the work of the previous researchers and adding features as each stage was determined to be robust enough for production. The initial application would only read in the point cloud data and create the solid model, but through succeeding iterations all desired capability was added and determined to be stable.

Solid Model Generation

The company for which the application was designed uses a handful of proprietary file formats for their turbine point cloud data depending upon the application used to design the turbine and the location at which it was designed. Each format is roughly similar regarding the way the points are organized. The airfoil points are divided into sections, each laterally ringing the airfoil. Some formats use a fixed number of sections, others support a dynamic number. Three separate parsing functions were developed to read in the data and store them in a consistent manner to avoid costly and inefficient repetitions of modeling functions within the body of the program.

The user interface requires the user to select the appropriate file format before the data is fed to the program. At that point the parser ignores any existing header data, then reads and stores the points in a three-dimensional array (referred to as lists in KF), the top-level array holding an array of points for each section. The application then loops through the list, drawing a spline through each array of section points. Each spline is stored as an element in a new array, which is, in turn, looped through by one of NX's multi-section solid operations using each spline as a guide to create the airfoil solid. Due to the complex curvature of turbine airfoils and the necessity of absolute smoothness and precision in the model, several multi-section solid functions had to be evaluated by the research team and the company's modelers before an appropriately precise and robust operation was found (Farin, 1997).

Layering and Coloring

The partner corporation has strict modeling guidelines regarding the development of models. Each type of reference and final geometry has to be placed on a different layer in NX both to avoid graphical cluttering of the final model and to make modifications and design changes easier as the part file circulates through different modelers during its design. For the airfoil generation application to be useful in a production context, the models it creates must conform to these standards. When every point, line, surface or solid is created, the application puts it on the appropriate layer. There is a set of default layers built into the program, but these can be changed before model generation through the user interface.

Due to the sheer volume of geometric data that the application creates, it was deemed necessary to alleviate potential visual clutter by making each piece of geometry noticeably different from the rest. The same command that allows for specific layer placement of newly generated geometry also allows the color to be controlled. Similar to the layering capability, default colors are stored for each piece of geometry, but these can be changed through the user interface. The layered geometry also reduces visual clutter, since the user can quickly hide construction or other geometry without being familiar with the feature tree generated by the application.

Face Tagging and Finite Element Analysis (FEA) Integration

The partner company is developing an automated CAD/FEA integration, discussed in detail in the BENEFITS section, that relies on named or "tagged" faces for automated meshing. When the initial solid model is generated, the operation is repeated with the added specification that the generated geometry be a surface instead of a solid, effectively wrapping the solid airfoil in a geometrically identical blanket. The hub and tip surfaces are then cut away from the initial surface wrap using the uppermost and lowermost section splines. Each point cloud file type has the potential to describe each section with a differing number of points, so the points in each section that represent the border between the four vertical faces must be identified based on the type of file in which they are contained. Once identified, the border points are saved in arrays where the program loops through them to create cutting splines running from the hub to tip of the airfoil. The surface wrapping the airfoil vertically is split into four individual faces using these splines as references. Each face is named using a convention recognized by the automated meshing program.

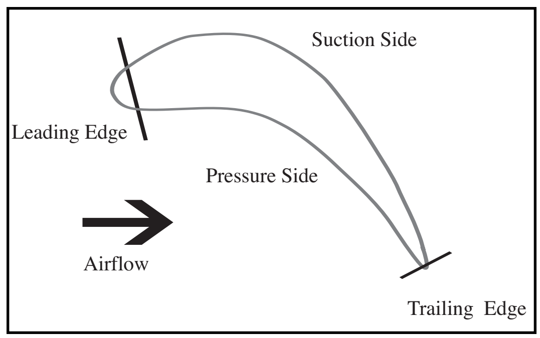

Figure 1: The key vertical faces of a turbine airfoil.

Internal and Coating Geometry

The turbine portion of an engine operates at very high temperatures, often exceeding the melting point of the metal of the airfoils, so some turbine airfoil designs include hollow internal geometry for cooling or a spray-on coating of a thermal-resistant compound (Newman, 2002). The coating can add weight and thickness that affects results of mechanical and aerodynamic analysis, and the internal cooling geometry is often complex, requiring significant time to model. Both could benefit from automation.

After the initial airfoil solid is created, the application's user interface can be reopened and the user can select whether the blade will be solid, hollow, coated, uncoated, or any combination thereof. If a solid or coated blade type is selected, the user is prompted to load a text file, referred to as a wall file, which contains thickness data for the selected operation. As shown in Figure 1, every wall file has offset information for both the coating and cooling geometry grouped by section and face (leading edge, suction side, trailing edge, pressure side). Each section is grouped by face, and each group of face data contains several pairs of numbers; one for the distance the coating or cooling geometry is offset from the original sections, and one that defines where on the face the offset will be located, expressed as a percentage of the face's total length.

To create the coating geometry, the program loops through each section spline of the original solid, and then through each face of each section. For each face, the program loops through the coating data in the wall file and offsets points outward from the original spline based on the thickness data provided; it then stores the offset points in an array. Once all the points are stored, they are looped through, section-by-section, and a new spline is drawn through them. The splines then are used to create a solid that represents the coating.

Creation of the cooling geometry operates on very similar principles, but with some added complexity. The coating offset thickness is by nature uniform, but the offsets for internal geometry are variable to allow for tailoring of the cooling properties as well as the physical strength of the resultant hollow blade. During initial design, a solid would be created from the cooling offset splines to hollow out the airfoil solid, but it was found in testing that modelers could finalize the complex internal geometry faster without the solid or a hollow blade, just using the cooling offset splines as references. The coating splines are visible in green outside the airfoil solid. The blue splines represent the hollow core as shown in Figure 2.

Gas Path Representation

All geometry in a turbine engine will at some level reference the path air takes through the compressors, into the combustion chamber, and out through the turbines. This is referred to as the gas path, and the splines that represent it would essentially be the highest level skeleton model for a completely relationally modeled

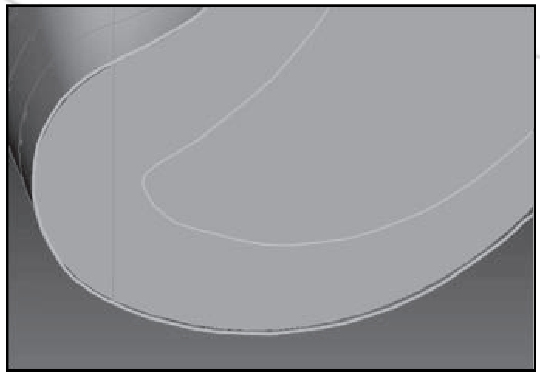

Figure 2: The leading edge of a hollow coated airfoil model done by the KF application. Curves digitally enhanced to aid visibility.

turbine engine. A tool for generating the gas path inside the turbine model was built into the airfoil generation application. The users may select whether they wish to display the hub annulus, tip annulus, or both through the user interface, and they are then prompted to load a text file. The text file contains a series of simple x,y,z points (typically 100-150) that the program loops through to create a spline.

Benefits

Time Savings

The first and most obvious benefit of automating a process is reduced time for executing that process. Surveys indicated that the typical modeler would take from 5 to 8 hours to create a solid model from Computational Fluid Dynamics (CFD) point cloud data. Using the automated airfoil generation tool, modelers were able to create the same airfoil in a uniform and consistent manner in 4 to 6 minutes. Members of the research team with more familiarity with the application would routinely generate airfoils in two minutes or less. The company estimates use of the KF tool will save approximately three quarters of a million dollars in direct costs alone on a single engine project.

The time savings created by the tool extend farther through the design process than the creation of the initial turbine model. Before the automated airfoil generation tool was put into production use, any change to an airfoil design would encounter a bottleneck in the modeling department. Each modeler works on multiple projects, and multiple parts per project, so a design change would have to be queued into the original modeler's current tasks, which would create a period of up to two weeks between a change in design from engineering and analysis where nothing could be done with the design. The dead time could be reduced by finding a modeler with available time to make a design change, but that modeler would have to waste considerable time deciphering the original modeler's techniques to make the appropriate changes. Even if the original modeler were immediately free to execute design changes, if the change was in the original CFD definition, the airfoil the model would have to be rebuilt virtually from the ground up. Not only would the modeler have to reinvest the 5 to 8 hours required to make the initial airfoil solid, but the additional time necessary to re-model attached geometry dependant on the airfoil, such as internal cooling slots or external features for mounting the blade to a turbine wheel.

By automating the process and making airfoil models the same way every time, any modeler can update the model just as efficiently as the modeler that originally created it. The tool requires no knowledge of CAD to operate, so a modeler would not be required to update the model provided robust relational modeling techniques were used to create cooling and turbine wheel attachment geometry. Using the application, an engineer could run analyses on several different design iterations in a single day without having to utilize a modeler for each design change.

Increased Iterations

Another benefit for reducing process execution time is the ability to run more design iterations in equal or less time for equal or less cost. As stated previously, the airfoil generation application was designed so the KF code would stay embedded with the part file after the application was run, allowing the user to re-run the program at any time, even after more geometry had been added, either by re-selecting the application though the NX menus, or by double-clicking on any of the geometry it creates. When the application is reopened, the user may replace any of the text files that define the automatically created geometry and the application will update all relevant geometry using the new text files. Because the geometry is updated and not deleted and recreated, any geometry added to the model that relationally references the application's geometry will also update.

There is much more than just an airfoil in a final turbine blade model. The initial airfoil model is purposely made longer on both the hub and tip ends to ensure that the part of the airfoil that will be used has contiguous curvature, so both ends must be trimmed. Complex internal cooling geometry is added when necessary, and geometry defining the blade's attachment point to the turbine wheel (often referred to as a "fir tree" because of its uncanny resemblance to a profile view of a Christmas tree) must be added, as well. Since it is not feasible to manually redefine the many thousands of points that define the CFD definition of the airfoil, a modeler would have to start from scratch, creating a new initial airfoil and rebuilding all the aforementioned geometry with each new design iteration created. With the airfoil generation KF application, that time investment is still required for the initial iteration, but subsequent iterations require only that the appropriate text files be changed, reducing the time required for additional iterations from days or weeks to a matter of minutes.

Robust relational solid modeling techniques are key for this process to work in a production context. Any piece of geometry not relationally referencing either the KF application geometry or another piece of geometry that relationally references it will not update with the rest of the model and could take longer to fix that it would have to create it from scratch. Because of geometrically complex nature of turbine blades, the type of relational referencing must be tested for robustness on updating. Several of the company's modelers were tasked with developing a standardized, documented, and robust method of modeling the additional geometry. At their request, a handful of axial and radial splines were added to the application to make fully relational modeling easier. Using the modeling techniques the partner company developed, final, fully modeled turbine blades can be completely controlled by the KF application's text files.

Increased Process Control and Quality

Turbine blades have a high degree of geometrical complexity and require skilled modelers to model them effectively. In the past, once aero engineers finalized the design of their airfoil in a CFD program, they were forced to pass their point cloud file to a modeler to create the CAD file, who would in turn pass the model on to analysts for FEA and so on until production. It was assumed that the CAD model would conform to the aero engineer's design intent, but there was no process in place to establish this empirically. Since the multi-section solid operation that creates the airfoil model uses the point cloud section as a reference, the model would be valid at those points, but the validity of the surfaces between the sections was in question.

The airfoil generation KF application removes virtually all the modeling skill required to create the initial solid. By distributing the application with a simple two-page user guide to aero engineers, the engineers were able to create the initial airfoils themselves. A separate KF application referred to as the Point-Body Comparison tool (PBC) was distributed as well. The PBC accepts a point cloud text file in the same format that the airfoil generation tool uses, then prompts the user to identify the pressure side, suction side, leading edge and trailing edge faces on the airfoil solid. When the application runs, it creates each point, measures the distance between it and the appropriate face, then colors the point based on its distance – ranging from blue, representing little or no difference, to red, representing larger differences. The result is an easy-to-interpret graphical representation of the solid model's conformity to original CFD design intent. By using the airfoil generation tool to create the initial airfoil, then exporting a new point cloud file representing the same airfoil but with sections in different places, now an aero engineer can verify that an airfoil model conforms to the original design intent before it ever leaves their control.

Quality issues surrounding that transfer of data between departments and employees also arose when the company was using an all-manual modeling process. Due to a lack of process documentation and the variety of dissimilar modeling techniques, it was not uncommon for necessary operations such as movements in the coordinate system or flipping of models to be done by one employee, then passed to another employee who would perform the operation again, sometimes resulting in costly errors. The airfoil generation application and the development of the relational modeling techniques that accompanied it not only standardized the modeling process, but also made it much easier for the company to rigidly define the roles of each employee in the design process, always performing each modeling operation at the proper time, always performing each translation and flip at the proper time.

Efficient Analysis Integration

Analysis is just as important to an effective product as the initial model itself, and like modeling, creating a robust mesh for FEA can be just as manually labor-intensive as creating CAD geometry. Just as each CAD modeler tends to employ a unique technique for creating a model, analysts tend to create meshes in their own way, which can lead to small differences in the final output. To both remedy this potential problem and to speed the design cycle, the partner company is interested in developing a method for automated meshing. Its method relies on indentifying four key vertical surfaces and two key horizontal surfaces on the airfoil to be used as references in the meshing operation. The vertical surfaces are the pressure side, suction side, leading edge, and trailing edge. The horizontal surfaces are the hub and tip.

The combination of the airfoil generation application's face tagging plus fast, text-file based design iterations and the company's development of an automated meshing tool makes for an incredibly fast analysis and optimization process. An analyst can sit down with a variety of CFD point clouds or wall file data or both, make a model for each desired combination, mesh and analyze them in batch and interpret the resultant data. The only factor significantly limiting the number of designs they can analyze in a day is the speed of the computer running the FEA program. The company estimates that the combination of the KF application and FEA integration will save approximately $3.7 million in direct costs on a single engine project.

Conclusion

Through thorough testing and evaluation, automated CAD design via built-in scripting tools has proven to be an effective way of reducing design time, increasing the number of feasible design iterations, increasing the quality of processes and the company's control over them, and enhancing integration with other automated processes outside of CAD. The turbine engine manufacturer has deemed the KF application robust and reliable and has recently put it into production on a current engine project.

Such automation also opens the door for further enhancements to the design process. Development of similar applications is possible for most engine components, and could automate most modeling required in an engine project. By using text files to control important engineered data in tandem with robust relational modeling techniques, it would be possible to achieve the company's goal of total gas path design and engine reuse. By total use of relational modeling with the gas path as the highest level reference, an existing engine model could be reused on a new project. The gas path could be changed to alter the overall sizes and airflow, and text files controlling airfoils and combustor geometry could be changed to meet new thrust and efficiency requirements. This, combined with quick iterations and automated analysis time-to-market, has the potential to drastically reduce overall time-to-market.

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Student Reflective Perceptions of High School Educational Cell Phone Technology Usage

M. Beth Humble-Thaden

Abstract

High school students are prohibited from using cell phones during the school day within most public schools in the United States; the majority of students, however, maintain possession of a personal cell phone within the high school setting. Most administrators and teachers regard cell phone possession and usage as a negative distraction and deterrent to learning rather than as an educational learning tool. This study investigates college freshman students' reflective perceptions of potential high school utilization of cell phones by students and teachers as educational learning tools. Positive response from surveys suggests there is interest in and potential for educational implementation and use of cell phones as learning tools in schools. Perceptional gender differences were uncovered suggesting further study is necessary before successful implementation can occur.

School policy regarding cell phones, within the majority of public schools in the United States, is generally quite prohibitive and requires students to leave their cell phones at home or turn them off and leave them in their lockers during the school day (Obringer & Coffey, 2007). Other schools report changing policy from banning cell phone use to allowing students to use them before or after school (St. Gerard, 2006). As a result of the rapidly occurring technological advances within the cell phone industry, schools have been hard pressed to make and keep current educational policy regarding the use of cell phones (Obringer & Coffey, 2007).

Students' personal and social cell phone use has been well established, but how do high school students reflect on the usage of such phones in an educational setting? Determining student perception toward using the educational technological capabilities of cell phones within a learning environment is a first step. Knowledge of students' attitudes could possibly lead to, aid in, and influence future decision making regarding the implementation of cell phone use for academic purposes within high school classrooms.

Literature Review

Administrators and teachers often regard the use of cell phones by students at school as a deterrent to student learning (Johnson & Kritsonis, 2007). Administrators often are concerned about inappropriate use of cell phones in schools and this is the major cause of restricting their use (Obringer & Coffey, 2007; St. Gerard, 2006). Cell phones ringing during a class time present unwanted distractions and, for some students, sending or receiving text messages can lead to cheating (Gilroy, 2003). The existing possibility of posting improper photos on the Internet is also a cause for concern (Obringer & Coffey, 2007). For these reasons, students are not allowed to visibly possess cell phones within most high school classrooms. The challenge faced by many administrators is to effectively balance the needs of the school with the demands of the students and the parents.

Parents characteristically agree with school policy and want their children to abide by the rules (Obringer & Coffey, 2007). In contrast, regarding school emergencies or schedule changes, parents have often demanded immediate communication, which cell phones can provide (Johnson & Kritsonis, 2007; Obringer & Coffey, 2007). Parents report safety as the primary reason for supplying their children with cell phones, whereas children place a greater value on the technological capabilities of the cell phone and its potential to facilitate socialization (Johnson & Kritsonis, 2007; Obringer & Coffey, 2007).

According to Prensky (2001a), students of today are referred to as "Digital Natives." They have grown up with technology and multitasking, and they are in the habit of processing information quickly (Prensky, 2001a). Digital Natives want to be involved in active learning as opposed to sitting passively in class (Prensky, 2001a). They thrive on interactive technology, for example, tools like the cell phone (Prensky, 2001b; Prensky, 2005). Instructors may miss an educational opportunity if they do not incorporate cell phone use into their learning process (Prensky, 2005).

Many teachers in a number of foreign countries already use cell phones as a learning tool (Librero, Ramos, Ranga, Trinona, & Lambert, 2007; Prensky, 2005). Often in remote areas connections to the Internet via cell phone are easier to access than connections via computer (Shinn, 2009). In these instances, cell phones are also less expensive to use (Shinn, 2009).

Some teachers in remote areas have been forced to abandon the practice of supplying one laptop per child as a result of increasing costs (Norris & Soloway, 2009). In the United States, administrators and teachers are finding the costs to continually purchase, repair, and upgrade computer technology to be overwhelming; thus, cell phones have become more appealing (Norris & Solway, 2009). As the number of services provided by telecommunication companies increases and cell phone technologies advance, the more likely it becomes that students will have fingertip access to learning opportunities, anywhere, anytime, and at a reasonable price (Houser, Thornton, & Kluge, 2002). Cell phone portability, online access, and device applications could allow and encourage students to enhance learning opportunities and group collaboration (Chen, Chang, & Wang, 2008)

Gender differences in computer technology applications have been studied and documented. According to Willoughby (2008), boys and girls who had access to a variety of computer technologies tended to use them for differing purposes and in differing amounts of time. High school males were reported to spend more time on the Internet and engaged in computer games than time spent by high school females (Willoughby, 2008). The overall amount of time engaged in technology by males could influence their perception and possibly increase their comfort level with technology applications within the school setting. What needs to be determined is whether there is a difference in male and female students' perception of cell phone use in education and if student interest to use cell phones as educational learning tools within the classroom exists. Determining answers to these questions may uncover underlying factors that may need to be considered and addressed before implementing cell phones as learning tools within the high school classroom. Differences in gender perception may necessitate varied forms of pretraining before implementation can take place.

Despite the cell phone's enormous potential, how students view their high school's current cell phone policies, their use of cell phones within the school setting, or their use as an educational learning tool is unknown. Before a school system adopts cell phones as learning tools, student perceptions should be investigated.

Purpose of Study

The purpose of this study was to investigate college freshmen's reflection of high school cell phone usage policies, the perception of cell phones as possible educational learning tools, and the potential perceptual differences by gender. College freshmen's reflective perceptions of cell phones used as learning tools initiated by high school teachers and usage as learning tools initiated by high school students were studied.

Method

Participants

Participants were 166 college students currently enrolled in one of nine sections of a semester-long, face-to-face, introductory university student success course in an upper-Midwestern university. One hundred and sixty-one participants (83 males and 78 females) completed the survey. Five surveys were excluded due to incomplete information. Current academic standing of the 161 respondents was as follows: freshmen (142), sophomores (11), juniors (5), and seniors (3). Because this study investigates the reflective perception of high school cell phone use, only the 142 freshmen (72 males and 70 females) respondents were used for the analysis.

Table 1. Demographic Information of Freshman Sample

Demographic Information of Freshman Sample

	Freshman n = 142 Count	%
Gender		
Male	72	50.7
Female	70	49.3
Age		
20 and under	133	93.7
Over 20	9	6.3
Academic Standing		
Freshman	142	100.0
Cell Phone Possession		
Did have	137	96.5
Did not have	5	3.5

Instrument

A twelve-item Institutional Review Board-approved survey containing three constructs was developed. Four survey questions comprised each of the following constructs: perception of fairness of school cell phone policy, perception of teacher initiated educational cell phone applications, and perception of student initiated cell phone educational applications. Responses were based on a six-point Likert-type scale with the neutral response omitted. Respondents selected one of the following responses for each question: strongly disagree: 1; disagree: 2; slightly disagree: 3; slightly agree: 4; agree: 5; strongly agree: 6. Construct one contained four questions regarding recollection of high school cell phone usage policies and the respondent's perception of policy fairness. Construct two contained four questions regarding student perception of teacher-initiated cell phone usage applications as

Table 2. Average Scores for Survey Questions (1=Strongly Disagree, 6=Strongly Agree)

Satisfaction School Policy				
q1.	While attending high school, I was aware of my high school's cell phone policy.	142	5.7	0.9
q2.	I felt my high school's cell phone usage policy was fair.	142	3.7	1.6
q3.	In my high school, I felt I could use my cell phone at any time.	139	2.8	1.6
q4.	I felt the consequences for using my cell phone during high school hours were fair.	141	3.4	1.7
Perception as Teacher Initiated Learning Tool				
q5.	I think cell phones could be used in high school as an educational learning tool.	141	3.7	1.5
q6.	I think cell phones could be used in high school by students to participate in surveys.	142	4.1	1.5
q7.	In my opinion, cell phones could be used in high school by teachers to provide feedback to students.	141	3.7	1.6
q8.	In my opinion, cell phones could be used by students in high school to compete in an educational activity.	141	3.6	1.5
Perception as Student Initiated Learning Tool				
q9.	In my opinion, cell phones could be used in high school by students to obtain peer tutoring.	141	3.9	1.4
q10.	I think that cell phones could be used in high school by students to submit assignments to teachers.	141	3.2	1.6
q11.	In my opinion, cell phones could be used in high school by students to collaborate with other students on class projects.	142	4.6	1.3
q12.	In my opinion, cell phones could be used in high school by students to seek teacher assistance on assignments.	141	3.9	1.6

an educational tool. Construct three contained four questions regarding perception of educational cell phone usage initiated by students to disseminate information between students and teachers or among fellow students. Included on the survey were additional check-list-type items including: grade level, gender, age (20 and under or over 20 years of age), high school cell phone status (have or do not have), and types of high school cell phone application usage.

Cronbach's alpha was used to measure internal consistency of the constructs. The reliabilities of reflective student perceptions of policy, teacher use, and student use were measured at 0.539, 0.873, and 0.827, respectively. For further statistical analysis, a factor analysis was conducted to determine interrelationships among the items of each of the three constructs (perception of policy fairness, perception of teacher initiated use, and perception of student initiated use). The principal axis method was used to extract components, followed by a varimax (orthogonal) rotation. It was determined that question one in the first construct did not relate to fairness of policy and was removed, leaving questions two, three, and four within construct one. Cronbach's alpha of the newly configured construct using questions two, three, and four measured at 0.603.

Procedure

Surveys were administered to a random pool of students enrolled in one of nine sections of an introductory university student success course over a two-day period. Sampling was conducted on a voluntary basis by the course instructor at the end of each class period. Participants were instructed that the survey was voluntary and asked to answer as many of the questions honestly with the option of stopping at any time. Principal investigator contact information was provided for further questions or inquiries regarding the study. The pool comprised a mixture of 166 participants from each of the four classifications of undergraduate academic credits earned by freshman through seniors. An approximate equal number of male and female students were sampled. Data were analyzed using Predicative Analytics Software Statistics 18 (PASW®). An independent-samples t test was conducted. The significance level was set as .05.

Results

Survey completion rate was 97% of the 166 participants surveyed. Because the intent of this survey was to determine the perceptions from recent high school graduates, only participants who categorized themselves as freshman (85.5%), 142 of the 166 total respondents, were included in data analysis. As shown in Table 1, of the 142 freshman survey participants, 50.7%

were male and 49.3% were female. Most of the participants (93.7%) were 20 years of age or younger. 137 participants or 96.5% reported having possession of a cell phone during their high school years.

Individual questions listed within each of the three constructs including the number of respondents, mean, and standard deviations are shown in Table 2. The question with the highest percentage of some form of agreement and the question with the highest percentage of some form of disagreement fell within construct one. Question one, which read, "*I was aware of my high school's cell phone policy,*" reported the highest mean of 5.7. Eleven of twelve questions reported a higher average percentage of some form of agreement than some form of disagreement. The exception was question three, which reported a higher average of some form of disagreement. The mean for question three, "*I felt I could use my cell phone at any time,*" was 2.8.

In addition, the researcher investigated differences in perception between freshman male and freshman female respondents in regard to high school cell phone usage as an educational learning tool. The survey items categorized into each of the three constructs were averaged and further analyzed to compare differences of means between genders by utilizing an independent-samples *t* test.

Construct one, policy, was analyzed by averaging questions two, three, and four. An independent-samples *t* test was calculated comparing the mean score of respondents who reported themselves as male to the mean score of respondents who reported themselves as female. The mean for all participants was 3.31; in addition, the mean for males was 3.27 (sd = 1.406), and the mean for females was 3.35 (sd = 0.999). The mean difference between males and females was 0.08. No significant difference was found, $t\ (140) = -.397$, $p > .05$.

Construct two, teacher initiated use, was analyzed by averaging questions five, six, seven, and eight. An independent-samples *t* test was conducted comparing the mean scores of male respondents and female respondents. The mean for all respondents was 3.77; in addition, the mean for males was 4.07 (sd =1.295) and the mean for females was 3.46 (sd = 1.187). The mean difference was 0.30. This was found to be statistically significant, $t\ (140) = 2.901$, $p < .05$.

Construct three, student initiated use, was analyzed by averaging questions nine, ten, eleven, and twelve. An independent-samples *t* test was conducted to compare the mean scores of male respondents and female respondents. The mean for all respondents was 3.91; in addition, the mean for males was 4.22 (sd = 1.222) and the mean for females was 3.60 (sd = 1.116). The mean difference was 0.62 and found to be statistically significant, $t\ (140) = 3.129$, $p < .05$.

Discussion

This study was conducted to determine students' reflective perception of cell phone policies and possible use as an educational tool within the high school setting. Although the respondents reported a higher percentage of some form of agreement in regards to the majority of items within the policy construct, having been removed from the high school setting for approximately five months and having been exposed to the less restrictive college environment where cell phone usage was more prevalent may have unintentionally influenced their reflections. Current high school student perceptions may not have yielded such favorable results. High school students who were aware of their high school cell phone policies may or may not have viewed them as favorable.

Results uncovered in the investigation to determine gender effect or influence on the students' perception revealed an overall positive reflective perception regarding the usage of cell phone technology in secondary education. Males responded with a statistically higher degree of acceptance toward cell phone use initiated by teachers-to-students in education and by students to collaborate with other students. These findings could indicate that males were more receptive to communicating indirectly through technology rather than directly by face-to-face communication. Igarashi, Takai, & Yoshida (2005) reported that face-to-face communication was more highly valued by females than by males. By implementing the use of cell phones in the classroom, some students may feel a higher level of comfort responding through technology rather than in person. Another possible interpretation of higher acceptance by males relates to gender differences in technology use with males historically overrepresenting occupational fields that involve math, science, and technology (Mammes, 2004). Instructors should be mindful of these possible gendered influences regarding the use of technology in the classroom and recognize that some students may feel more comfortable than other students using cell phone applications and technology. Therefore, instructors may wish to consider the use of this type of technology in the classroom as an option rather than as a requirement.

Although this study has shown significant differences in perception by gender, some limitations do warrant further study. This study has not specifically included the perceptions of actual high school students, post high school students that did not go on to attend college, or individuals of different ethnicities, nor has it shown how culture affects perception of cell phone use as learning tools as studied in the Philippines and Mongolia (Librero, et. al., 2007). This study was limited to only one school, which represented the perceptions of first-year academic standing college freshman students who possessed their own cell phones and did not shed any light on the perceptions of foreign students in foreign countries, where use has been more prevalent and research on technology use in education has been more abundant (Campbell, 2007).

Although students today have grown up surrounded by technology, only during the past decade have schools begun to integrate the use of technology within the curriculum (Kim, Holmes, & Mims, 2005; Prensky, 2001a). The introduction of technology in education at lower grade levels translates to a considerable increase in the number of years a student will have been exposed to technology upon reaching high school. Therefore, it is imperative that research be continued in the area of educational technology and student perception.

Further studies should be conducted that explore the perception of students currently enrolled in high school courses and their perceptions of cell phone usage as teaching and learning tools within the classroom. Research is also needed to analyze school administrator, faculty, and community perception of cell phone use in an educational setting in order to determine whether or not their implementation would be feasible.

Policy regarding cell phone use by students in school will not change unless studies indicate that administrators and faculty also view them as valuable learning tools. With further research, it is possible that cell phone policy can be changed, allowing cell phones to be used within schools by students not only for socialization but also as a valuable learning and resource tool between students and teachers (Kharif, 2008). Cell phones are not going away. Cell phones can be used as a learning tool for knowledge construction if educators teach students how to use them appropriately (Kolb, 2006).

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Appendix 1

Student Recollection of High School Cell Phone Usage Survey

Please take a moment to complete the survey below. Participation is voluntary and participants must be age 18 or older. The purpose of this survey is to assess student opinions of cell phone usage in **high school education**. I appreciate your time and willingness to participate.

1. In High School, I used my Cell Phone for:

Check all that apply.
___ Calling
___ Texting
___ Photos
___ Videos
___ Internet access
___ Calculating
___ Calendar
___ Clock
___ Alarm Clock
___ Planner
___ Games
___ Light
___ Other (please explain)

2. High School Cell Phone Status
___ I did have a cell phone
___ I did not have a cell phone

3. Current Academic Standing
___ Freshman
___ Sophomore
___ Junior
___ Senior

4. Gender
___ Male
___ Female

5. Current Age
___ 20 and under
___ Over 20

Please rate each of the statements below by circling the appropriate option based on the following questions:		Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
1.	While attending **high school,** I was aware of my high school's cell phone usage policy.	1	2	3	4	5	6
2.	I felt my **high school's** cell phone usage policy was fair**.**	1	2	3	4	5	6
3.	In my **high school,** I felt I could use my cell phone at any time.	1	2	3	4	5	6
4.	I felt the consequences for using my cell phone during **high school** hours were fair.	1	2	3	4	5	6
5.	I think cell phones could be used in **high school** as an educational learning tool.	1	2	3	4	5	6
6.	I think cell phones could be used in **high school** by students to participate in surveys.	1	2	3	4	5	6
7.	In my opinion, cell phones could be used in **high school** by teachers to provide feedback to students.	1	2	3	4	5	6
8.	In my opinion, cell phones could be used by students in **high school** to compete in an educational activity.	1	2	3	4	5	6
9.	In my opinion, cell phones could be used in **high school** by students to obtain peer tutoring.	1	2	3	4	5	6
10.	I think that cell phones could be used in **high school** by students to submit assignments to teachers.	1	2	3	4	5	6
11.	In my opinion, cell phones could be used in **high school** by students to collaborate with other students on class projects.	1	2	3	4	5	6
12.	In my opinion, cell phones could be used in **high school** by students to seek teacher assistance on assignments.	1	2	3	4	5	6

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The Relationship Between the Time Spent Studying Subject Knowledge and the Attitude of Trainee Teachers to the Subject(s) They Will Teach

Stephanie Atkinson

Abstract

The study emanated out of a mounting concern regarding the lack of subject knowledge of students training to become teachers of Design and Technology (D&T) in England and Wales. The article presents the research carried out to establish whether or not the length of time a student spent studying subject knowledge might have some bearing upon how positive their attitudes and beliefs were about the subject and teaching it. The data were collected from a cohort of 83 D&T Initial Teacher Training (ITT) students from a University in the North East of England using a self-completed attitude measurement scale comprising 22 statements concerning a student's attitude to teaching D&T, their beliefs about the subject, and their perception of their own D&T ability with particular reference to design activity.
The results of the survey were discussed in detail, and conclusions and implications were drawn.

Keywords: subject knowledge, designing, attitudes, trainee teachers

In this article the author considers the relationship between attitude and the time available to study subject knowledge for students who are training to become teachers of Design and Technology (D&T). Literature has indicated a strong link between positive attitudes, motivation and being successful in whatever task is undertaken (e.g. Atkinson, 2009; Sternberg, 2005; Weiner, 1992). This is particularly so in tasks where creativity is an integral part of that activity (Cropley, 2001; Hennessey, 2007; Sawyer, 2006). In D&T taught within schools in the United Kingdom and elsewhere around the world, designing which involves creativity forms a central aspect of the subject. The literature on creativity would suggest that pertinent knowledge is required for creativity to occur (Cropley, 2001; Sternberg, 2005; Urban, 2007) as well as it being crucial for a teacher to be successful (Barlex & Rutland 2003, 2004; Ball, Hill, & Bass 2005; Lewis 1996; Simmons 1993). The lack of substantive knowledge acquisition during the training of D&T teachers in England and Wales has become a concern of researchers and practitioners over the past decade (e.g. Banks & Barlex, 1999; Martin, 2008; Rutland, 1996, 2001; Tufnell, 1997; Zanker, 2005).

Although it is recognized that subject knowledge in the context of D&T can refer to a plethora of skills, knowledge, and understanding, in this study it is the knowledge, skills, and understanding that surround the central and fundamentally important activity of designing, which have been targeted.

Data collected from previous research (Atkinson, 2009) concerning the difficulties D&T students on Initial Teacher Training (ITT) programs had with the activity of designing hinted that the longer students studied D&T the better their attitude became toward D&T in general, the activity of designing, and teaching D&T.

This article presents the research carried out in 2009 to establish whether or not these indications were accurate and if so what the implications could be. In this instance data were collected from a cohort of 83 D&T ITT students from the same University in the North East of England where the previous research had been carried out.

Initial Teacher Training of D&T Teachers

There are eight routes available in the UK for those wishing to achieve Qualified Teacher Status (QTS) that will enable them to teach in state-maintained schools throughout England and Wales (see Table 1).

Referring to these eight routes the Training and Development Agency for Schools (TDA) (2010) for England and Wales explained that the "…training comes in all shapes and sizes, providing options to suit everyone – no matter what the qualifications, experience, preferences or personal circumstances are." There are six employment-based or training-based routes that enable trainees to qualify while working in a school and there are routes offered by a number of Universities that after rigorous and frequent inspection by the government are allowed to provide programs of ITT. These programs either combine training to become a teacher while completing an undergraduate (UG) degree of two or three years duration, or, for those who already possess a degree, there are postgraduate (PG) programs of ITT that last for one or two years. The research presented in this article concerned University based ITT and not employment-based ITT.

Table 1. The Eight Routes Available in the UK for Those Wishing to Achieve Qualified Teacher Status

Route		Explanation
University based	Postgraduate Certificate in Education (PGCE)	One-year Program for Graduates
	Undergraduate BA/BSc (Honors) with QTS or Bachelor of Education degree	Students study for a degree and complete ITT at the same time
School-based	School Centered Initial Teacher Training (SCITT)	Graduates train in a school environment
	The Graduate Teacher Program (GTP)	Graduates achieve QTS while teacher training and working in a paid teaching role
	Teach First	Graduates train to be effective teachers in challenging schools
	Registered Teacher program (RTP)	Employed by a school, earn a salary complete a degree and work towards QTS all at the same time
	Assessment-based training	Candidates with substantial school experience may be able to qualify with minimum teacher training
	Overseas Trained Teacher Training Program (OTTP)	Program for teachers qualified outside the European Economic Area

Reason for the Study

In the UK a recent report into teacher training for the Department for Children Schools and Families (CSFC, 2010) suggested that the government should withdraw its financial support for UG Secondary ITT programs. The reason given was that PG ITT programs provided a better quality of teacher. If this report were to be accepted then all UG D&T ITT programs would cease to exist, as such programs would become unviable without government financial support. This would mean that D&T teachers would be trained by either employment-based routes or within a University environment using the One-Year PG route only, which provides little time for students to develop any further subject knowledge upon which to base their Pedagogical Content Knowledge (PCK) (Shulman, 1986; 1987) and subject constructs (Banks et al., 2004) that are essential if they are to become successful D&T teachers. This possibility is therefore of great concern to all those who wish to provide the best possible D&T teachers to meet the educational needs of school pupils in the future.

It was therefore decided to carry out a small-scale study looking at the attitude and beliefs of 83 D&T students at the University in the North East of England where Three- and Two-Year UG and One- and Two-Year PG ITT programs were all being studied. It was believed that the data from this project could add to the picture gained from earlier research (Atkinson, 2009) by indicating which program provided the students with the most positive attitude and beliefs about the subject they were training to teach.

A Review of the Literature

Attitudes and Beliefs

As explained in the introduction attitudes and beliefs have a bearing upon being successful in achieving a goal. In this article that goal is for each student to become a successful teacher of D&T. Galletta & Lederer (1989) suggested that attitudes provide people with a framework within which to interpret the world and integrate experiences, whilst the aim of attitude measurement has been shown to derive indices of socially significant behavior (Lemon, 1973) or as Ajzen & Fishbein (1977) suggested, that by understanding an individual's attitude towards something, one could predict an individual's overall pattern of responses to a situation.

Fishbein & Ajzen's (1975) definition of attitude as a ". . . learned predisposition to respond in a consistently favorable or unfavorable manner with respect to a given object" (p. 10) is an accepted definition although different researchers would tend to place different emphases, or have different understandings concerning each element of that definition. In 1993 Robson agreed suggesting that ". . . the term 'attitude' is somewhat slippery" (p. 256) leading to a lack of response consistency in attitude tests, partially because of the plethora of interpretations of the definition and partially because it is not easy to assess something like attitude by means of a single question or statement. To help rectify this problem the attitude scale devised for this study using a Likert-type scale included several items targeting the same attitude from different angles in an attempt to provide triangulation and allow a much fuller picture of the attitude under question to be built-up. The researcher was aware that problems could arise in statement selection in terms of demonstrating that the different items were related to the same attitude and determining that the method used to pull together the responses in terms of the numbers assigned to particular answers were justified, while being aware that combining statements relating to several dimensions on the one scale may well reflect the underlying structure of the attitude, but could make it difficult to interpret cumulative scores.

However, given all these pitfalls, Robson (1993) explained that a well-designed Likert-type scale could be quick, and easy for respondents to complete and that respondents were more likely to co-operate and provide considered replies than when using other forms of questionnaire that could be seen as boring.

The Importance of D&T Teachers Understanding the Process of Designing

Archer and Roberts suggested in 1992 that:The design act is one of discovering and elaborating and adapting requirements and provisions to match one another. The problem is obscurity about what the requirements might be, ignorance as to what sorts of provisions might be suitable and uncertainty as to how well the one might fit the other. (pp. 3-4)

In 2004, Miliband (then a junior Minister in the government's Department of Education and Skills) wrote that "designing is the combination of, and movement between, thought and action and an aspect of D&T that helps to make it distinctive in the curriculum" (p. 4). That statement continues to provide a sound educational reason for designing being part of every child's education, while within the D&T curriculum itself designing continues to play a vital role. Without it, the subject, as we know it in England and Wales today could not exist. Unfortunately, taught poorly it has been shown to taint the view that many pupils have of the subject (Atkinson, 2000) and regrettably there has been considerable evidence from the Office for Standards in Education (OFSTED) (1998, 2000) and others (e.g., Toft, 2007) who suggested that too often designing in schools has not been taught as well as it could be.

One of the aims of D&T teachers should be to develop a pupils' understanding of how to design effectively and efficiently so that they can make functionally appropriate, creative, and innovative products that are fit for purpose. Through various appropriate forms of design activity pupils can learn to appreciate the relevance of designing as a significant part of their D&T curriculum, not the unpalatable means to an end, which it is perceived to be by many pupils today (Atkinson, 2000). The "end" being referred to here is the activity of "making," which is understandably enjoyed by the majority of pupils. In terms of manufacturing a well-crafted product "measure twice and cut once," says it all. Sadly, the complexity of designing is such that it cannot be summarized in as simple a maxim. It is this complexity that has caused various educators over the past 50 years to produce simplified models of the activity for teachers and their pupils to follow.

Pupils should be able to enjoy designing as much as making, and some of them do, although quite often the reason for their enjoyment is nothing to do with the process of designing itself and more to do with an enjoyment of the individual skills that they use during that process (Atkinson, 1994). Pupils need to believe that although it can be a challenging learning experience, it can, if carried out successfully, lead them into making their design into a product that they will be proud to own. Although teachers need to be aware that badly designed products however well made, and whatever new skills have been learnt along the way, will be a disappointment. Such outcomes are frustrating to those pupils who were born with, or who have developed tacit design intelligence that enables them to understand what is or is not well designed. Unfortunately these very pupils are the ones who easily become bored by the simple step-by-step models that they are often expected to follow. Frequently, these are the pupils who become disenchanted with the entire subject. However, at the opposite end of the spectrum are many D&T pupils who need a structure to follow. They require considerable help in order to understand what they must do, how they must do it, and what they should be thinking about in order to achieve the level of "designerly" thinking that should be inherent in the activity.

Designing can be divided into two main sets of knowledge and understanding. It is essential that both sets are explained, thought about, and taught if teachers are to provide the necessary support and learning required by pupils when they are carrying out the activity. There is a set of easily taught physical skills and there is a set of difficult, intangible concepts that include intellectual thinking skills. The first set incorporates areas of learning such as drawing skills, presentation skills, CAD and CAM skills, researching skills, specification writing skills, 3D modeling skills, and tasks to encourage creativity. This set also embraces a plethora of practical skills concerning appropriate materials, components, and processes that need to be understood well enough to be used when turning ideas into reality. These are all straightforward to teach, but very time- consuming. It is the second set, the intangible designerly thinking aspects of the activity that are difficult for teachers to provide a simple and yet not constrictive set of explanatory guidelines for pupils to understand.

Acquiring new conceptual tools consists of putting a complex series of individual ideas, or unconnected pieces of knowledge together to make sense of them as an integrated whole (Antonio, 2009). The point at which the pieces come together as a whole is the point at which our minds have grasped hold of a new conceptual tool (Polanyi, 1958), and it is these conceptual tools which the author believes are the crux of the problem for pupils in schools and for some of their teachers. Especially as many teachers seem to be unaware that such skills have to be developed slowly over time rather than being taught just once, or worse still not at all, when it is believed that they are skills that everyone possesses and therefore do not need to be taught.

Designing has been considered problematic within D&T in the UK by educational researchers since its incorporation into the school curriculum in the early 1980s (Secondary Examinations Council [SEC], 1986). The process itself, the procedural knowledge required, the practical skills, the thinking skills, the creative skills and an understanding of the complex relationship among them, have provided the author and other researchers with aspects requiring in-depth study (e.g., Baynes, 2009; Kimbell & Stables, 2007; Nicholl, McLellan, & Kotob, 2009; Norman, 2008; Toft, 2007; Spendlove & Rutland, 2007; Welsh, 2007). As early as 1986 the SEC indicated concern about the rigid design process model that was being used in school design activity, while in the early 1990s Archer and Roberts (1992) and many others (e.g., Atkinson, 1993; 1994; Kimbell, Stables, Wheeler, Wonsiak, & Kelly1991) referred to the use of rule-based models that failed to help pupils solve design tasks with briefs that appeared simple but were in fact often ill-defined and complex. Part of the problem has been that all the models produced over the years have been of necessity a simplification of the real process. A simplification that is useful as a set of reminders of what might be involved (SEC, 1986) but unhelpful in explaining the complex, interactive nature of the activity. Hennessey and McCormack (2002) provided a pertinent insight into what they called "a veneer of accomplishment" (p. 119) in which pupils appear to use a process (and hence have apparently learned it) but in fact may not have understood it. By comparison, teachers and pupils have tended to find the knowledge and physical skills required to support design activity straightforward to teach and/or learn, although the sheer volume of knowledge and skills required and whether this should be learned before or on a need-to-know basis has attracted much attention and debate.

For the past ten years OFSTED reports (1998; 2000) have identified that designing skills lag behind making skills. The author's own research (Atkinson, 1997) and that of Barlex and Rutland in 2003 and 2004 have all suggested that this has consistently been the case since the introduction of D&T into England's National Curriculum. This would appear to be due to a combination of factors. First, there are difficulties in teaching pupils the necessary conceptual tools, and yet there is the need to do so as many pupils without tacit design intelligence are unable to develop an understanding of these tools. Second, designing was not part of a craft teachers' training at the time designing was introduced into the curriculum. This has had a "knock-on" effect over the past 20 years because of the cyclical movement of knowledge from teacher to pupils who then become teachers and lecturers training the next generation of teachers to design. This has inevitably resulted in many teachers in schools today still not displaying a deep understanding of the activity within their teaching. While many would suggest this is caused by a lack of teachers with the necessary required physical skills, others would lay the blame at the door of GCSE and A level [1] examination boards, citing imposed assessment regimes as the cause of the problem. However, the author would suggest that although this may be the case for some teachers, for many others the problems arise more from the lack of a secure understanding of designing and the feeling of security that the examination board models of assessment provide for them. For one can find examples from schools of excellent practice where examination work has not been strait-jacketed by the process undertaken, and where design activity has achieved top grades plus the "wow" factor that well-designed outcomes deserve.

Unfortunately, in recent years this is far from the norm. Evidence from visits to schools, from work as an external examiner at a number of different universities, and from applicants who wish to study at the author's own university having completed their school examinations in D&T, would suggest that many pupils are still not encouraged, even at A level to understand the complexities inherent in the activity or how they can design creatively within an examination structure. Unfortunately, the model of the activity that is used is all too often just a repeat of the simple model used earlier in their education – re-enforced by their Grade A at GCSE level leading them and their teachers to believe that pupils must have been taught to design correctly to achieve such a good grade, so a repeat of the same is all that is required at A level. Sadly their beliefs are often supported by "good" A level grades too. Once at University these students expect that the "successful" design process used in school will continue to serve its purpose; however, many of them find that they have to spend valuable time struggling to come to terms with their misconceptions and poor design practice. The more mature UG students who come to train as teachers of D&T do not necessarily have A Level D&T qualifications but have experience and qualifications appropriate to an industrial setting. These students also tend to have either limited or no design skills having been in the school system at a time when they either used the tightly structured simple design model already described or attended school before design activity was carried out at all. Many of them have then spent time in an industrial setting building up practical expertise pertinent to a narrow aspect of D&T with little attention given to developing their understanding of designing as that has often not been a requirement of their occupation.

There are of course students studying to become D&T teachers whose designing activity is excellent and whose skills are such that they will be able to transfer that knowledge into an appropriate form for use in the classroom when they become teachers. However the author does not believe that the D&T community can be complacent about the group of students that do not fit into this category, either for the sake of the pupils they will teach in the future or the prospect for our subject in the years to come.

Six small-scale research projects carried out by the author (Atkinson, 2003, 2005, 2007, 2008, 2009) over the past 10 years have identified that there is a growing number of students training to become teachers for whom the activity of designing is problematic. The analysis of the data collected has indicated factors that could be causing these problems. For instance, students on D&T programs at the university under question are now drawn from all four material specialisms that form the D&T curriculum found in state-maintained schools in England; that being Materials Technology (MT) (wood, metals, and plastics), Electronic Communications Technology (ECT), Textile Technology (TT), and Food Technology (FT). This breadth of applicants' subject knowledge means there is significant variation in their understanding of designing. In addition students who come to the university straight after completing A level examinations, are arriving with weaker D&T knowledge than they had in the past.

Time Spent Studying Subject Knowledge

Out of these earlier studies a third factor has emerged. Students are now studying subject knowledge during their degree programs for less time. Until the early 2000s D&T teachers were mainly trained on a Four-Year UG program. On such programs they studied subject knowledge that was equivalent to three years of the total program study time and learned how to teach for the equivalent of one year, both sets of skills interwoven throughout the four years. This schedule meant that these students carried out at least nine minor design projects during the first three years of their degree program followed by a major design project that lasted throughout their final year. This timetable provided plenty of opportunity to revisit misconceptions and misunderstandings about designing that enabled the students to develop conceptual tools and the procedural and physical skills required to carry out the processes. They also developed the ability to teach these skills during school placements, while developing understanding of the process, which helped them to refine both

Due to pressure from the government and competition between ITT institutions, Four-Year programs were re-designed to last for only three years. At the university in this study this was achieved by reducing the three D&T material specialisms (MT, ECT and TT) studied by all students in the Four-Year program to the government's minimum requirement (Design and Technology Association DATA, 2003) that students in ITT programs must study any two out of the four possibilities (MT, ECT, TT and FT).

At the same time in line with other ITT institutions, school placements and all knowledge, skills, and understanding concerned with learning how to teach were placed in the final "professional year" of all ITT programs, meaning that subject knowledge on Three-Year programs was undertaken only in the first two years of that program. Unfortunately, this has meant that students only have time to complete two minor and two major design projects meaning that there is not enough time to re-visit misconceptions and misunderstandings about the design process to the same extent as in the past. Nor, as mentioned previously, are students able to develop their understanding of how to teach pupils to design in parallel to the development of their personal understanding of that process.

In an even worse position are UG students in a shortened Two-Year program. These students will have already studied some aspect of D&T during a Two-Year Higher National Diploma (HND) course aimed at industry. These courses will not necessarily have included appropriate design activity and will have targeted one rather than two D&T material specialisms. In only one year these students must acquire enough physical and conceptual skills to address the D&T core and their two chosen material specialisms to degree level, for as already mentioned their second year is the professional year, which is devoted to learning how to teach. During the subject studies year these students can only complete one minor design project and one major design project, providing virtually no time for visiting misconceptions and misunderstandings.

In terms of PG provision, there are One-Year and Two-Year programs. Those in the Two-Year PG program will have studied at least one aspect of the D&T curriculum to degree level; however, that degree will not have covered a second specialism or in some cases aspects of the common core. These students like the Two-Year UG students will study one year of subject knowledge followed by the professional year, although they do have the advantage of having studied certain aspects to degree level rather than only to HND level. Finally there are One-Year PG students. These students have already successfully studied to degree level some aspect of D&T, although this will have been targeted at an industrial context and not aimed at developing the understanding of the subject required for teaching pupils in schools. These students devote the whole of their year at University to learning how to teach. There is no time for them to complete any design projects at all in order to develop their personal understanding of the process, even though like HND students, their first qualification may not have required them to design in a manner that is akin to the activity carried out in school D&T. Any limited subject knowledge time during the professional year is devoted to converting subject knowledge into school knowledge (Banks et al., 2004) referred to as Pedagogical Content Knowledge (PCK) by Shulman (1986, 1987) and others.

Observation of students training to become D&T teachers over many years has led the author to believe that students are unable to determine their PCK, how they will teach designing, unless they have a secure understanding of the activity of designing beyond that of the simple models many of them used in the past. Also, for these trainee teachers the development of their subject constructs using unsound content knowledge can lead to the next generation of pupils with unsound designing skills themselves and cyclically lead to the next generation of D&T teachers with misconceptions apropos the activity.

It was therefore decided to carry out a small-scale study looking at the attitude and beliefs of 83 D&T students at the University in the North East of England where Three- and Two-Year UG and One- and Two-Year PG ITT programs were all being studied. It was believed that the data from this project could add to the picture gained from earlier research (Atkinson, 2009) by indicating which program provided the students with the most positive attitude and beliefs about the subject they were training to teach.

Methodology

Measuring Instrument

A self-completed attitude measurement scale with 22 statements concerning beliefs and attitudes regarding D&T was developed through an analysis of existing attitude scales and the methodology surrounding them. The statements themselves were developed by a focus group of specialist D&T lecturers from the university involved in the study. The scale was then trialed using a small cohort of D&T students not involved in this study. Interviews with a selection of the sample after completing the scale led to changes in the wording of three statements—due to mixed understanding of the precise meaning of those statements.

Contextual data concerning the program being studied, how many years of study had been completed; and each student's major specialism was collected at the start of the questionnaire using a tick box system alongside a list of appropriate possibilities. This was followed by the 22 statements concerning a student's attitude to teaching D&T (5 statements), their beliefs about the subject (10 statements) and their perception of their own D&T ability with particular reference to design activity (7 statements) (see Appendix for a list of the 22 statements). These were placed in a mixed order. Dispersed at irregular intervals throughout the scale were 5 statements that were negatively scored. It was expected that a student with a positive attitude would disagree with these particular statements and therefore a high score for disagreeing with the statement was fitting. Students were asked to pick what they believed was the most appropriate response to each statement using a four-point Likert-type scale (strongly agree, agree, disagree, and strongly disagree).

There was an additional column that could be ticked at the right hand side of the table, for those who held no opinion on an individual statement. There is evidence (Robson, 1993) to suggest that if no option is given for those with no opinion, that a substantial number of people will manufacture an opinion, which could then provide inaccurate data. In this study the use of this column was highly insignificant at 1.2% (variance 1569992.000, df 1, chi-square 1569992.000 p-value <0.0001) compared to the 20% usage of a "no opinion" option generally expected when using Likert-type scales (Robson, 1993).

The Analysis of Each Statement to Check for Its Discriminative Power

In order to test the ability of the statements in the attitude scale to discriminate between a positive and negative attitude, each item (i.e., statement) in the scale was subjected to a measurement of its discriminative power (DP). That being its ability to discriminate between the responses of the upper quartile (25%) of respondents and the responses of the lower quartile using the overall mean attitude score for each member of the sample to establish a rank order.

Items with the highest DP indices were then chosen for the final scale. Five statements were not used because of their low DP values, meaning that 17 out of the 22 statements were retained when scoring overall beliefs and attitudes, although the data concerning these five statements were kept for analyses of individual statements when it was pertinent to do so.

Sample

The sample was made up of 83 students from seven program cohorts studying on the four D&T Education programs taught at the author's university. In terms of PG D&T students there were 30 One-Year students; 17 Year 1 students from the Two-Year PG and nine Year 2 students from the same program. In terms of the two UG programs, the cohorts from the Three-Year and Two-Year programs were amalgamated, as the two cohorts on the Two-Year UG program were so small (two students in each year). This provided an UG sample of 18

Year 1 UG students and nine Year 2 UG students. There were no Year 3 UG students as the program had only been running for two years.

In terms of the specialism choices of the sample, there were 30 whose major specialism was MT, three whose major specialism was ECT, 32 whose major specialism was TT and 18 whose major specialism was FT. As can be seen, students were unevenly distributed among the material specialisms, with nearly double the number of Material Technologists and Textile Technologists compared to Food Technologists. Because there were only three students studying ECT it was not viable to keep them as a separate group, and they were added to the MT cohort to form a single group of students studying what traditionally used to be the only specialism studied prior to 1994, that being the combined subjects of MT and ECT.

Data Collection

In terms of data collection, all students were given the single-sided attitude measurement scale to complete during a taught session toward the end of the Autumn Term 2009. This supported the high return rate of 98%. Only one Year 1 student from the Two-Year PG program and one Year 1 student from the Three-Year UG program were absent and therefore unable to take part in the study. After explaining to each cohort what the purpose of the research was and providing them with an assurance that individuals would not be identified from the information given, each member of each cohort completed the scale without discussing it with peers. It took between five and eight minutes to complete. Methods of coding had already been established when the attitude scale was designed enabling the researcher to score and analyze the data using the software package StatView

Results and Discussion

The mean score for the total sample in terms of attitudes and beliefs was 3.1 (the maximum possible score being 4 and the minimum possible score being 1). This result indicated that overall the students had an above average positive attitude. When the mean scores for each member of the total sample were scrutinized the highest score was 3.6 and the lowest score was 2.7. Therefore, even the least positive student achieved an attitude score above the mathematical mean—that being 2.5.

The Five Statements Gaining the Most Positive Mean Scores

Out of the five statements that gained the highest mean scores the two most positive statements were as predicted. One would expect potential teachers of D&T to be passionate about D&T education (mean score (*ms*) = 3.7) and also one would expect them to be looking forward to teaching the subject (*ms* = 3.7). It was also gratifying to see that being a creative person (*ms* = 3.5) and believing that pupils could be creative within D&T (*ms* = 3.5) both ranked highly in the students' beliefs. It was also heartening to see that students thought that it was important to invest time in teaching pupils to design (*ms* = 3.5), as this is something that OFSTED and many others have referred to as being problematic in schools today and is something that is discussed with all students during their training.

The Five Statements Gaining the Least Positive Mean Scores

In terms of the five statements with the least positive scores, although as already pointed out, these were all above the mathematical mean; it was disappointing to see the low score for the statement: Knowledge skills and understanding are better understood and remembered if they are acquired on a needs to know basis whilst designing and making (*ms* = 2.8) as the modules that the students study have been designed by academics in the belief that knowledge skills and understanding placed in a context rather than taught in isolation is a sound teaching/learning strategy and one that is often discussed with students.

In one of the statements that was scored negatively it was disappointing to find that there was a low score for Designing to meet assessment criteria is more important than designing to achieve a creative solution (*ms* = 2.8) as creativity and the lack of it in D&T in schools has been discussed at great length by OFSTED and educational researchers during recent years and the fact that well-designed creative outcomes can easily meet assessment criteria is often discussed with students during subject studies modules. Students with a true understanding of designing should have strongly disagreed with this statement and as it was negatively scored it had been expected that this statement would achieve a much higher mean score. It was especially disappointing as so many of the students had indicated that they were creative and believed that one could teach pupils to be creative. Nor did their indicated belief that it was possible to teach pupils to be creative marry with their lack of belief in the statement that pupils could be taught to design successfully (*ms* = 3.0).

In terms of finding it easy to design (*ms* = 2.9) the low mean score was disappointing, although it might help to explain why so many of the sample do not believe that pupils can be taught to design successfully if they themselves found it difficult.

Beliefs and Attitude Scores Split by Program

Once the attitude and beliefs data were split into the separate program cohorts the results supported the indications reported in earlier research (Atkinson, 2009) in that the length of study of D&T subject knowledge did appear to have a bearing upon how positive students' beliefs and attitudes were (see Table 2).

Table 2. The Mean Attitude Scores Split by Program with an Indication of Years Studying D&T

Program	Mean Score	Rank Order	Yrs studying D&T
Two-Year PG – Year 2	3.31	1	5
Two-Year PG – Year 1	3.19	2	4
UG – Year 2	3.16	3	2
One-Year PG	3.12	4	4
UG – Year 1	2.92	5	1

The data indicated that Two-Year PG students who had studied D&T for a total of five years (four years subject knowledge made up of three years on their UG degree and the first year of their Two-Year PG, followed by one year of learning how to teach) had the most positive attitude (*ms* = 3.31). First-year UG students, who had only studied D&T in Higher Education for one half of a year, had the least positive score (*ms* = 2.92). Students in Year 1 of their Two-Year PG program who had studied D&T for a total of four years had a mean score of 3.19, while second-year UG students had a mean score of 3.16. If the One-Year PG students were removed from the analysis it was evident that the longer students studied D&T the more positive they became. If the PG students were kept in the equation the analysis was not as clear-cut. They bucked the trend, for they were the second least positive cohort in terms of attitude and beliefs (*ms* = 3.12) and yet on completion of their program, these students would have studied for a total of four years in HE, one more year than any UG student.

In trying to tease out possible reasons for this result the differences in terms of the length of time students spent studying subject knowledge pertinent to teaching on a degree program specifically targeted at ITT and the time students spent studying subject knowledge for an industrial context on degree programs which were not designed to train students to become teachers was scrutinized. Analysis of this data suggested that the time spent studying subject knowledge pertinent to teaching D&T could be the factor that made the difference, for as already discussed One-Year PG students did not have the opportunity to study subject knowledge pertinent to teaching during any of their four years of university study.

However it was felt that the specialism of the students might have influenced the results, for as mentioned earlier there was an uneven distribution of students following the different material specialisms within each cohort (see Table 3).

Table 3. Percentage of Each Cohort Studying MT/ECT, TT and FT

Program	RO in terms of Attitude	%MT/ECT	%TT	%FT
Two-Year PG – Year 2	1	11	56	33
Two-Year PG – Year 1	2	41	47	12
UG – Year 2	3	33	22	45
One-Year PG	4	50	40	10
UG – Year 1	5	39	28	33

Beliefs and Attitudes Split by Specialism

The Beliefs and Attitude Data for the total sample indicated that there was indeed a difference in the attitude of those studying different material specialisms (see Table 4). Textile Technologists were the most positive (*ms* = 3.23). Food Technologists were the least positive (*ms* = 3.01), closely followed by Material Technologists (*ms* = 3.06).

When the relationship between specialism data and program data were combined the data continued to indicate differences that might affect the interpretation of the results. As can be seen from Table 3, 56% of the most positive

Table 4. The Overall Mean Scores of Textile Technologists, Material & ECT Technologists, and Food Technologists

Specialism	Mean Score	Rank Order
Textile Technology	3.23	1
Material Technology & ECT	3.06	2
Food Technology	3.01	3

Two-Year PG students were Textile Technologists (see Table 3). A conclusion from this finding could be that because there were fewer Textile Technologists with a positive attitude in the One-Year PG cohort that this could be the reason why they were less positive than Year 2 of the Two-Year PG program.

However when looking at the data for the least positive specialism in terms of attitude—Food Technology, it was found that only 10% of One-Year PG students were Food Technologists in comparison to 33% of Two-Year PG Year 2 (see Table 3). This data analysis would suggest that Year 2 of the Two-Year PG should be the least positive because such a large proportion of their cohort were Food Technologists, and yet as already discussed this was not the case (see Table 2).

Therefore to try to tease this out further a final analysis of the mean scores for each specialism split by the five program cohorts in the study were scrutinized and the rank order was calculated.

From these data (see Table 5) it can be seen that no matter which specialism was targeted Year 2 students from the Two-year PG were the most positive and One-Year PG students varied between third and fifth in the rankings.

Conclusion

In conclusion, it would seem that there is support for believing that in the context of the students within this small study, that in terms of attitude and beliefs about D&T those students in the UG ITT degree and the Two-Year PG programs benefitted from being taught subject knowledge that not only targeted personal knowledge and skill acquisition, but also set out to develop an understanding of the underlying processes that were pertinent to being able to teach those processes to pupils in school. It is therefore a concern that governmental pressure may close these very programs because it believes that a graduate with a degree targeted at industrial employment plus a one year ITT program will provide a better teacher than students trained on UG programs. This belief was not supported by the data collected in this research project.

Table 5. Mean Scores Split by Program and Specialism

Program	Overall RO	TT	RO	MT	RO	FT	RO
Two-Year PG – Year 2	1	3.33	1	3.25	1	3.30	1
Two-Year PG – Year 1	2	3.21	3	3.14	2	3.00	3
UG – Year 2	3	3.26	2	2.99	4	3.23	2
One-Year PG	4	3.19	4	3.08	3	2.82	5
UG – Year 1	5	2.97	5	2.98	5	2.99	3

The data also indicated that Textile Technology students had the most positive attitude and beliefs about the subject, and that their perceptions of their own D&T ability, with particular reference to design activity, was strongest. This would therefore suggest that more rigorous support mechanisms need to be put in place during subject knowledge inputs to help Material Technology, ECT, and Food Technology students to develop more positive attitudes and perceptions regarding their own ability, particularly in the field of designing, which is as stated at the start of this article, central and fundamental to D&T activity within schools in the United Kingdom.

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[1] GCSE is the General Certificate of Secondary Education that is taken by pupils at the end of compulsory education (Age 16). A Level is the Advanced GCSE which is taken two years later by those who continue to study in order to gain a qualification that will enable them to apply for a place at University

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Appendix

List of the statements used in the Beliefs and Attitude Scale

1 One must be a good designer to be a good teacher of D&T

2 I understand how to design in the context of D&T

3 Knowledge, skills & understanding of materials & processes must come before one is expected to design

4 I am passionate about D&T education

5 A well designed creative solution will achieve a high mark when assessed

6 One does not need to teach a pupil how to design as it is a skill that everyone has

7 I find it easy to design

8 Designing is a key feature of successful D&T education

9 I am a creative person

10 I am passionate about wanting to teach D&T

11 Knowledge, skills & understanding of materials & processes are better understood and remembered if they are acquired on a needs to know basis whilst designing and making

12 I think I am good at designing

13 I am more passionate about making things than designing things

14 The process of designing needs to be taught

15 All pupils can be creative in D&T

16 I understand enough about the processes involved in designing to help others to design

17 I am passionate about 'designing' as an activity in D&T education

18 I believe it is important to invest time in teaching pupils how to design

19 Designing isn't something I need to think about, I just do it

20 Teachers need to understand the activity of designing to be successful D&T teachers

21 Designing to meet assessment criteria is more important than designing to achieve a creative solution

22 Everyone can design successfully if taught to do so

A Focus on Technological Literacy in Higher Education

John M. Ritz

Abstract

Technological literacy continues to be an important construct for learners in all societies.Quite often it is a knowledge area not required of university students unless they are engineering or technology majors. If the mission of design and technology education is literacy for all, this same mission should apply at the university level. An analysis was made of 256 students to determine their attitudes of knowledge gained from a general studies technological literacy course. The course was offered at the 100 level and was designed to expose students to various technologies so they would have a better foundation for selecting a major. It was found that this was the first time that 64% of the students studied technology. It also was noted that students gained improved understandings of the effects of technology, a working knowledge of technology, and technology and careers.

Literacy is an important term when one judges the capabilities of people. Connotations of the term literacy reflect on citizens' abilities to read, write, and use basic mathematics. Countries, where average adult literacy rates are low, often are referred to as developing countries. The levels of literacy are not equal around the globe. Often literacy is associated with a country's ability to graduate its youth from high school. These rates are important considerations when one applies for a position at a company in the developing and developed world (e.g., high school graduate, college graduate, graduate with a master's degree). In the U.S. Workforce Investment Act of 1998, literacy is defined as "an individual's ability to read, write, speak in English, compute and solve problems at levels of proficiency necessary to function on the job, in the family of the individual and in society" (p. 131).

Demographics on worldwide education can be used to compare the education rates of different countries. According to Huebler (2008),

> The unweighted mean of the adult literacy rate is 81.2 percent. In 71 countries – including most of Eastern Europe, East and Southeast Asia, and Latin America – 90 percent or more of the adult population can read and write. The highest adult literacy rate, 99.8 percent, is reported for Cuba, Estonia and Latvia. Most countries without data are in the group of industrialized countries, where literacy rates are also likely to be above 90 percent. In 23 countries, the adult literacy rate is between 80 and 90 percent. (para. 2)
>
> At the other extreme are eight countries with literacy rates below 40 percent: Mali (23.3), Chad (25.7), Afghanistan (28.0), Burkina Faso (28.7), Guinea (29.5), Niger (30.4), Ethiopia (35.9), and Sierra Leone (38.1). Another 16 countries have literacy rates between 40 and 60 percent: Benin (40.5), Senegal (42.6), Mozambique (44.4), Central African Republic (48.6), Cote d'Ivoire (48.7), Togo (53.2), Bangladesh (53.5), Pakistan (54.9), Liberia (55.5), Morocco (55.6), Bhutan (55.6), Mauritania (55.8), Nepal (56.5), Papua New Guinea (57.8), Yemen (58.9), and Burundi (59.3). Almost all of these countries are in Sub-Saharan Africa and South Asia. (para. 3)
>
> Finally, the world's two largest countries in terms of population have very different literacy rates. In China, the adult literacy rate is 93.3 percent. In India, only 66 percent of the adult population can read and write. (para. 4)

A useful demographic data source for analyzing adult literacy rates is NationMaster (2009), a massive central data source and a handy way to graphically compare nations. This tool is a vast compilation of data from such sources as the CIA World Factbook, United Nations (UN), and Organisation for Economic Co-operation and Development (OECD). This source lists the top 100 nations in the world by the average years of schooling completed by its youth. The top five countries cited include the United States, Norway, New Zealand, Canada, and Sweden.

The bottom five countries among the 100 noted for years of schooling includes the following: Guinea-Bissau, Mali, Niger, Mozambique, and Afghanistan.

Also, NationMaster (2009) lists the mathematical literacy found in countries; the top five were Japan, South Korea, New Zealand, Finland, and Australia. They include grade 12 advanced science students such as those in Norway, Sweden, Denmark, Slovenia, and Germany.

Why are these figures important? Governments from around the world are now taking a strong interest in the educational issues and barriers within their specific nations. Regarding high-tech industries, companies have been vying for the brightest graduates from science, computer science, and engineering. Developed countries continue to do this, but there is competition from Brazil, Russia, India, China, and South Korea, also known as the BRICK countries, and these countries fight immigration roadblocks from their own governments to increase their power in the world economy. What the countries seek in the form of education is the following**:**

> A new form of literacy – a technological literacy . . . This is a vital necessity if citizens are to participate in assessing and determining the relationship of technological systems to human needs. To function in this role requires that all citizens be conversant in the language of technological systems and comprehend basic concepts of the dynamics of the interrelated systems for all levels of society. (DeVore, 1980, p. 338)

Countries are reexamining their policies and educational systems to enhance the education of their citizens in the STEM subjects (Science, Technology, Engineering, and Mathematics). Although this push is for primary and secondary education systems to improve the education of their students, the word on U.S. campuses is STEM. Much of this is pushed by the funding avenues established by the National Science Foundation. This U.S. government foundation funded 138 STEM projects from September 2003 through April 2009. A total of $149,838,383 was approved to conduct research to improve the teaching of STEM subjects (NSF, 2010). A new objective for the NSF in recent years has been to fund innovative grants for kindergarten through high school (K-12) STEM enhancements.

STEM education and technological literacy are interwoven concepts, and many educators in design and technology education have focused their curriculum and student study in these knowledge areas. Technological literacy has become the aim of much of design and technology education that is being taught worldwide. It has been defined in *Standards for Technological Literacy* (ITEA, 2000) as "the ability to use, manage, understand, and assess technology" (p. 242). In practice, its study has been focused mainly on technical expertise, instead of how useful or pertinent technologies can be (Ginestié, 2008).

To "understand, use, assess, and manage technology" (ITEA, 2000, p. 242) is much different than to develop expertise in a few technologies. According to Pearson and Young (2002),

> Technological literacy is not the same as technical competency. Technically trained people have a high level of knowledge and skill related to one or more specific technologies or technical areas. . . a technologically literate person will not necessarily require extensive technical skills. Technological literacy is more a capacity to understand the broader technological world rather than an ability to work with specific pieces of it. (pp. 21-22)

However, tradition has led many educators to teach technical expertise. This may be in part because a design and technology teacher is given a laboratory with a variety of tools within its confines. It is natural for educators to teach these technologies when they are given these new tools. Might it be a systematic technology means-or-end problem that new technology creates?

Because much of the world continues to experience new technologies and changing economic situations, and the education system is almost void in explaining these developments and how or if they should be used for the betterment of society, these knowledge and abilities should eventually become one focus of teacher instruction through their design and technological studies programs. According to

DeVore (1972), "It is self evident that we can control only that which we know about and understand in behavioral terms" (p. 8).

School children (all ages) should become more literate about technologies. In some countries, the study of design and technology is mandatory. In others it is an elective subject. The design/technology/engineering education professionals are constantly working to get the study of technology into the required school curriculum. In different countries professionals have taken differing approaches to gain this leverage. Recently, in the United States, the decline of scientific, technological, engineering, and mathematics workers has led to a legislative act to increase STEM education (America Competes Act, 2007). Others are getting a nudge from the engineering professions to teach engineering principles at the high school level in order to attract more young people to engineering careers (e.g., Project Lead the Way in the U.S.A.). These trends are aimed at keeping the United States an economic leader through the generation of technological innovations. Industrialists believe that students should be taught how to innovate, using STEM skills, so they will become the generation that creates new technologies and products that the world's consumers will demand. Entrepreneurs also know that schooling in the sciences, technologies, engineering, and mathematics is crucial to their companies, if they are to remain productive and develop products that will gain an increased market share.

Pearson and Young (2002) stated that "technological literacy – an understanding of the nature and history of technology, a basic hands-on capability related to technology, and an ability to think critically about technological development – is essential for people living in a modern nation . . ." (pp. 11-12). Such people have knowledge of technology and are capable of using it effectively to accomplish various tasks. They can think critically about technological issues and act accordingly. Technological literate people would possess knowledge, ways of thinking and acting, and capabilities that assist them as they interact with the technology found in their environments (Pearson & Young, 2002). These "traits" include the following:

Knowledge

- Recognizes the pervasiveness of technology in everyday life.
- Understands basic engineering concepts and terms, such as systems, constraints, and trade-offs.
- Is familiar with the nature and limitations of the engineering design process.
- Knows some of the ways technology shapes human history and people shape technology.
- Knows that all technologies entail risk, some that can be anticipated and some that cannot.
- Appreciates that the development and use of technology involve trade-offs and a balance of costs and benefits.
- Understands that technology reflects the values and culture of society.

Ways of Thinking and Acting

- Asks pertinent questions, of self and others, regarding the benefits and risks of technologies.
- Seeks information about new technologies.
- Participates, when appropriate, in decisions about the development and use of technology.

Capabilities

- Has a range of hands-on skills, such as using a computer for word processing and surfing the Internet and operating a variety of home and office appliances.
- Can identify and fix simple mechanical or technological problems at home or work.
- Can apply basic mathematical concepts related to probability, scale, and estimation to make informed judgments about technological risks and benefits. (Pearson & Young, 2002, p. 17)

Context

At the author's university, faculty members have worked for the past 30 years to make technological literacy a general (or liberal) education requirement for all students. Faculty members have worked to put technology into the university curriculum, just as the social sciences and sciences are part of all students' liberal education. This work culminated in 1994 when the university decided it was time to re-visit its core liberal studies curriculum. At our university, this process occurs about every 10 years. (It was found that if one is not at the table when these study committees commence to work, it is very difficult to have an impact on the general studies offerings.) Thus, the author worked to get onto the committee that was responsible for the review.

The committee deliberated for two years, and much was to be said by the arts and letters and science faculty. The author worked with engineering and business faculty to have a voice to establish the importance and impacts that technology will continue to have on the graduates who studied at the university. The arts and science faculty listened. These faculty members needed to be educated in the idea that technological literacy was much more than the use of computers, although computer education was also needed and became a part of the curriculum.

This university included in its curriculum lower level (100/200) general education ***foundation*** courses and (300/400) level general education ***perspective*** courses. The technology education faculty members attempted to have one course in each category (foundations and perspectives), and they were successful in their endeavor. The 100-level course designed to meet the science and technology foundations is *Technology in Your World*. The intent of this course is to show the many technologies that impact and are used in differing careers. Through it students study the background of technological literacy, the systems of technology, such as medical, agricultural and bio-related, energy and power, information and communication, manufacturing, and construction technologies (ITEA, 2000), and careers that are found in these technologies. The intent is to help first-year students to be better educated when selecting a career and major.

At the 300/400 level, students can select cluster courses (focused study coming from an interdisciplinary perspective). Technology education faculty developed a 300-level course titled *Technology and Society* to meet this interdisciplinary study general education requirement (Old Dominion University, 2010).

The technology education faculty members have supplemented their programs by enrollments in these courses via general studies students (enrollment for the university is approximately 24,000 students). Annually, 14 sections of the 100-level course are offered and five sections of the 300-level course are offered. There is an additional section of the 300-level courses offered each fall on televised distance learning; enrollment averages 120 students. Old Dominion University has made technological literacy a mainstay of its course offerings. These courses enroll approximately 600 students annually.

The general studies program of the university was again reviewed in 2006. This review had a much smaller committee, and it did not include faculty from the technology education program. Faculty members knew that if they had data from assessments showing that students thought these technological literacy courses were important to their education and if it could be shown the types of knowledge students gained, there would be a much better chance of retaining this subject (technological literacy) as a general studies requirement at the university.

To enable this to happen, the author developed a survey that measured the educational objectives of the 100-level *Technology in Your World* course. This survey was administered for two years. The author was invited to a private meeting of the 2006 general education review committee to discuss changes the members were making to a computer literacy requirement for the university. The technology education program offers a course to meet this requirement in general education. Having the invitation, the author clarified questions the committee had about computer literacy. The committee praised the content that the technology education program covered in its information and computer literacy course (Word Suite plus information literacy, i.e., determining what was good information, searching the internet, and paper formatting), and it did not like the way that the other campus departments were teaching the course (Word Suite driven).

After this short discussion with the general studies committee, the author addressed the technological literacy courses that were offered and gave an overview of students' perceptions of the 100-level *Technology in Your World* course. Data had been gathered two years prior from students who were enrolled in this course.

Survey on Technological Literacy

In an effort to protect the gains made in bringing technological literacy into the university's general education program, our faculty decided that it would measure the educational progress of students who enrolled in *Technology in Your World*. Faculty decided to assess student progress according to the goals established by the general education committee for the technological literacy perspective: assessing the impacts technology has on humankind (us), the knowledge of the workings of technology, and the assistance given to students in making informed career decisions.

Over the two-year period that the survey was administered: 256 students participated. A five-point Likert-type scale was used to assess student opinions, with (5) representing strongly agree and (1) representing strongly disagree. It was found that taking this general studies course was the first time this group of students studied technology. Amazingly, it was the first such study for 64% of the general studies group. Following is an analysis of the survey findings.

Impacts of Technology

Questions 1-5 addressed the topic of impacts of technology and if these impacts had an effect on the students enrolled in the course. Question 1 stated: *I am aware of and understand how technology has evolved from the Stone Age to the present*. Many students (163) responded with strongly agree (52.0%), 103 (40.1%) agreed, 14 were uncertain (5.5%), 5 disagreed (2.0%), and 1 strongly disagreed (0.4%). The mean was 4.41, indicating agreement with this statement.

Question 2 read: *I understand the impact technology has on the development of society*. More than half (166) students responded strongly agree (64.8%), 87 agreed (34.0%), 1 was uncertain (0.4%), 1 disagreed (0.4%), and 1 strongly agreed (0.4%) with this statement. The mean score was 4.63, strongly agree.

Question 3 stated: I *feel comfortable in using the problem solving methods to solve a problem*. This was a teaching strategy used with hands-on knowledge reinforcement activities throughout the course. Less than half (110) strongly agreed (43.0%), 103 agreed (40.2%), 34 were uncertain (13.3%), 8 disagreed (3.1%), and 1 (0.4%) strongly disagreed with this statement. The mean score was 4.22, agree.

Question 4 read: *I understand that different career fields are based upon the application of technology*. Many students (130) strongly agreed (50.8%), 110 (43.0%) agreed, 14 were uncertain (5.5%), and 2 disagreed (0.8%) with this statement. The mean score was 4.44, agree.

Question 5 stated: *I have taken technology courses prior to this course*. Surprisingly, 64% indicated that this was the first course they had taken in the study of technology. This was an unexpected finding that these students had not taken courses in technology, either in high school or at the university, prior to enrollment in this course. This question points out that in the United States not as much emphasis is placed on the study of technology as should be. Table 1 presents a summary of impacts of technology information from university students in this study.

Technology Working Knowledge

The *Technology in Your World* course included readings, discussions, video information, and laboratory activities that focus on the systems of the technologically designed world. The next set of questions on the survey sought to measure students' understanding of concepts associated with these technological systems.

Question 6 read: *I understand the difference between energy sources*. One half of the students (128) strongly agreed (50.0%), 111 agreed (43.4%), 14 were uncertain, and 3 disagreed (1.1%) with this statement. The mean score was 4.43, agree.

Question 7 stated: *I understand that many products may be made from polymer and composite materials*. Less than half of the students (102 or 39.8%) strongly agreed, 109 agreed (42.6%), 36 responded uncertain (14.0%), 8 disagreed (3.1%), and 1 strongly disagreed (0.4%) to this statement. The mean score was 4.21, agree.

Table 1. Impacts of Technology

Item	SA		A		U		D		SD		Mean
1. I am aware of and understand how technology has evolved from the Stone Age to the present.	133	52.0%	103	40.1%	14	5.5%	5	2.0%	1	0.4%	4.41
2. I understand the impact technology has on the development of society.	166	64.8%	87	34.0%	1	.4%	1	.4%	1	0.4%	4.63
3. I feel comfortable in using the problem solving method to solve a problem.	110	43.0%	103	40.2%	34	13.3%	8	3.1%	1	0.4%	4.22
4. I understand that differing career fields are based upon the application of technology.	130	50.8%	110	43.0%	14	5.5%	2	.8%	0	0.0%	4.44
5. I have taken technology courses prior to this course.	Yes	92	36%		No	164	64%				

Question 8 asked: *I have used materials to construct/build something of my own*. Many students (108 or 42.2%) strongly agreed, 105 agreed (41.0%), 16 were uncertain (6.2%), 24 disagreed (9.4%), and 3 strongly disagreed (1.2%) to this statement. The mean score was 4.14, agree.

Question 9 stated: *I know that technology evolves over time*. Seventy-six percent of the students (196) strongly agreed with this statement, fifty-eight (22.6%) agreed, 1 was uncertain (0.4%), and 1 disagreed (0.4%) with this statement. The mean score was 4.75, strongly agree.

Question 10 read: *I understand that all technologies have social, cultural, environmental, economic, and political impacts*. More than half of the students (164) strongly agreed (64.1%), 86 agreed (33.6%), 3 were uncertain (1.2%), 2 disagreed (0.8%), and 1 strongly agreed (0.4%) with this statement. The mean score was 4.50, strongly agree.

Question 11 asked: *I can identify the basic components of an electrical circuit.* Sixty-four students strongly agreed (25.0%), 112 agreed (43.8%), 44 were uncertain (17.2%), 26 disagreed (10.2%), and 10 strongly disagreed (3.76%) to this statement. The mean response to the statement was 3.76 or agree.

Question 12 inquired: I *enjoy working with my hands.* Ninety-six students strongly agreed (37.5%), 106 agreed (41.1%), 28 were uncertain (10.9%), 20 disagreed (7.8%), and 5 strongly disagreed (2.0%) with this statement. The mean response to this statement was 4.05 or agree.

Question 13 stated: *I use the Internet as a resource tool to locate information on topics of interest to me*. Two hundred-one students strongly agreed (78.5%), 49 agreed (19.1%), 39 were uncertain (15.2%), and 3 disagreed (1.2%) to this statement. The mean score was 4.75, strongly agree.

Question 14 determined: *I use the Internet on a daily basis*. Two hundred-eight students strongly agreed (81.2%), 46 agreed (18.0%), and 2 disagreed (0.8%) with this statement. The mean score for this statement was 4.80, strongly agree.

Question 15 sought: *I communicate mainly by e-mail/text messaging*. Eighty-six students responded strongly agree (33.6%), 97 agreed (37.9%), 20 were uncertain (7.8%), 51 disagreed (19.9%), and 2 strongly disagreed (0.8%) with this statement. The mean score was 3.84, agree.

Question 16 inquired: *I see that computers can be applied to various technologies*. One hundred-seventy-four students strongly agreed (68.0%), 81 agreed (31.6%), and 1 was uncertain (0.4%) with this statement. The mean score for this item was 4.68 or strongly agree.

Table 2. Technology Working Knowledge

Item	SA		A		U		D		SD		Mean
6. I understand the difference between energy sources.	128	50.0%	111	43.4%	14	5.5%	3	1.1%	0	0.0%	4.43
7. I understand that many products may be made from polymer and composite materials.	102	39.8%	109	42.6%	36	14.0%	8	3.1%	1	0.4%	4.21
8. I have used materials to construct/build something of my own.	108	42.2%	105	41.0%	16	6.2%	24	9.4%	3	1.2%	4.14
9. I know that technology evolves over time.	196	76.6%	58	22.6%	1	0.4%	1	0.4%	0	0.0%	4.75
10. I understand that all technologies have social, cultural, environmental, economic, and political impacts.	164	64.1%	86	33.6%	3	1.2%	2	0.8%	1	0.4%	4.60
11. I can identify the basic components of an electrical circuit.	64	25.0%	112	43.8%	44	17.2%	26	10.2%	10	3.9%	3.76
12. I enjoy working with my hands.	96	37.5%	106	41.4%	28	10.9%	20	7.8%	5	2.0%	4.05
13. I use the Internet as a resource tool to locate information on topics of interest to me.	201	78.5%	49	19.1%	39	15.2%	3	1.2%	0	0.0%	4.75
14. I use the Internet on a daily basis	208	81.2%	46	18.0%	0	0.0%	2	0.8%	0	0.0%	4.80
15. I communicate mainly by e-mail/text messaging.	86	33.6%	97	37.9%	20	7.8%	51	19.9	2	0.8%	3.84
16. I see that computers can be applied to various technologies.	174	68.0%	81	31.6%	1	0.4%	0	0.0%	0	0.0%	4.68
17. I understand the purpose of construction building codes.	104	40.6%	96	37.5%	38	14.8%	13	5.1%	5	2.0%	4.10
18. I know that different types of construction require different technologies.	130	50.8%	116	45.3%	8	3.1%	2	0.8%	0	0.0%	4.46
19. I understand how products are manufactured.	89	34.8%	127	49.6%	32	12.5%	7	2.7%	1	0.4%	4.16
20. I understand that transportation is a vital component of advanced societies.	178	69.5%	73	28.5%	5	2.0%	0	0.0%	0	0.0%	4.68
21. I know what is meant by biotechnologies.	124	48.4%	110	43.0%	19	7.4%	2	0.8%	1	0.4%	4.38
22. I know what is meant by nanotechnology.	78	30.5%	104	40.6%	42	16.4%	26	10.2%	6	2.3%	3.87

Question 17 stated: *I understand the purpose of construction building codes*. One hundred-four students strongly agreed (40.6%), 96 agreed (37.5%), 38 were uncertain (14.8%), 13 disagreed (5.1%), and 5 strongly disagreed (2.0%) with this statement. The mean was 4.10, agree.

Question 18 asked: *I know that different types of construction require different technologies*. One hundred-thirty students strongly agreed (50.8%), 116 agreed (45.3%), 8 were uncertain (3.1%), and 2 disagreed (0.8%) with this statement. The mean score was 4.46, agree.

Question 19 inquired: *I understand how products are manufactured*. Eighty-nine students strongly agreed (34.8%), 127 agreed (49.6%), 32 were uncertain (12.5%), seven disagreed (2.7%), and 1 strongly agreed (0.4%) with this statement. The mean score was 4.16, agree.

Question 20 stated: *I understand that transportation is a vital component of advanced*

Table 3. Career Decisions

Item	SA		A		U		D		SD		Mean
23. I understand the relationship between technology and the economy.	120	46.9%	119	46.5%	12	4.7%	4	1.6%	1	0.4%	4.38
24. I understand that the more I know how to use technology, the more valued I am to an employer.	156	60.9%	88	34.4%	6	2.3%	4	1.6%	0	0.0%	4.58
25. I realize technology will continue to affect my life.	193	75.4%	59	23.0%	3	1.2%	0	0.0%	1	0.4%	4.73
26. This course offered opportunities for me to use technologies associated with the workplace.	109	42.6%	100	39.0%	24	9.4%	16	6.3%	7	2.7%	4.13
27. This course provided experiences to assist me with future career selections.	88	34.4%	87	34.0%	46	18.0%	23	9.0%	12	4.7%	3.84

societies. One hundred-seventy-eight students strongly agreed (69.5%), 73 agreed (28.5%), and 5 were uncertain (2.0%) with this statement. The mean score was 4.68, strongly agree.

Question 21 asked: *I know what is meant by biotechnologies*. One hundred-twenty-four students strongly agreed (48.4%), 110 agreed (43.0%), 19 were uncertain (7.4%), 2 disagreed (0.8), and 1 strongly agreed (0.4%) with this statement. The mean was 4.38, agree.

Question 22 stated: *I know what is meant by nanotechnology.* Seventy-eight students strongly agreed (30.5%), 104 agreed (40.6%), 42 were uncertain (16.4%), 26 disagreed (10.2%), and 6 strongly agreed (2.3%) with this statement. The mean score was 3.87, agree.

Technology and Careers

The third part of the survey sought student responses to questions about technology and their careers. The *Technology in Your World* course covered content on technological systems. During this analysis implications were continually directed to the use of these technologies with various career fields. These were summary questions about these interrelationships.

Question 23 read: *I understand the relationship between technology and the economy*. One hundred-twenty students strongly agreed (46.9%), 119 agreed (46.5%), 12 were uncertain (4.7%), 4 disagreed (1.6%), and 1 disagreed (0.4%) with this statement. The mean score was 4.38, agree.

Question 24 stated: *I understand that the more I know how to use technology, the more valued I am to an employer*. One hundred-fifty-six students strongly agreed (60.9%), 88 agreed (34.4%), 6 were uncertain (2.3%), and 4 disagreed (1.6%) to this statement. The mean score was 4.58, strongly agree.

Question 25 said: *I realize technology will continue to affect my life*. One hundred-ninety-three students strongly agreed (75.4%), 59 agreed (23.0%), 3 were uncertain (1.2%), and 1 strongly disagreed (0.4%) to this statement. The mean score was 4.73, strongly agree.

Question 26 stated: *This course offered opportunities for me to use technologies associated with the workplace*. One hundred-nine students strongly agreed (42.6%), 100 agreed (39.0%), 24 were uncertain (9.4%), 16 disagreed (6.3%), and 7 strongly disagreed (2.7%) to this statement. The mean score was 4.13, agree.

Question 27 asked: *This course provided experiences to assist me with future career selections*. Eighty-eight students strongly agreed (34.4%), 87 agreed (34.0%), 46 were uncertain (18.0%), 23 disagreed (9.0%), and 12 strongly disagreed (4.7%) to this statement. The mean score was 3.84, agree.

Discussion

Literacy is important to citizens of the world. Literacy goes beyond the educational basics of reading, writing, and mathematics. Literacy has moved into other school subjects. For nations to prosper economically, the technological literacy capabilities of its citizens are important. University technology departments can contribute to the literacy of nations. Technological literacy courses at the university level can be used to support design and technology's contributions to the general education of all students. Student enrollment in general education courses can be used to support and further justify the very existence of our programs. Universities continually review program enrollments to make decisions on those that it wishes to support financially. If our design and technology program relies entirely on enrollments from teacher preparation students, it could become labeled as a low-enrolled program. By gaining support for technological literacy courses as a general education requirement, design and technology education programs can build enrollment and, at the same time, increase their teaching of technological literacy to a wider population of university students.

Having data from students who complete technological literacy courses can show the value of these courses and the data can be used as a tool to support discussions of why these courses should be offered. Faculty members of other technological literacy courses in the program at Old Dominion are now conducting this type of research, and they have noted the value of conducting such research.

The surprising response to this study was the lack of experiences students had with the study of technology, prior to the selection of this course. Sixty-four percent of the students indicated that they did not take a prior course on technology either in high school or at the university before this course. The first-year statistics for this study indicated that this number was as high a 70%. Students found that technology does have an impact on the world in which they live and the career path that they plan to purse.

There are many technologies that compose the designed world. Although each technology has its particular systems and subsystems, its development has progressed because of the innovative and problem solving abilities that people working in these areas have pursued. Students were exposed to many systems, including agriculture, communication and information, construction, energy and power, manufacturing, medical, agriculture and bio-related technologies, and transportation technologies. Students learned to use activities in these areas to solve problems. In doing this they were (and can be) exposed to some of the knowledge and skills needed if they pursued careers in these technologies. Students indicated the value of such courses in their preparation for careers after they complete their degrees.

Summary

Faculty members have found the importance of enabling students to study technological literacy at the university level. Technology can contribute to the education and literacy of university students. If one looks at the larger picture of education and the technological literacy of its students, is not this the mission that our profession has as design and technology educators? Expanding design and technology courses to the university general population can be used as numbers to support academic programs while also contributing to a wider student population. This helps us achieve technological literacy for all.

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Mentoring Teachers in Technology Education: Analyzing the Need

Luke J. Steinke and Alvin R. Putnam

Abstract

Mentoring programs have been shown to have an influence on the overall success of retaining teachers. Studies have shown that not only are teachers who participate in mentoring programs more likely to stay in teaching positions, but also the overall economic value of retaining teachers goes beyond the cost savings related to attrition. Beginning technology education teachers typically participate in the same traditional mentoring programs all teachers follow. These programs tend to overlook the unique nature of a technology education teacher's job. Because a technology education teacher's job generally requires additional and sometimes more stressful duties, such as lab components, this study sought to address the areas that traditional mentoring programs overlooked. Specific attention was paid to technology education teachers' need for assistance regarding technical experts and managing a laboratory environment.

This study applies the situational mentoring framework (SMF) model to address the issues related to mentoring programs for technology education teachers.

Purpose of this Paper

Although mentoring programs have been effective in retaining beginning teachers in general, a review of literature regarding mentoring programs for technology education teachers reveals limited to no research on the topic. More specifically, there is currently no research addressing the overall effectiveness of mentoring programs or the development of a mentoring program (model) for technology education teachers. The purpose of this article is to examine the current status of mentoring pr ograms within technology education by focusing on (a) the overall benefits and effectiveness of mentoring programs, (b) the unique aspects of technology education that are overlooked within traditional mentoring programs, and (c) the methods for developing and implementing effective mentoring programs within technology education. In order to address the unique aspects of technology education, the situational mentoring framework (SMF) will be applied for the systematic development of a model mentoring program for technology education teachers.

Teacher Shortage

Few would argue that the field of education is facing a significant teacher shortage. Numbers do not lie: there were more than 60,000 reported teaching vacancies in the United States during the 2003-2004 school year (Mihans, 2008). Even though many fields of education have experienced teacher shortages, several areas of study are particularly troubling. Technology education and its allied fields have been experiencing a shortage of qualified teachers for approximately 20 years. This problem is exacerbated because, as demands for a technologically literate society increase, so has the demand for technology- related subjects at the elementary, secondary, and post-secondary levels. Meade and Dugger (2004), Ndahi and Ritz (2003), Newberry (2001), Ritz (1999), and Weston (1997) indicated that technology education has experienced and will continue to experience a significant teacher shortage unless educators act to reverse this problem.

Teacher Attrition

Although there is a shortage of teachers, many studies have indicated that this is not necessarily the result of a lack of newly trained teachers. According to Ingersoll and Smith (2003), much of the teacher shortage issues are the result of a "revolving door," whereby teachers leave the profession early. An estimated 50% of new teachers leave the profession after 5 years (Ingersoll & Smith, 2004). Reasons a teacher might leave the profession vary.

In general, these factors include low salaries; lack of career advancement, professional development, or administrative support; student and peer issues; and other school/ environment-related concerns (Darling-Hammond, 2003; Ladwig, 1994; Marlow, Inman, & Betancourt-Smith, 1996; Marso & Pigge, 1997; McCreight, 2000). Researchers who specifically considered attrition rates in technology education found similar results, with additional frustrations for technology education teachers related to a lack of funding for equipment, supplies, and facilities plus a lack of understanding and support for technology education by administrators and counselors (Wright, 1991; Wright & Custer, 1998).

These are all certainly important factors to address for schools systems, administrators, and other teachers who wish to retain teachers, but what factors typically result in a teacher's leaving after one year? Anyone who has taught can certainly remember the difficulties of the first year. Teaching is often done in isolation. Ingersoll (2003) likens a teacher's first year experience to being "lost at sea," because new teachers are often left to fend for themselves within the confines of their own classroom (also referred to as the sink-or-swim year).
Within any profession, new employees usually are at a significant disadvantage; most often they are not given much support during their first year on the job. (It takes an entire year in any job to begin to understand the subtleties of politics, the demands of people in charge and peers, and the quality and quantity of work that is expected.)

Technology education teachers in particular can face a significantly difficult first-year experience. On top of the same difficulties any new teacher would face, such as developing effective instruction and managing a classroom, technology education teachers have the tasks of trying to integrate various technologies into the classroom, managing labs, and developing hands-on projects. As new teachers focus more on surviving the first difficult years, they often focus less on pedagogical developments for the classroom. In addition, technology education courses have been and often continue to be perceived as "vocational." These classes can be filled with students who the administration and teachers believe are not college bound. The new technology education teacher therefore may have a classroom of many students, even classrooms of students, who are less prepared to learn. Even the most experienced teacher would have difficulties within this environment. Finally, new technology education teachers often have few colleagues to turn to for help. Depending on the school, many of the new technology education teachers' peers could have limited experience with a lab-based environment.
Therefore, all new teachers as well as new technology education teachers can experience many problems, challenges, and issues that could have a significant impact on whether they remain teachers.

Along with this overarching strain on the technology education teacher, the burden of teacher attrition places a significant hardship on schools as well. As schools must recruit new teachers to replace teachers who leave, and a job search can result in extensive resources plus significant costs for a school/school system. The turnover costs attributed to hiring, training, and adjusting to the learning curve of new teachers can be staggering (Texas State Board for Educator Certification, 2004). Schools (superintendents, principals, administrators, etc.) should spend the required time in effectively filling teaching positions, but they often settle for inexperienced teachers, teachers who meet only basic requirements, or substitute teachers who have limited knowledge of either the subject matter or teaching in general. As these new teachers adjust to the position's learning curve, their students' academic preparation may suffer, resulting in a negative impact on the school's overall performance.

Additional strain is placed on schools as teacher attrition increases. In particular, schools are burdened with hiring teachers with subject matter knowledge relevant for technology education. In the past, technology educators relied on two solutions for addressing teacher shortages: giving emergency certifications and hiring teachers from fields similar to technology education. Emergency certification is used when an individual has a bachelor's degree and technical knowledge but does not have teacher certification; this certification is given temporarily so a person can fill the open job. Such a teacher will go through an alternative certification process eventually to earn a teaching certification, but his/her first years of teaching are spent with limited knowledge of pedagogical techniques. Ruhland and Bremer (2002) found that alternatively certified teachers felt less prepared in the area of pedagogy than did traditionally certified teachers. The practice of hiring teachers from allied fields is also common within technology education to fill open teaching positions. Teachers from mathematics, biology, and other science subjects are hired to fill technology education positions. The case for hiring someone from an allied field is based on the idea that the knowledge areas are similar enough for the teacher to succeed.

In both cases, these new teachers experience issues within the classroom. The emergency certification teachers can have difficulties due to limited experiences as classroom teachers, and teachers hired based on having certification in a "similar area" can have limited experiences with an applied/hands-on environment that is typical of technology education. In either case, the school and students themselves often suffer while such new teachers develop the necessary skills to provide effective instruction. This time period could be weeks, months, or perhaps even years.

Induction and Mentoring Programs

To address the high teacher attrition rates, many schools have implemented induction and mentoring programs. Induction and mentoring programs have been designed to offer new teachers opportunities to share experiences and ideas; additionally, they can collaborate on classroom concerns with veteran teachers. The most common form of induction is the mentoring program (Feiman-Nemser, 1996). The purpose of the mentoring program is to establish a workplace relationship between a veteran and a beginning employee, and it is based around the premise that employees learn good practices through several years of study, consultation with experienced peers, and reflective practices (Fox & Certo, 1999). Researchers have continuously indicated that mentoring programs can increase the retention of beginning teachers (Brown, 2003; Darling-Hammond, 2003; Kajs, 2002; McCormick, 2001).

Overall Benefits of Mentoring Programs

Many teachers and administrators would agree with the research that induction and mentoring programs are effective in retaining teachers, but what makes these programs effective? Mihans (2008) pointed out that what makes mentoring of teachers so effective is purely the necessity of the profession. According to Mihans (2008), "teaching is the only profession that requires the same responsibilities of its beginning practitioners as its masters" (p. 763). This would seem to suggest that successful mentoring starts with the very existence of a mentoring program, but clearly effective mentoring goes deeper than the simple existence of a program. Regardless of type of mentoring program, several key benefits of mentoring programs have been identified.

One of the key and main benefits of a teacher mentoring program is increased teacher retention. Mentoring programs have been designed to address some of the key factors that result in beginning teachers' leaving the profession. Even though the level of increased retention will vary based on the type of program, Ingersoll and Smith (2004) pointed out that the probability of teacher turnover is reduced when teachers participate in induction and mentoring programs. This reduction in teacher turnover has other benefits than simply maintaining the number of teachers within the school district. For example, Villar and Strong (2007) conducted a benefit-cost analysis of teacher mentoring programs and found that increases in teacher effectiveness due to mentoring programs actually outweighed cost concerns related to attrition. Therefore, while mentoring programs can be beneficial in reducing the cost of turnover, the financial benefits go beyond simple turnover.

While assisting beginning teachers is the primary goal and benefit stream for mentoring programs, experienced teachers who participated as mentors can also benefit from such programs. Mihans (2008) indicated that experienced teachers can view mentoring as an incentive to stay in the teaching profession because they can learn from and share with colleagues, while providing the leadership roles that are important in retaining experienced teachers. This would indicate that the practice of mentoring for teachers may not only reduce the likelihood that beginning teachers would resign, but also it may help reduce the number of teachers who exit the teaching profession altogether.

Research conducted by Steinke and Putnam (2007) found that one of the primary influential factors in technology education teachers' staying in a teaching position is whether they participated in an induction and mentoring program. Therefore, the benefits associated with mentoring certainly are applicable to addressing attrition within technology education.

What Traditional Mentoring Programs Overlook

Despite the known benefits of mentoring programs, not all are effective. As Ingersoll and Smith (2004) pointed out, the kinds and numbers of support provided by schools to beginning teachers vary, as does their effect on retention. Currently, there are no standards for mentoring new teachers, and programs can vary from one school district to the next. In a 2001 study conducted by the American Federation of Teachers (AFT), only 21 states had established guidelines for the selection of mentors. The type of mentor selected and the overall mentoring process can have a significant impact on whether a mentoring program is effective. Gratch (1998) found that the simple presence of a mentor does not guarantee success. Mentors who are not given instructions on how to effectively teach adults, for example, probably will not create effective mentors (Gratch, 1998). Traditional programs that simply assign a mentor might overlook factors that are important to teachers within a particular field such as technology education.

Ingersoll and Smith (2004) indicated that one of the strongest factors related to retention is having a mentor from the same field. Within technology education, this establishes a problem because technology education already faces a significant lack of teachers within the field, so the odds for new technology education teachers having a mentor within the field are not great. Most schools will likely find that providing mentors from a "similar field" is a sufficient answer for mentoring teachers within technology education. The issue here is if teachers from science or mathematics have sufficient backgrounds in technology education to effectively mentor technology teachers. Brown (2003) indicated that lab environments are different than traditional classrooms and have different procedures than traditional classrooms. Additionally, Brown (2003) indicated that lab-based teaching environments, such as technology education, must also organize internships, service learning, and monitor cooperative learning activities. Mentors for teachers within these lab environments must be familiar with the procedures, equipment, and processes of a typical lab.

Because mentoring programs are designed to address teacher attrition, it is important for mentors to be familiar with key factors that impact whether teachers leave the profession. Certainly the typical mentoring program will be designed to address the reasons why the average teacher leaves, but technology education teachers have been found to leave for a variety of reasons. Wright and Custer (1998) and Steinke and Putnam (2007) found that a lack of funding for supplies and equipment can affect the retention of technology education teachers. Clearly mentors within technology education must be familiar with and able to address issues involving technology resources in classrooms and labs. In addition, Steinke and Putnam (2007) found that technology education teachers are concerned with the long hours required to deliver a quality program, the low status of technology education, and the lack of understanding of what technology education is among administrators and colleagues. These are all factors that affect the overall retention of technology education teachers that many traditional mentoring programs do not address.

Technology education teachers who do not receive the needed support in their first years are more likely to leave the teaching profession because technology education offers professionals the opportunity to make much higher wages working in non-teaching careers (National Association of State Boards of Education, 1998). It is therefore imperative to provide the proper support to technology education teachers early, including the development of mentoring programs that address the main areas of concern for technology education teachers. In order to develop a successful mentoring program for technology education teachers that address these concerns, a systematic approach should be used.

Technology Education Mentoring Programs

In designing an effective mentoring program for technology education teachers, there are many different factors to consider. Technology education teachers encounter different issues than the many teachers, but school districts may also have a difficult time addressing those issues through standard mentoring programs. School districts need a process for developing a mentoring program that is adjustable and allows for situational variability. Kajs (2002) suggested the situational mentoring framework (SMF). This model has four components that include: (a) mentor selection, (b) mentor and novice teacher preparation, (c) support team, and (d) accountability. The four components are interrelated and the approach is dynamic, allowing for changes related to technology, processes, and personnel. For this reason, the SMF is ideal for developing the foundations of an effective mentoring program for technology education teachers. Each of the four components is considered next and how each can specifically be used to design an effective mentoring program for technology education teachers are discussed.

Mentor Selection

Selecting the right mentors and matching those mentors with the proper protégés can be crucial in any mentoring relationship. The SMF model calls for a collaborative process to ensure the proper selection of mentors by using a systematic process for their selection (Kajs, 2002). Though it is the task of a selection committee during this component to develop criteria for potential mentor candidates and determine a pool of prospects, Allen, Eby, and Lentz (2006) pointed out that this process should really focus on allowing individuals to feel as though they have as much input into the matching process as possible. The more a formal mentoring program simulates an informal mentoring relationship, the more effective it will be (Allen, Eby, & Lentz, 2006).

During the mentor selection process, the process of creating an informal-feeling mentoring relationship begins with determining a pool of experienced expert teachers that are willing to take on the responsibility of mentoring (Kajs, 2002). Allen, Eby, and Lentz (2006) indicated that both creating a sense that the program is voluntary to potential mentors and looking at the proximity and background of the mentoring pool are important. For example, they found physical distance between mentors and protégés can be a challenge in a mentoring relationship, along with a mentor's overall knowledge of a department/area of study. Once a pool is identified, the prospective mentors and novice teachers should spend time discussing different viewpoints relating to mentoring, as well as potential relationships. This will create a sense of perceived input into the mentoring process between both groups, as well as provide needed input for properly matching mentors to protégés.

This process in particular can be beneficial for technology education teachers. First, actively identifying a pool of experienced teachers to be mentors through a formal process may increase the number and quality of teachers who are willing to participate. This is particularly important in technology education, given the nature of the lab-based teaching environment. Second, by focusing on the proper selection of mentors and allowing them to get to know the novice teachers, novice technology education teachers are more likely to be assigned a mentor who understands their jobs and potential difficulties. The prevailing practice of simply assigning an experienced teacher to mentor a novice certainly does not allow for this likelihood. Finally, if an insufficient number of qualified mentors are available or one is not identified for a technology education teacher, a formal mentoring selection process allows for a principal/committee to identify and request the participation of an experienced teacher to fill that need (Papalewis, Jordan, Cuellar, Gaulden, & Smith, 1991). Since a shortage of technology education teachers already exists, this may be necessary. If an experienced technology education teacher is unavailable, this issue could be addressed in the fourth component Support Team (discussed later).

Mentor and Novice Teacher Preparation

Many traditional mentoring programs assume that an experienced teacher has the knowledge and skills necessary to be an effective mentor. The reality is that the knowledge and skill set to be an effective teacher is different than the knowledge and skill set to effectively mentor a colleague. Although most formal mentoring programs offer some form of training (Allen, Eby, & Lentz, 2006), many tend to be more informational than knowledge based with skill development (Kajs, 2002). Therefore, the SMF model emphasizes the need for both mentors and novice teachers to develop skills to promote an effective relationship (Kajs, 2002).

A variety of different types of knowledge and skills are needed in order for a mentor to be successful. In particular, Hanuscin and Lee (2008) identified skills such as listening skills, knowledge of effective teaching, modeling inquiry, and helping a new teacher to focus on students' thinking as important. These identified knowledge and skills building on the work of Kajs, Willman, and Alaniz (1998) and others, who identified the stages of teacher development, adult learning principles, and professional development assessments as important for mentors. Additionally, the SMF model stresses the importance of developing the interpersonal skills of novice teachers. Eby and Lockwood (2005) indicated that providing training to help novice teachers develop appropriate expectations and clarify the objectives and purpose of the program should improve the quality of the mentorship.

By addressing the overall knowledge and skills of the mentors in the development of the mentoring program, there is an increased likelihood that the issues novice teachers face with be addressed. Within technology education, mentors, in particular, should be aware of and able to deal with the specific needs of new technology education teachers. For example, given the nature of the lab-based technology education classroom, mentors may need to be aware of and able to deal with specific safety- and technology-related concerns. This creates a two-fold advantage for technology education. It develops technology education mentors who can address a variety of concerns and feel comfortable dealing with different equipment, procedures, and classroom environments. Additionally, given the potential lack of experienced technology education teachers to participate as mentors, detailed mentor development may allow other teachers to provide valued assistant to novice technology education teachers.

Support Team

Providing a support team or supporting system for mentors is something few traditional mentoring programs offer. Hanson (1996) indicated that given the increased responsibility mentoring put on a teacher, the time constraints associated with mentoring can have a negative affect. As mentioned previously, given a potential lack of experienced teachers or teachers within a specific field of study, such as technology, mentors might experience frustration with these limitations (Kajs, 2002). The SMF model uses the development of a support team to address these limitations and frustrations.

Support teams can be designed to include a variety of different experts from areas such as different campuses and school districts; they can even incorporate university educators who demonstrate the necessary knowledge and skills to help novice teachers (Kajs, 2002). Support teams can be used to identify the necessary knowledge and skills needed for mentors and protégés, provide training, assist current mentors reducing their time commitment, and can be used to evaluate and improve the mentoring process. Since the physical distance between mentor and protégé can affect the success of the relationship (Allen, Eby, & Lentz, 2006), the use of support teams can also create a feeling of closeness between the mentor and protégé by providing more options for support. Finally, Kajs (2002) concluded that because the support team includes different participants from the school district, both the novice and the experienced teachers may feel a higher degree of commitment for the mentoring program.

Since many school districts may have very few experienced teachers who have lab and technology background to be effective mentors for novice technology education teachers, support teams may provide a solution to this issue. Technology educators specifically can see significant benefits of including and using a support team by identifying and providing a committee of individuals, both in the school district and out, who can be of assistance to technology education teachers. For example, the support team may consist of technology education professionals from within the school district, from a school district nearby, from a regional two- or four-year college, and from state and national teacher associations. Each member of the support team may have experiences with different concerns related to managing a lab, dealing with student, and developing programs and internships. The support team can work individually with each novice teacher to determine concerns and offer support in different ways, whether face-to-face or via electronic means. The advantages are that experienced technology education professional has a chance to collaborate, the mentor's time commitment is reduced, and the novice teacher gets the needed support.

Accountability

Many traditional mentoring programs lack a feedback loop or systematic method for measuring the success of the program. Even though all programs encounter various barriers to success, a systematic means for determining what is accomplished and how the process can be improved is important. The SMF model can be used to develop a systematic plan of program benchmarks. Kajs (2002) indicated that these benchmarks can be met through a series of observations to ensure: (a) appropriate pedagogy is modeled and practiced, (b) work in the classroom is assessed and improved, and (c) mentor/protégé interactions are constructive. The advantage of developing such a component allows for the overall assessment and improvement of the program. Additionally, building in accountability and benchmarks provides a guide for both mentors and protégés to strive toward. Providing measurable goals for both the mentor and protégé to follow also makes scheduling of visits easier and can be helpful in guiding development activities. Within technology education, the accountability component can provide an opportunity for both experienced and novice teachers to reflect on current practices and make improvements to enhance student learning. Given the changing nature of technology, it is particularly important for technology education teachers to reflect on their teaching methods and determine new ways to incorporate and change with technology.

Conclusion

An effective mentoring program not only can enhance the abilities of teachers, but it also can have a significant impact on overall retention of teachers. By successfully retaining more teachers, school districts can address the significant teacher shortage; additionally, costs may be contained or at the very least kept at an acceptable level. While the development of a comprehensive mentoring program using the SMF model may be more expensive and time consuming than a traditional mentoring program, such a cost would be offset by the overall reduction in cost related to teacher attrition (Villar & Strong, 2007). The SMF model provides a systematic approach and structure for the development of an effective mentoring program, and it can provide the needed components to address the issues currently overlooked by traditional mentoring programs (Kajs, 2002). In particular, this systemic approach is needed to address the issues that may be overlooked in a traditional mentoring program concerning technology education. The field of technology education continues to experience a significant teacher shortage (Meade & Dugger, 2004; Ndahi & Ritz, 2003; Newberry, 2001; Ritz, 1999; Weston, 1997), while traditional mentoring programs continue to overlook: (a) the lab-based nature of technology programs, (b) issues related to a lack of funding for supplies and equipment, and (c) the need for mentors with similar backgrounds and technical expertise.

Even though the SMF model is an appropriate step for developing effective mentoring programs for technology education, other areas of research must be undertaken to make this happen. First, given the need for the development of knowledge and skills for mentors, research should be conducted to determine the specific knowledge and skills needed for technology education mentors. A study could be developed to consider knowledge and skills, paying close attention to the knowledge and skills that are most frequently used, most critical, and most difficult to master. This study could then be used to develop effective development activities for technology education mentors. Another study could then be initiated to measure the overall effectiveness of these development activities, looking specifically at issues of mentor and protégé development, increases in teaching effectiveness of novice teachers, and the difficulties of retaining teachers.

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Discovering New Zealand Technology Teacher's PCK

P. John Williams and Mishack Gumbo

Abstract

An important and under-researched area of technology education is teachers' pedagogical content knowledge (PCK). This concept reflects the notion that expert teachers' knowledge is a unique integration of their pedagogical technique and their understanding of technology content as applied in a particular instance.

The authors are interested in inquiring into technology teachers' PCK from a comparative perspective between New Zealand and South African teachers, who have implemented and reviewed their technology education curriculum according to a similar timeframe. This article therefore reports on the first phase of this study on lower secondary technology teachers' PCK, with the focus on New Zealand. The ultimate aim is to compare the PCK of New Zealand technology teachers and the PCK of South African technology teachers via a case study approach. The findings in this paper are reported from the interviews, classroom observations, and document reviews of four New Zealand technology teachers.

Introduction

This ongoing study aims to inquire into the pedagogical content knowledge (PCK) of secondary school technology teachers. The study is a collaborative and comparative project between South Africa and New Zealand. In this article, the authors deal with the findings from the initial New Zealand-based inquiry. According to Nicholas and Lockley (2010), curricular changes have implications on classroom practice and teachers' concepts of what being a successful teacher of technology education means. Both South Africa and New Zealand have recently experienced curriculum transformation and change, which resulted in the introduction of technology education. New Zealand introduced and implemented technology education in 1997 (Jones & Moreland, 2004) and South Africa in 1998 (Stevens, 2005). Both countries have also had curriculum reviews, the latest in New Zealand was in 2007 (Nicholas & Lockley, 2010), and the latest in South Africa was in 2000 (Department of Education, 2000) and 2009 (Department of Education, 2009). These parallel processes motivated the authors to use a comparative study to investigate technology teachers' PCK. Technology education is a relatively new subject in both of these contexts, and research into this area has the capacity to enhance understanding of what constitutes an expert teacher. Thus, the research question arises: What is secondary technology teachers' pedagogical content knowledge?

This research question can be elaborated through the following subquestions that have been derived from the literature:

- What do technology teachers understand as the nature and purpose of technology education?
- What constitutes the technology teachers' knowledge of the technology education curriculum?
- What are the pedagogies that teachers believe are suitable to teaching technology?
- What types of assessment activities do the technology teachers utilize and how are these related to the content?
- What technological teaching and learning resources do the technology teachers use?
- How do the technology teachers integrate indigenous technology in their teaching?

Theoretical Framework

Literature relates the historical treatment of content knowledge and pedagogical knowledge by teachers in a dichotomized way (Ball & McDiarmid, 1990; Shulman, 1986a; Veal & MaKinster, 1999). For example, Veal and MaKinster (1999) became aware of this problem in the area of science and alluded to the traditional polarization of content knowledge (CK) and pedagogical knowledge (PK) that exists in science teacher preparation programs; however, it is counterproductive that these two concepts are treated in a dichotomized fashion (Gore, Griffiths, & Ladwig, 2004). In technology, the parallel dichotomy is often characterized as between theory and practice

(Williams, 2002) where the pressures of timetables, classrooms, and examinations encourage teachers to separate theory and practice, each accompanied by a suite of different conventions related to pedagogy and content.

The origins of PCK date back to 1986 (De Miranda, 2008) when the coiner of the concept, Lee Shulman, gave his presidential address to the American Educational Research Association (Van Driel, Veal, & Janssen, 2001). Van Driel et al. (2001, p. 2) related Shulman's conception of the idea:

> Shulman argued that, for a long time, research on teaching and teacher education had undeservedly ignored questions dealing with the content of the lessons taught. Shulman presented a strong case for pedagogical content knowledge (PCK) as a specific form of knowledge for teaching, which refers to the transformation of subject matter knowledge in the context of facilitating student understanding. Shulman emphasized the importance of research on PCK by referring to it as a "missing paradigm."

Shulman's concern lies at the foundation of transformation in the context of teaching – teachers transforming content into meaningful understanding by learners. Having realized the gap that exists between CK and PK, Shulman (1986a) developed a framework for teacher education by introducing the concept of PCK, such that teacher training programs should combine CK and PK to effectively prepare teachers. Teaching begins with an understanding of what is to be learned and what is to be taught (Shulman, 1987). Shulman and Sherin (2004) argued further, that teaching and learning to teach must be viewed in discipline-specific perspectives. As Geddis (1993) emphasized, "The outstanding teacher is not simply a 'teacher,' but rather a 'history teacher,' a 'chemistry teacher,' or an 'English teacher' (p. 675). The purpose of this study is to research the PCK of a technology teacher.

According to Shulman (1987), PCK includes special attributes that a teacher possesses, which help him/her to guide a student to understand content in a manner that is personally meaningful. Shulman (1987), having identified teacher knowledge as central to teacher quality, developed a seven-part classification of teacher knowledge built on elements that include knowledge of subject matter; pedagogical content knowledge; general pedagogical knowledge; knowledge of curriculum; knowledge of learners and their characteristics; knowledge of educational contexts; and knowledge of educational aims, purposes, and values. In contrast, Cochran, King, and deRuiter (1991) were interested in four elements:

- Knowledge of the subject matter
- Knowledge of learners
- Knowledge of environmental contexts,
- Knowledge of pedagogy.

(cf. Veal & MaKinster, 1999; Smith & Neale, 1989).

Another alternative conceptualization of PCK was developed by Magnusson, Krajcik, and Borko (1999), which is helpful in clarifying this special form of a teacher's professional knowledge by proposing that PCK is made up of five components. In their view, an experienced teacher's PCK encompasses his/her:

- Orientations toward teaching (knowledge of their subject and beliefs about it)
- Knowledge of curriculum (what and when to teach)
- Knowledge of assessment (why, what, and how to assess)
- Knowledge of students' understanding of the subject, and
- Knowledge of instructional strategies.

PCK can further be viewed as a set of special attributes that help someone transfer the knowledge of content to others in a manner that will enable them to develop it in a personally meaningful way (Geddis, 1993; Shulman, 1986a, 1986b, 1987; Van Driel et al., 2001). Cochran, King and deRuiter (1991) defined PCK as the manner in which teachers relate their PK to their subject matter knowledge in the school context, for the teaching of specific students. The CK of PCK also implicates both Western and indigenous forms of technological knowledge. Hence, teachers also need to integrate indigenous technologies, understand their nature, and work to address the technological bias toward them (Gumbo, 2000; Maluleka, Wilkinson, & Gumbo, 2006).

There is a strong research history in the Technology Education community about pupils' attitudes toward technology (PATT) (Ankiewicz, Van Rensburg, & Myburgh, 2001; Burns, 1992; Rennie & Treagust, 1989; Van Rensburg & Ankiewicz, 1999; Volk & Wai Ming, 1999), but less related to PCK, which therefore presents an opportunity for research in technology education. The findings of a study by Rohaan, Taconis, and Jochems (2008, 2009) revealed that a link exists between teachers' knowledge and learners' concept of and attitude toward technology.

Jones and Moreland (2005) suggested that teachers require a clear understanding of the nature of technology and the conceptual and procedural aspects of the different technological areas. Reddy, Ankiewicz, De Swart, and Gross (2003) contended that technology teachers' inability to make technological experiences cumulative, purposeful, and empowering resides in their inability, for example, to see the inter-relationship between technological content knowledge, skills, attitudes, and values and technological capability.

In this article, the authors draw from this literature to continue the research into PCK in the context of technology education.

Research Design

A convenience sample of four schools was selected to become case studies, two in a city, one in a small town, and one in the countryside. In each case, the Head of the Technology Department was approached, and in two cases this person became the participating teacher, and in the other two cases, teachers in the department were delegated to be involved. In all cases, the participants were identified as expert teachers and were willing to cooperate.

A convenient day was negotiated with each teacher; during which time they would be teaching a lesson that could be observed and the teachers had time free for interview and discussion. Classes were observed by both researchers, in order to help validate the data; an observation schedule based on the elements of PCK derived from the literature was used. Observation is deemed important to counter possibilities of bias that could emerge during interviews (Kelly, 2006).

In general, observation was followed by the interview. An in-depth interview can be a qualitative research technique involving intensive individual interviews with a small number of respondents to explore their perspectives on a particular idea, program, or situation (Boyce & Neale, 2006). The goal of an interview is to deeply explore the respondent's point of view, feelings, and perspectives (Guion, 2009).

Also, documents and resources used by the teachers were analyzed. According to Silverman (2005), qualitative researchers analyze a small number of texts to understand participants' categories and see how they are used in concrete activities.

Data analysis began with the interview data, adopting a variation of the coding strategy used by Marshall and Rossman (1999). This involved a stepped process moving from a general approach of listening to the recordings to initially develop themes and codes to noting the themes from the transcribed data, and then detailing the themes. The variation on this coding strategy was the use of analyst-constructed typologies, which were based on the principles of PCK developed from the literature. These typologies became the categories for analysis, but not exclusively so, in order to allow for emergent themes. The analyst-constructed themes were subject matter, curriculum, assessment, learners, pedagogy, educational context, educational aims, purposes and values, and indigenous dimensions.

Once the audio transcripts were analyzed, they were integrated with the teaching observation notes, the document analyses and incidental personal memos that the researchers had been keeping (Marshall &Rossman, 1999). The outcome was four integrated narratives about each of the cases; an alias was given in order to protect the teachers' identity.

Findings

In this section, the findings from the different sources of data are presented. Initially, each of the four cases were contextualized, noting some features of the observations that were made, and this was followed by a presentation of findings.

1. Morris

Morris, one of six technology teachers in a rural school that had approximately 700 students in Years 9-13, is 50 years old and has taught for 10 years; originally he was a mechanic.

This teacher was observed in a Year-10 class of 20 male students who were completing folios and final projects. The emphasis on folio work was in preparation for to the following year, that is, eventually to develop more significant portfolios to accompany projects. The teacher gave specific directions to students, including a handout pro forma to complete. This assignment was to be completed by the next class.

After 15 minutes of discussion, the students moved into an adjacent workshop to work on their projects. Without direction from the teacher the students continued their work. The atmosphere in the class was relaxed, and some stayed off task, but most got on with their work.

2. Fraser

Fraser is in an urban school with a population of 1800 students. The department has five technology teachers, a full-time technician, and spacious facilities. Fraser recently updated his teaching qualifications after teaching for 10 years.

We observed two classes of Year-10 students, which were team taught. Only one female student was present, who did not contribute to the class. Six male students were in an adjacent teaching room playing music from cell phones and a guitar.

After experiencing disciplinary problems with this group of students, the teacher decided to excuse them from the project, knowing that they would repeat the project during the following year. Many students wore their backpacks while in the workshop which hampered their movements somewhat, despite sufficient shelving for this purpose. Some students wore aprons, others not.

The class worked on a race car project. Each student fabricated a design from pine wood. The design specifications were met by three of the students, and all worked at their own pace with minimal supervision by the two teachers. The students were at different stages of their projects, some were consistently engaged, others were not. Some students approached the teachers for clarity on the challenging parts of the project. Eventually the teachers moved around the working stations to give support and guidance whenever needed, and to check if the projects were consistent with the specifications, and to call the roll. The teachers responded only to individual requests for assistance, and there was no conclusion to the lesson. The teachers instructed students to clean up and put tools back in order, however, there was no structure to cleaning and packing up. Some students left immediately at the sound of the bell. Others who stayed and cleaned, did not do a good job, and the researchers helped the teacher who had to finish cleaning.

3. Cam

Cam teaches at a coeducational state secondary school with about 1400 students in Grades 9 to 13, set in a town of about 20,000 that is surrounded by rural areas. The technology department includes seven teachers, and a new technology center is being built at the school entrance.

Cam teaches graphics in adjoining classrooms at the back of the school; the classrooms share a storage room of drawing equipment. One class of 22 Year-10 students included both females and males. The traditional seating arrangement had 28 old wooden single desks organized in rows; each with a drawing board angled on top. A laptop computer and data projector were used to present the activity; students assisted during setup, and a chalkboard was used to illustrate the drawing technique.

Cam, who has built a positive teacher-student rapport over time, demonstrated how he freely related to students. The class began with a "question of the day" (for e.g., favorite comfort food), and students responded to the roll call by answering the question. The atmosphere in class was quite relaxed while students worked on drawings while chatting and moving around freely. Cam kept the noise level in check. He also provided individual support to students and reminded the class of the following 4 x B's sequence:

Brains: first try and think it through.

Board: use black board support to assist.

Bro: ask a classmate to help.

Boss: ask the teacher.

Very few students requested teacher assistance, and most problems were solved with the help of other students. The students stopped work, packed up, and departed while the teacher was talking to the researchers.

4. John

John teaches in an urban boys' school of 660 students with six other teachers in the Technology Department. He is 50+ and has been teaching for 20 years following a career as an automotive engineer.

A Year-8 class of 14 students (both male and female) was engaged in completing a range of projects. These students spent two hrs/week in the technology workshop at the high school to which they traveled by bus from their local primary school. They were in various stages of completing a range of projects based on their individual designs. The general design context was small souvenir items of wood or acrylic, which were to represent New Zealand. A small band saw, sander, and drill press were located on the wall benches, which the students were allowed to use, but they could ask the teacher to handle cutting with the band saw. A high level of organization was evident, and the teacher trusted the students who helped themselves to supplies as needed.

The teacher wanted to get the students "hooked" on technology, give them an attractive project to take home, and enable them to engage in some design work that included skills and materials knowledge. They completed a small portfolio, which was used to assess their work against Level 1 or 2 of the curriculum.

In the following section, the authors summarize their findings in terms of research questions.

Q 1: What do technology teachers understand as the nature and purpose of technology education?

Two teachers believed that skill development and vocational goals were the main purposes of technology education, and they thought that general problem solving and creativity skills were extremely important. In a practical way, these philosophies were evident in the school provision of vocational unit standards or more general achievement standards. The external measure of success in achieving the goals of technology education was competitive for some teachers; for example it helped teachers to discuss their students' work at standardization meetings, and some teachers feared being embarrassed by the quality of student work. Other teachers mentioned the measure was the number of "Excellences" that students achieved.

Regardless of the overall purpose, all teachers recognized that student conceptual development, through the medium of design and making, was a significant goal. They believed strongly that a major goal was to develop research and thinking skills in their students because that reflects the reality of life. Using a process to make decisions is a part of everyday activity, regardless of what vocation students eventually pursue: "[Students] still have to make informed decisions about what they're doing," "it reflects the reality of life and it provides a process of problem solving and thinking about things, [that is] coming up with answers and being able to discuss ideas with other people."

Underpinning this cognitive goal was the belief that all students have this ability. This was made explicit because there are some technology teachers who believe that their students have limited abilities, which prevent the development of cognitive skills and the documenting of design processes. One teacher who had been a national assessor and moderator stated: "If the teacher says, 'I had a bad group of kids this year, they didn't work hard,' instantly you know it's the teacher's fault."

Skills that could be generalized were prioritized by one teacher to include developing an understanding of how things are made, how they work, and how they are manipulated; he believed that "[students] can learn lots of other stuff, but that practical aspect is so, so important …"

The teachers emphasized the need to progressively work toward the development of thinking and research skills, considering that students have to start thinking and recording their ideas at least in Year 9. There was recognition also that the culture of the technology area is a significant factor: "If kids come into an untidy and dirty workshop expecting not to have to think at all from day one, having the attitude that we're just going to make stuff in here and the teacher just focuses on manipulative skills, then it becomes the culture of that department and is very difficult to break in later years."

One teacher placed the rationale for his student goals within a national context, recognizing that New Zealand is a small country that does not have a broad manufacturing base; thus, there is a need to be at the cutting-edge of inventing and making things by teaching design and technology in schools.

After a review which focused the technology curriculum more on students understanding of the nature of technology, a number of teachers considered that technology wasn't adequately developing or promoting a practical approach.

Q 2: What is the technology teachers' knowledge of the technology education curriculum?

The depth of understanding of the curriculum was polarized, with one teacher being involved in the national curriculum development and implementation and another aware of neither the changes in the new curriculum nor the extensive, available support material. This latter teacher offered students a range of unrelated projects which were also unrelated to the curriculum.

All the teachers were aware of the curriculum, particularly as changes (adding two new strands, the Knowledge and the Nature of technology) were being implemented at the time of this study. The degree of curriculum accountability has changed over time. When the terminal qualification was the High School Certificate there was no external accountability for technology teachers, but since the National Certificate of Educational Achievement was introduced to Years 11-13, specified standards and levels of attainment must be achieved, which are moderated, some of which are externally assessed.

Achievement standards and unit standards have caused a division among teachers. Unit Standards are vocationally aligned, skills oriented, competency based; they were developed by industry. Achievement standards are related to technological literacy. Some teachers offer both, and others offer only one.

One teacher had a unit standards class to teach, but believed that the students were capable of achieving more than a range of skills competencies:

> I thought, I am going to teach these kids Technology. So we did a huge project, and went through it using very much the same process that I would have done with Achievement Standards, slightly watered down in some areas, and probably with a slightly more practical focus . . . . These students are just absolutely firing ahead because they can do practical stuff and they can think. The folders they produced were equal to [those at] any school around that is doing Achievement Standards.

This teacher is contrasted with another who offers vocationally oriented unit standards in areas of furniture making, carpentry, engineering and automotive technology; however, he also offered a couple of achievement standards, "Because if we don't – then we would lose the students who need the achievement standards."

One argument for the offering of unit standards is that the achievement standards are too theoretical for the type of students attracted to technology. Conversely, another teacher believed that achievement standards offered a good balance: "When they first started a lot of the teachers felt that skills had been taken out of the achievement standards, but we've demonstrated that there's plenty of room for you to make something worthwhile, which is supported by relevant theory."

A related issue is the expectation from industry that standards above Level 2 must be offered in an industrial context. Historically, Level 1-3 was aligned with the last three years of schooling, Years 11-13. Consequently, the concern is that there are few standards now available for Year 13 students.

All teachers agreed that a sequence of technology activity is necessary in order for students to achieve to their potential by the end of secondary schooling at Year 13. Students are not usually admitted to Year 13 classes unless they have done preparatory work during the previous two years. There was a strong objection to students entering technology classes "because they want to come and make something, or because timetabling says so; well, they just have to go away."

Teachers perceived the sequence, however, to involve different elements. One teacher thought progress could be measured through student conceptual idea development, where in Year 9, students' different concepts are really just one idea that has been changed slightly, and the progress toward diversified thinking peaks in Year 13 with a range of genuinely diverse ideas.

For another teacher, progress developed through increasingly broad design briefs in which there were rigorous limitations on Year 11 students, but by Year 13, it is quite open and students can mostly do what they want. "In Year 13 students [take on] a client with a genuine issue that has to be solved. The teacher's role is to make sure it's not too expensive or out of control, [that the project offers depth], and that the stakeholders are available to talk to the students."

Q 3: What pedagogies do technology teachers believe are suitable to teaching technology?

Though some teachers found it difficult to explain their pedagogies, through discussion and observation it became clear that these varied. One teacher had a limited repertoire of strategies to use with students; mainly consisting of demonstrating skills followed by responding to individual needs. On the other hand, another teacher indicated a range of pedagogical strategies, which varied by year of the students, the goal of the activity, and the nature of the project.

Often, pedagogy was linked to the nature of the laboratory. One teacher emphasized that the physical state of the workshop affected students' attitudes and productivity, and if the workshop is dirty and untidy, then the students will respond in kind and not take pride in their work.

Another teacher used the physical arrangement of the workshop to complement pedagogies. Three hexagonal island benches with vices were available as was one long bench where the entire class could sit to work on their portfolios. This bench arrangement, according to the teacher, demonstrated a balance between theory and practice in the teaching of technology by enabling students to move easily between practical work and theoretical work on their portfolios.

One teacher commonly used small groups, which were observed to be engaged and cooperated in completing their projects. The teacher generally decided on the group members to ensure that weaker students were teamed with stronger designers, and like-minded students did not always work together.

All teachers mentioned some form of sequencing student work. It was a common perception that when students begin technology classes, they just want to do practical work, but they must have the understanding from early on that there is theory to be done.

One teacher particularly stressed that students only need to know what they need to know at a specific point in time. For example, "I'm not going to waste their time telling them how steel is produced because they don't need to know about it." Another teacher reinforced this just-in-time approach, by providing new information and demonstrating new skills to students when they need to know it, when the students see it as relevant. This teacher saw a fine line between teaching the students so they are not put under stress, but stretching their cognitive skills enough to make them think critically about what they were doing.

This teacher considered it important to initially develop a toolbox of hand skills, thus providing a foundation from which the students can move on to solving problems and dealing with briefs and stakeholders, and, finally, researching and presenting their work.

In contrast, the experience of another teacher was that if students are left to their own devices to work at their own pace, "they tend to back off a bit, so we need to keep onto them." But conversely, he also found that too much pressure on students to progress had a negative effect. He provided one sheet or one section of a workbook at a time to the students so as not to overwhelm them and thought this was effective.

The ability to have a flexible approach to classroom management and to respond to the needs of students at a given time was a common thread among the teachers' methods. All the teachers reinforced the need to have a personal relationship with students, though through observation this did not seem to be the case in reality with all the teachers. One teacher only taught content areas or projects that he personally found interesting and exciting.

Another teacher's focus was on the pedagogies of management, which "is quite difficult at Year 10, where one student is making a skateboard, another is making a scooter, and another a surfboard." He found this management a lot easier at the higher levels of study, for example in Year 13, because the students have stronger skills, a grasp of personal management issues, and a level of maturity that facilitates focused constructive work.

Q 4: What types of assessment activities do the technology teachers utilize and how are these related to the content?

Student achievement in the New Zealand curriculum in each subject is described by means of progression through eight levels of attainment, from entry to school to Year 13. Years 11-13 are the post-compulsory years and students in these years can achieve, accordingly, the National Certificate of Educational Achievement (NCEA) at Levels 1, 2, or 3. The NCEA is comprised of a range of achievement standards around which teachers can organize the learning programs they offer to their students. The Achievement Standards at Level 1 line up with progression indicators of the preceding years.

The coverage of technology education at middle schools (Years 7-8) in New Zealand is various, and students progress to Year 9 and secondary school with a range of different experiences and performing at different levels. Many secondary schools attempt to develop students' performance to Level 6 of attainment by Year 11, which corresponds to NCEA Level 1. This reasonably enables students to finish their secondary schooling in Year 13 with an NCEA Level 3 qualification, but teachers noted such progress was often difficult for students in years 9-10.

Within this context, the assessment strategies used by teachers were diverse, some involving the simple addition of numerical values for certain specified criteria seemingly unrelated to the formal curriculum, and others developed from assessment matrices that, in turn, were based on statements of levels of attainment. For all teachers, however, assessment was based on activity rather than a task (e.g., examination) designed specifically for assessment purposes.

One teacher saw progression through assessment as a theory – skills balance: "In Year 9, I'm probably looking at 80% skills and 20% theory; in Year 10, I'm probably presenting 60-65% skills and the rest of it is in the theory; and of course once they get to Year 11, the theory side of it is just as important as making it."

Another teacher's focus for assessment was to evaluate the students' level of planning, their understanding of the processes, and their ability to evaluate whether they have achieved their goals.

The teacher who used small groups extensively in his class organization also used the groups to determine peer assessments. One teacher was concerned about the reporting of student achievements to parents. This teacher did not explain achievement in terms of levels to the parent but instead explained students' work in terms of "excellent ability to select materials." At the upper secondary levels, the assessment structure is predetermined. The assessment of vocational pathways consisted of noting the mastery of skill achievement, and the assessment of Achievement Standards according to the standard and developed from the indicators of progression.

Q 5: What technological teaching and learning resources do the technology teachers use?

Resources used by teachers tend not to be books, unless some specific information is required. Technology education departments had libraries of technology education books, but no class sets, so these were used mainly as reference resources.

Colleagues commonly used each other as a resource to bounce ideas off, either visiting each other in schools or meeting at the regular opportunities for professional development. The internet was also commonly used, both in general terms as a source of information, and by specifically using the TechLink website, which has been developed with government support as a resource for technology teachers and contains a significant amount of curriculum support material. One teacher, however, was not aware of any available internet based support material.

Teachers maintained a constant lookout for resources, one stating: "I spend a lot of time in toyshops … I go into lots of home appliance and hardware shops." It seemed common for teachers to utilize a range of technologies that they coincidentally come into contact with.

In the senior curriculum, one of the objectives is for students to work with an external client; consequently, some teachers build a significant network of industry contacts for their students. One teacher used these contacts as his main resource.

Q 6: How do the technology teachers integrate indigenous technology in their teaching?

The teachers were generally a bit bemused about indigenous issues in their technology education program. Two teachers related the issue to the low numbers of Maori students in their classes, and so believed it was not important and did not incorporate it into their practice. However one teacher believed that when this was done properly, it can benefit many people: "Other students need to know about it but we also need to know about other things as well, so it's a matter of getting the mix right."

Teachers' understanding about the incorporation of indigenous technology seemed fairly superficial. One school included cultural heritage as a faculty goal each year, but examples which achieve that goal seemed elementary.

In a context in which students are encouraged to develop their own designs as solutions to problems, teachers seemed content to allow that latitude to encompass the inclusion of indigenous influences, often exhibited as a form of decoration that has cultural significance. There was no structure evident in any of the sources of data to permit a planned instructional sequence that would enhance all students' understanding of indigenous technology.

Conclusions

Teachers' PCK varied significantly in these case studies, which confirms the research that PCK is individual, unique, varies from class to class, and changes over time. As a framework for developing an understanding of teachers' PCK, the methodology used in this project seems to be appropriate. The observation of the teachers' context and of their teaching, the interviews, and to a lesser extent the document analysis provided for the collection of a rich data source for each teacher, and generally triangulated to provide valid results (Cohen, Manion & Morrison, 2007). Where triangulation did not validate data, for example, where the teachers' interviews did not match the observations of their class, the dual sources of data are particularly important.

Although all the participating teachers in this project were teaching the same year span of students and followed the same curriculum, quite diverse PCK was revealed across all the components: the subject matter that was taught, the interpretation of the curriculum, strategies for assessment, conceptions of the learner, and the purpose and aims of technology education.

The curriculum context in which this research took place possibly had a clarifying effect on teachers' PCK. A revised technology education curriculum was currently being implemented, which was perceived by many to present a more theoretical approach to the subject, at the same time that the opportunity for schools to offer vocational qualifications was being limited.

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Printing Processes Used to Manufacture Photovoltaic Solar Cells

Tina E. Rardin and Renmei Xu

Abstract

There is a growing need for renewable energy sources, and solar power is a good option in many instances. Photovoltaic solar panels are now being manufactured via various methods, and different printing processes are being incorporated into the manufacturing process. Screen printing has been used most prevalently in the printing process to make solar cells, but some companies have used the offset web press type methods to put material onto foil; they also have created solar cells with inkjet printing. The printing of solar cells has helped to reduce manufacturing costs in most cases, and it also has increased the various applications in which solar power both is and can be used. Many more options for photovoltaic solar panels are available, and not simply the traditional ones that are often placed on rooftops. Such a variety of solar panels are partially to the result of the implementation of suitable printing processes during the production of these cells.

Introduction

With ever-increasing political and economic oil conflicts as well as climate change, a growing need for renewable energy that comes from natural resources, such as sunlight, wind, rain, tides, and geothermal heat, is warranted. Wars have been caused in part to protect oil supplies, and millions of tons of pollutants and greenhouse gases are emitted into the atmosphere every year due to the burning of fossil fuels to create energy. There is no other area of technology than renewable energy technologies that can both "meet the challenges of climate change and secure an energy supply in an intelligent manner" (Wengenmayr & Bührke, 2008, p. 1). A number of options for new technologies of renewable energy exist, that is, from geothermal to wind to hydrogen fuel cells to hydropower; however, one of the most accessible and widely used technologies is solar energy. Solar power does not create any noise when it is working, "is non-polluting, does not generate greenhouse gases, and creates no waste products," (Brenner, 2010, p. 27), which is also why it is an increasingly preferred renewable energy. Additionally, the potential for solar power is immense. The energy from the sunlight that strikes the earth for only forty minutes is equal to the global energy consumption for an entire year (Zweibel, Mason, & Vasilis, 2008). All of that energy is of no use, unless it can be captured. A good method to harness this immense amount of energy and thus to eventually use it as electricity is through the use of photovoltaic (PV) energy systems.

Photovoltaic Power

According to the U.S. Department of Energy (2010, p. 1), "the diversity, adaptability, and modularity of PV technology make it distinct from other renewable resources." Solar photovoltaic power is extremely useful because it can be produced in a number of ways from a variety of materials, and it can be used for numerous applications. Photovoltaic cells can be used for anything (e.g., from a small strip that powers a simple calculator to personal panels on homes to larger commercial settings and solar farms spread out over vast areas of land). Photovoltaic modules are also useful since they have minimal maintenance costs and are extremely long lasting; some manufacturers offer up to 25-year warrantees (Brenner, 2010). In 2008, photovoltaic systems were the largest producer of electricity directly from solar energy in the world, in terms of kWh produced per year (Vanek & Albright, 2008).

The photovoltaic or PV cell is a type of technology that uses semiconducting materials to convert the energy in sunlight into usable electricity. Derived from Greek, the term *photovoltaic* can be translated as "electrical energy from light" (Wengenmayr & Bührke, 2008, p. 42). The cells transfer the energy of the photons penetrating the solar panels to electrons that are "channeled into an external circuit for powering an electrical load" (Vanek & Albright, 2008, p. 249). A PV panel is made up of multiple photovoltaic cells, anywhere from 50 to 120, which are connected together in an electrical circuit that can then be connected to an exterior circuit at a single point. An entire PV system often is comprised of a number of panels, so that a greater, more desirable amount of voltage is produced. These PV cells take on many forms and are produced in a number of different ways, often including various printing processes.

Printing Solar Cells

In order to make the use of solar power a likely alternative to fossil fuels, it needs to be economically comparable to conventional energy sources like coal, natural gas, and oil. This matter of cost is the largest issue facing the success of photovoltaic solar panel use. Efficiency of solar cells is the percentage that they are efficient at "converting the radiation from the sun into electricity for the area of the active part of the module" (Brenner, 2010, p. 29). Efficiency is possibly the most important factor when determining the overall use and quality of a solar cell, and it can play a large role in reducing overall costs. The two main strategies to reduce the cost of power production in photovoltaic devices are to increase efficiency and to lower production costs of the starting materials (Wengenmayr & Bührke, 2008). Implementing different printing processes throughout certain steps of manufacturing has recently helped to accomplish both efficiency and lower costs. Certain printing processes like screen printing, inkjet printing, and even web press offset printing lend themselves to being just what is needed to make various types of solar cells. These processes are becoming a large part of solar-cell manufacturing for different kinds of photovoltaic solar energy, each with its own benefits and drawbacks. It is important to understand the different types of solar cells and materials that are used to make them in order to understand where these printing processes can fit in.

Traditional PV Material

Conventional solar cells are made from silicon, are flat plated and rigid, and generally have the highest efficiencies. Crystalline silicon (c-Si) is the most widely used and most efficient material expended in the production of photovoltaic solar cells, with commercial efficiencies sometimes reaching 20%. It is estimated that about 80% of all photovoltaic solar panels are created with crystalline silicon, and this material is especially useful because it has shown both long-term performance and reliability (Applied Materials, 2010). Crystalline silicon cells are made from silicon wafers that can be either mono-crystalline or multi-crystalline structures, depending on what is available or what is needed for that particular process. All structures using pure silicon will face shortages, especially since the material is used in other semiconductor industries as well as in solar PV. Silicon is a plentiful element in the earth's crust, but most of it occurs in compounds that would be costly to extract the pure silicon from them (Vanek & Albright, 2008). Crystalline silicon has been the go-to material to make efficient solar panels; however, because of shortages and the general high costs of silicon, other options have been developed with other materials or smaller amounts of silicon.

Thin Film PV Materials

Thin film solar cells offer the best option in terms of producing solar cells. Thin film solar cells require less semiconductor material, so material costs are substantially reduced (Zoomer, 2010). The versatility of applications with thin film could also vastly increase the use of solar power. While numerous different materials have been used for thin film, the most widely used at present are amorphous silicon, organic polymers, and a combination of conductive metals including compounds of copper, indium, diselenide, and sometimes gallium.

In terms of the more conventional materials, amorphous silicon (a-Si) can be mass produced more easily than crystalline silicon, and it can be very thin, even to the point of being flexible, so much smaller amounts are required (Vanek & Albright, 2008). Since the atoms are not arranged in any particular order, like in a crystalline structure, there is more flexibility with what can be made with amorphous silicon. The material is full of defects naturally so impurities are not a problem, and it can be applied uniformly over very large surfaces, making it more usable than crystalline silicon. Amorphous silicon does not have the same quality of electrical properties as crystalline silicon, but the gap has been closed in recent years (Amorphous Semiconductors Research Group, 2010).

Several combinations of conductive and semiconductive metals and compounds can be used to create solar cells, but the most acclaimed and most common seems to be one consisting of copper indium diselenide, also known as CIS (Goetzberger, Knobloch, & Voss, 1998). As early as 1978, high efficiencies without degradation were observed, which made this a very important material in the thin film solar industry. Recently, a similar but even more productive combination of copper, indium, selenium, and gallium, also known as CIGS, has been used (Inslee & Hendricks, 2008). These materials help to make the mass production of solar cells more of a reality, and since CIGS can potentially have similar efficiencies to traditional cells, about 19.5% (Contreras, et al., 2005), this is one of the most promising new PV technologies.

A company called Konarka Technologies has developed thin film solar PV cells from organic polymers in the form of "Power Plastic." These organic photovoltaics are a third-generation type of solar power that uses a photo-reactive polymer that can be combined with several other very thin layers to be used in a number of products. The Power Plastic can be printed on large rolls of flexible substrates, is made from recyclable materials, and converts light to energy both outdoors from the sun and indoors from a light bulb (Konarka Technologies, 2010). Another application of organic polymers is seen when it is used as a dye that is a combination of nanoparticles that convert light to electricity (Fraunhofer-Gesellschaft, 2008). Both of these applications of organic polymers immensely help reduce the cost of manufacturing solar cells, but they are not as efficient as silicon-based cells, and the longevity is not known of these new cells.

Screen Printing

The basic principle of the process of screen printing is simply the use of a stencil to reproduce the same image over and over again. This is currently conventionally done with the use of a mesh screen coated with light-sensitive emulsion that is then exposed to light with the desired positive image blocked, and then washed out to create the mesh stencil. There are other ways to make the stencil, but the use of photographic emulsion is most common. Ink is then applied to the screen and pushed through with a squeegee to transfer the ink on the open image area to the desired substrate. This process can be repeated as many times as the screen materials will last. Screen printing is one of the most versatile printing processes because almost anything from glass to paper to fabric to plastic can be printed on, and a very thick amount of ink can be laid down, unlike in other printing processes. A number of factors should be considered when screen printing is used, depending on the type of materials and images that are being printed. Factors including mesh count, screen angle, emulsion-on-mesh thickness, stencil surface smoothness, ink type, how detailed the image is, how many impressions the screen can last, and squeegee pressure can all affect the overall quality of the product that is being printed. This screen-printing process has been used as part of the process to make conventional silicon solar cells due to its versatile nature.

According to Peter Brenner (2010), global marketing manager of photovoltaics for DuPont Microcircuit Materials, "Screen printing photovoltaic cells is the most reliable method and fastest growing application in industrial printing" (p. 26). Screen printing is also the most commonly and conventionally used printing process throughout the manufacture of photovoltaic solar cells. In fact, over 90% of all crystalline silicon modules are manufactured using screen printing, and about 60% of flexible thin film modules use screen printing in the manufacturing process (Brenner, 2010).

The way that screen printing is used in the process of making solar cells is that PV solar cells are often metalized through a screen-printing process. This is the application of three different types of metallization pastes onto the c-Si cell. The first paste is the front-side silver used on the side facing the sun; it makes up the collector gridlines and the silver bus bars, and the second is the rear-side tabbing silver or silver-aluminum, and the third is the rear-side aluminum paste that actually reacts with the silicon to create the back surface field (Brenner, 2010). The screen-printing process is especially useful in applying these pastes since consistency in each application as well as the ability to lay down different thicknesses for the different types of pastes are both very important. However, according to Brenner (2010), similar to screen printing any object, a number of variables involved in screen-printing photovoltaics must be monitored: ink composition (solid content, viscosity, rheology, evaporation rate, dispersion), press setup (squeegee durometer and shape, attack angle, squeegee pressure, print speed, snap off, registration control), screen/stencil (mesh count, wire diameter, percent of open area, emulsion thickness, mesh tension), and the environment (room temperature, humidity, air turbulence, cleanliness, substrate surface, shelf life of ink and screens). Each of these variables is generally something that should be considered in any type of screen printing, but it is especially important with printing PV modules due to the nature of the materials and the accuracy that is needed.

Another way that screen printing is utilized in the manufacture of solar panels is through the use of organic dye, a combination of nanoparticles, which serves as a semiconductor to convert sunlight to energy. The versatility of this dye allows for different colors and designs to be printed, making this an excellent option to be integrated into the façade of a building or to serve as a decorative element. These panels could be integrated into windows and not only convert sunlight to electricity but also serve as a sunshade to the interior of the building, saving additional energy. Even though screen-printing this dye onto glass makes it an excellent choice for building integration, the cells only have an efficiency of about 4%, so they are not yet competitive with conventional silicon panels. The longevity of this technology is yet to be determined, though it did seem to perform well in initial tests (Fraunhofer-Gesellschaft, 2008). Even with these drawbacks, this organic dye could be a very popular choice by consumers due to its more aesthetically pleasing qualities and consumers' options to have whatever design or color they desire.

Inkjet Printing

Inkjet printing is one of the newest and most experimental methods used to make solar cells, and it could potentially have a very big role in making solar panels accessible to everyone. The most common type of personal computer printers use inkjet technology, and it is also used widely in industrial applications such as the production of numerous microscopic items, the formation of conductive traces for circuits, and the manufacture of color filters in LCD and plasma displays (Clark, 2008). Inkjet printing is a non-impact printing that uses a number of nozzles to spray ink droplets directly onto the paper or substrate without touching it (Tyson, 2010). This basic principle makes inkjet printing very useful in that not only can it spray onto a number of different surfaces, but also it can spray onto a number of materials. It is not simply conventional printing ink that can be sprayed. Inkjet printing recently has been used in the production of both flexible thin film solar cells as well as more conventional rigid silicon cells.

Using inkjet printing to apply semiconductive material onto flexible substrates that could result in the formation of a thin film PV solar cell has the potential to become available to any person who has an inkjet printer. While this is not the case yet, many places are using inkjet printing to reduce manufacturing costs and trying to increase efficiencies of thin film solar cells. Konarka Technologies is using inkjet printing as part of the production process of their Power Plastic thin film solar cells, which are made of organic polymers. This material has been in production and development for a few years, and in 2008, inkjet printing was used, making the process much cheaper than it previously had been (Masamitsu, 2008). This paper-thin plastic has infinite possibilities and can be applied to any flexible surface such as tents, umbrellas, and handbags, but there are a few drawbacks. The efficiency of this inkjet printed material is only 3-5%, so to get anywhere near the amount of energy a conventional silicon solar cell can get, there would need to be a very large area available to lay down this Power Plastic. These cells also only last about a couple of years, as opposed to decades that conventional cells last (Bullis, 2008). These drawbacks currently limit the use of the product, but the benefits are still very great since potentially anyone could print these cells. That may be a few years away, but the versatility and massive amount of places this plastic could be used are not to be taken lightly. Inkjet printing has played an important role in helping to make this happen.

Inkjet printing is also now being used in place of screen printing to make electrical connections during the process of making more conventional crystalline silicon solar modules. The inkjet method can be more precise than previous methods, and since the print heads do not make contact with the silicon, a thinner, more fragile piece can be used. Conventional screen printing methods need to use silicon wafers that are at least 200 micrometers thick because any thinner wafer will likely break. It is estimated that 100 micrometers of silicon can be used with this inkjet process, and since silicon can account for 75% of the total cost of materials and production, this could greatly reduce overall costs (Bullis, 2009). The silver gridlines can be printed with inkjet printing and the ink used is more conductive than the silver paste in screen printing. Maikel van Hest, a scientist at the National Renewable Energy Laboratory, noted more precise lines of 35 to 40 micrometers wide, compared with 100 to 125 micrometers wide with screen printing can also be printed (Bullis, 2009). This ultimately means that not as much silver will need to be used, saving additional money and resources. The thinner lines also can block less of the solar collecting material, so that the sun's radiation can hit more of the surfaces that are actually collecting it, as opposed to bouncing off because of the thicker silver lines. These thinner lines make the cells more efficient, although at the moment the amount of increased efficiency is unknown.

No matter what application inkjet printing is being used in, the process is proving to be a very important part of making photovoltaic solar cells more economical and more accessible. While currently it is only used in mass production, the potential of being able to print on a personal printer is definitely a considerable advantage that this process has over any of the others. Not only is inkjet printing improving already-developed PV manufacturing processes, but it is also a key component to an entirely new type of thin film that could be used for any number of purposes. Inkjet printing is helping to reduce costs of manufacturing and increase the efficiency and availability of solar cells, which are currently vital goals of the photovoltaic solar industry.

Web Printing

Though not exactly using the principle of offset lithographic printing, there are companies using web press applications to coat semiconducting materials onto flexible substrates. The substrates that are currently being used are plastics and metal foils. Offset printing is a type of planography, because the plates used during printing are completely flat. The principle of offset lithography is that the oil-based ink only sticks to the hydrophobic image area on the plate, which is transferred to a blanket, and then transferred onto the substrate. Web offset printing is a continuous process that prints on rolls of substrates, though it is still an indirect process due to the nature of offset lithographic printing. Newspapers, for instance, are often printed by an offset web press and then cut down into the necessary sheets. With the manufacture of solar cells, certain principles of web offset printing are applied, and they are shown to greatly decrease costs and increase production capabilities.

Nanosolar is a company that prints the semiconductive compound of copper, indium, gallium, and selenium (CIGS) onto thin foil. The company uses a web press application and "can produce a hundred feet of continuously rolled solar cell per minute" (Inslee & Hendricks, 2008, p. 72). Their nanoparticle ink mixture, consisting of CIGS and the necessary components for proper dispersion, is coated onto "a specially-prepared proprietary alloy of metal foil using high-throughput coating/printing techniques" (Nanosolar, 2010, paragraph 4). This method of printing has replaced the conventional process of high-vacuum deposition, which is much more time consuming. Nanosolar has taken the economics and processes of printing and applied them to the formation of solar cells and seems to have done so very successfully. Their process should make this type of solar cell electricity as cheap as the current electricity taken off the grid (Inslee & Hendricks, 2008). The National Renewable Energies Laboratory certifies that their solar cells have up to a 15.3% efficiency (Nanosolar Communications, 2009), which is comparable to conventional crystalline silicon cells. The product itself is also thin and flexible, which could be useful in a number of applications. Nanosolar's thin film cells are much more economical than traditional silicon cells, and they can be mass-produced very quickly thanks to the use of a printing process.

Konarka's Power Plastic uses not only inkjet printing but also a web press application in some instances. They use a type of coating process that is continuously rolled to get the right substrate combination of usable photographic film and organic polymers (Bullis, 2008). Though not exactly a printing process, this application is most definitely inspired by traditional web printing, and this is an important part of the process of the manufacture of Power Plastic.

Web press applications are fairly new to the photovoltaic solar cell industry, but they are playing a very important role in the ability of this industry to use mass-production processes. This ultimately makes the cells more economical, and in the case of Nanosolar, the cells are fairly comparable in efficiency. The use of web printing is definitely a help for the solar-cell industry

Conclusions

In these times of uncertain energy sources and with the impacts that they are having on the atmosphere, clean, renewable solar energy is a good alternative. However, it is still more expensive than methods used currently by consumers, and in order to be a viable option, it has to be attainable and affordable. With the use of different materials and thin film technologies, the use of photovoltaic solar energy for the average person is becoming more of a reality.

Printing processes have helped the photovoltaic solar industry by providing useful solutions to decrease manufacturing costs and increase the availability of these technologies to consumers. Screen printing has been used for years as a good option for metallization when producing traditional crystalline silicon solar cells, and it has more recently been used as the means of applying organic semiconducting dye to make photovoltaic solar cells. Inkjet printing is useful in the production of solar cells as both a new replacement for the screen-printing metallization and in the manufacturing of thin film solar cells. Even web offset printing has inspired some of the processes used to make thin film solar cells, and it is a very effective way to mass-produce these cells quickly. Each of these processes has helped to make solar cells more affordable and attainable.

Thin film solar cells would not be as widely produced and researched if it were not for the printing processes that helped make them as useful as they currently have become. Conventional crystalline silicon solar cells are efficient and have great longevity, but they cannot be used everywhere since they are rigid; they also are very expensive and resource intensive to produce. Thin film seems to be the direction that the people who make solar cells are heading, and if they can get equal efficiencies then there is no reason why these cells should not be used as replacements for conventional energy methods. Thin film cells also can be used on roofs, but they can also be placed just about anywhere and are more aesthetically pleasing, which would make them more marketable than conventional solar panels. There are a number of new developments in the photovoltaic solar industry, and with the help of processes inspired by the printing industry, this industry will continue to develop, and eventually PV cells will be a highly sought-after energy source.

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Sustainable Design: An Educational Imperative

David Klein and Ken Phillips

Abstract

This contribution presents a curriculum model and pedagogy for teaching sustainability concepts to industrial design students at the Metropolitan State College of Denver (MSCD). The curriculum provides students with instruction about low-impact material and process selection (renewable, toxic, embodied energy); energy efficiency (transportation, processing, use of product); quality and durability; design for reuse/recycling; and social relevancy/value, consumer value, responsible production/procurement (fair labor). Although the authors are aware of the interrelationship of these categories, they isolated each one to make them easier to teach, explain, and assess.

In our industrial design studio courses, sustainability and product life cycle assessment are established as design parameters for all projects throughout the curriculum. Sustainable principles are internalized as students devise practical design solutions. This pedagogy enables students to practice sustainability in relation to product design as they conduct product feasibility studies, design development, and production planning.

This article aims to advance design education by serving as an example of how sustainability may be taught and integrated into a curriculum and by providing case studies of completed student design projects.

Introduction

Design is concerned with the development of products, tools, machines, artifacts, and other devices produced on a massive scale, resulting in a profound and direct influence on ecology (Papanek, 2003). When design students are made aware of the context in which products are manufactured, they are more likely to consider barriers to sustainability outside of their usual parameters; increasingly resource-hungry technology, a culture that focuses on the short term, and pervasive advertising and marketing efforts aimed at increasing consumption. According to Orr (1994), "the truth is that without significant precautions, education can equip people merely to be more effective vandals of the Earth" (p. 5).

The traditional definition of sustainability calls for policies and strategies that meet society's present needs without compromising the ability of future generations to meet their own needs. Industrial designers make their living developing designs that meet the needs of the present, but are not always bound to consider future generations. They are integral components of a manufacturing system that maintains product flow, and they make decisions concerning the production processes and materials that, in turn, have the most impact on whether or not a product is sustainable. It is particularly important that industrial designers be aware of—or even be—champions for sustainable practices. Principles of sustainability can stimulate technological innovation, advance competitiveness, and improve quality of life. Sustainable development reflects not only the trade-off between business and the environment but also the synergy between them.

A responsible design educational program should help students realize that environmental protection does not preclude economic development and economic development must be ecologically viable now and in the long run.

True sustainability involves a wider range of issues than the design, manufacture, and disposal of industrially produced products. The numerous factors that contribute to a culture of consumption and consumerism beg to be considered, " . . . the urge to consume is merely symptomatic of a stimulus-hungry species dwelling in a homogenized and over-streamlined world where the prevailing mode of existence comes with the majority of problems already solved" (Chapman, 2005, p. 29). Designs embedded with meaning, those that stimulate consumers on a multitude of levels (functional, emotional, status reinforcement, etc.), are less likely to be victims of product replacement (Chapman, 2005). Notable exceptions to this concept are "technology" objects, like computers, whose existence relies on software and microchips that apparently require an update every two years, according to some.

Our Industrial Design program has developed a curriculum that addresses the following categories of sustainability concepts, listed in no particular order of relevance.

1. Low-impact, renewable, nontoxic material selection, minimal embodied energy requirements

2. Efficiency in transportation, consumer use, and manufacturing of products

3. Life cycle assessment

4. Product design that considers reuse/ recycle

5. Social relevancy of concept/product.

This article presents the pedagogy and curriculum utilized in teaching these sustainability concepts to industrial design students at MSCD.

Sustainability Issues and Industrial Design

The sum total effect of factors contributing to ecological impact of a product, or a society, may be cumulatively referred to as the "ecological footprint" that is "occupied." Plato may have been the first to acknowledge an ecological footprint when he realized that adequate human support cannot be fixed without consideration of the land and surrounding resources. Modern ecological footprint analysis is an accounting tool that enables us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area (Wackernagel & Rees, 1996).

It is especially important to recognize that economic and ecologic sustainability go hand in hand. There may, in fact, be capitalist motivations that spearhead efforts toward true long-term sustainability. Smart entrepreneurs, movers, and shakers invest their time and capital in endeavors that offer economic growth and prosperity, and long-term commercial success relies on acceptable environmental performance. Excessive resource depletion and pollution are disruptive and costly, and it can call into question the social responsibility of a company (Mackenzie, 1997). People are accustomed to thinking of industry and the environment as being at odds, because conventional methods of extraction, manufacture, and disposal have historically been destructive to the natural world. It is a condition that complicates efforts to achieve sustainability. "As natural as drawing breath, the urge to consume is merely symptomatic of a stimulus-hungry species dwelling in a homogenized world where the prevailing mode of existence comes with the majority of problems already solved" (Chapman, 2005, p. 29). But our environment is saturated with messages and images to remind us that we, indeed, need more. Studies have shown that the more people look outside of themselves as a way of satisfying needs (affluenza, peer approval, etc.), the less likely they are to have their actual needs met (Thorpe, 2007).
The "environmental crisis" is perhaps less an environmental and technical problem than it is a behavioral and social one (Wackernagel & Rees, 1996). But there is a need for playfulness and desire in our lives which consumer-led design helps to meet. It is the extent to which these products have become dominant that is troublesome. Papanek (1973) held that “in an age of mass-production when everything must be planned and designed, design has become the most powerful tool with which man shapes his tools and environment (and by extension, society and himself)” (p. 14).

Higher education has largely been shaped by the drive to extend human domination, to "manage" planet Earth to its fullest. Design competence requires the integration of first-hand experience and practical competence with theoretical knowledge (Orr, 1994).
Our leaders and technologists have been educated in a system that emphasizes theories instead of values, concepts rather then human beings, abstraction rather then consciousness, answers instead of questions, efficiency rather than conscience. This points to the fact that education itself is no guarantee of decency or wisdom. "It is not education, but that of a certain kind that will save us" (Orr, 1994, p. 8). Designers have not been taught in consideration of the larger social context and ecological impact, so they assume that their area of responsibility is limited to functional and aesthetic experiences (Mackenzie, 1997).
The value of contributing to positive social change emphasized by Papanek (2003) and others has more recently been downplayed in favor of form giving and branding. “The action of the profession has been comparable to what would happen if all medical doctors were to forsake general practice and surgery and concentrate exclusively on plastic surgery and cosmetics” (Whiteley, 1993, p. 99). In the end

“the most important ability that a designer can bring to their work is the ability to recognize, isolate, define and solve problems” (Papanek, 1973, p. 160).

Design approaches that embrace the natural world are perhaps more inherently sustainable. The branch of industrial design known as biomimicry begins with an examination of natural systems, particularly the many biomechanical characteristics found in nature. The rationale for this approach is the ideas that appropriate solutions for a given natural life form may provide inspiration for "natural" solutions to man-made problems (Birkeland, 2002). It also reinforces respect for nature and serves as a reminder that we are "of " nature, and not simply existing within it. Biomimics explore what works, and what lasts, in the natural world.

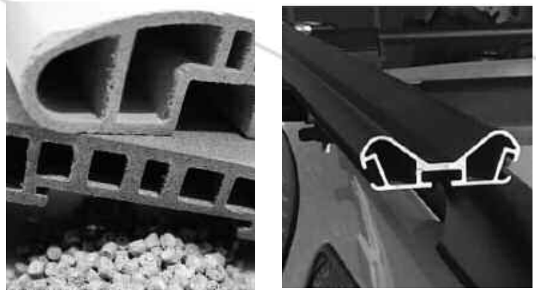
Figures 1 and 2.

The more our world looks and functions like the natural world, the more likely we are to exist in harmony (Benyus, 2002). Natural forms and patterns famously inspired design styles like Art Nouveau, but there is more to learn by studying the deeper underlying principles found in nature. Examples of biomechanical principles applied to product design include pliers based on the mechanics of the human jaw, Velcro based on the Burdock plant cockleburs, ball-and-socket joints based on the human hip joint, tensile fibers inspired by spiderwebs, and a drinking fountain that mimics a leaf form (Klein, 2010, Figs. 1 & 2). Designers can benefit in many ways by being students of the natural world.

Case Studies

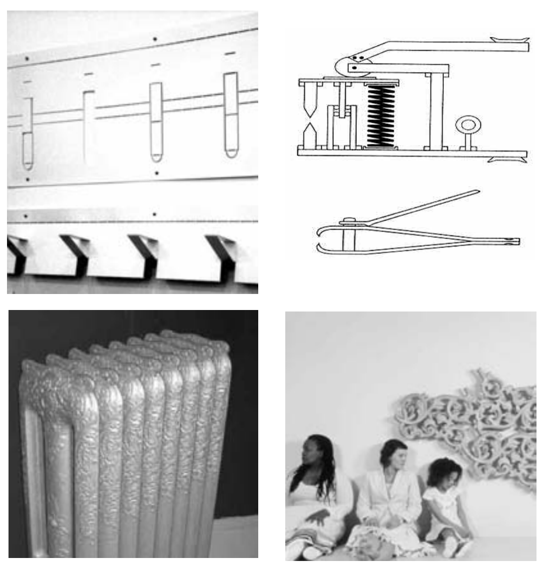
Designs that show particular sensitivity to each category of sustainability in our curriculum may provide further understanding of the underlying principles.

Wood-based materials utilized for extruded shapes (Guidot, 2006, p. 123, Fig. 3) are a



Figures 3, 4 and 5. *(clockwise from left)*

renewable material alternative to plastic and metal, while specifying aluminum alloys with low melting points (Rocky Mounts bike rack, photo by David Klein, 2010, Fig. 4. Reproduced with permission) reduces manufacturing energy in comparison to other metals. Using recycled aluminum reduces energy required in the bauxite mining process, although it also presents its own energy requirements. Industrial Designer Ali Tayar designed a chair that relies on a single extruded shape, placed in different positions in order to reduce the manufacturing and energy costs associated with multiple tooling dies (Terragni, 2002, p. 357, Fig. 5).



Figures 6–9. *(clockwise from left)*

Flat-pack designs conserve shipping space for improved efficiency in transportation. They often result in less material waste if cut shapes can be nestled (Coat rack by Blu Dot, www.bludot.com, Fig. 6. Reprinted with permission). The most effective steps toward efficient manufacturing are simplification of the design and reduction in the number of required components (Bralla, 1999). This idea is illustrated in a nail clipper design comparison by Professor Karl Ulrich, of the Wharton School (Bralla, 1999, p. 7.9, Fig. 7. Reprinted with permission). The recognizable design on the bottom is improved in respect to efficiency, functionality, and aesthetics.

The Heat Wave electric radiator for Droog by Joris Laarman, (Photographer: Robaard/Theuwkens, Styling by Marjo Kranenborg, CMK, Fig. 8. Reprinted with permission) offers increased surface for airflow opportunity so that more heat is obtained with less energy than the traditional design (public domain, Fig. 9). A more interesting aesthetic is also achieved, and less floor space is required.

Life cycle assessment of plastic cutlery reveals a life span that far exceeds functional requirements. Cutlery made from plant starch (www.ecoproducts.com, Fig. 10. Reprinted with permission) or semolina flour material (Designer unknown, Fig. 11) offers a sustainable alternative to petroleum-based plastic utensils and will decay in landfills more rapidly.

Figure 10.

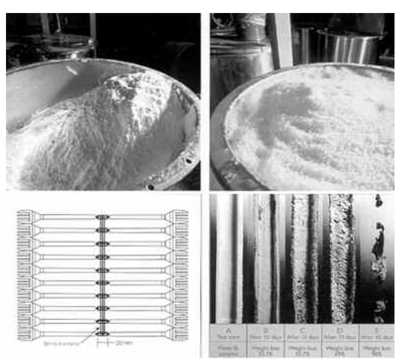


Figure 11.

The Heineken WOBO (short for WOrld BOttle) bottle never made it to the consumer market (Terragni, 2002, p. 418, Fig. 12). The concept of this bottle considered product reuse as a building "brick." The bottles were designed to fit modularly, with dimples on the flat surfaces to grip mortar.

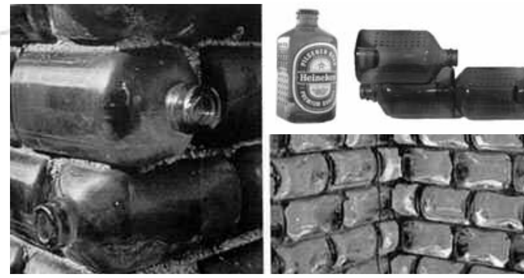


Figure 12.

The Hanger design offers an opportunity to reuse plastic bottles (Design by Xuan Yu , for the RE-think + Re-cycle competition at www.designboom.com, Fig. 13. Reprinted with permission). Even though such designs may not win wide public acceptance initially, it is more important that they provide inspiration for future designs that will.

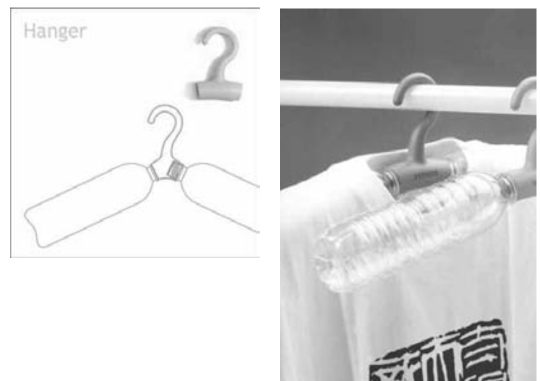


Figure 13.

The Mirra chair, produced by Herman Miller, represents an admirable model of sustainably produced furniture. The production line uses 100% green power (50% wind turbines, 50% captured off-gassing from landfills), and 96% of Mirra's content is specifically designed for recycle or reuse. The exceptions follow (courtesy of Herman Miller Inc., Fig. 14. Reprinted with permission).

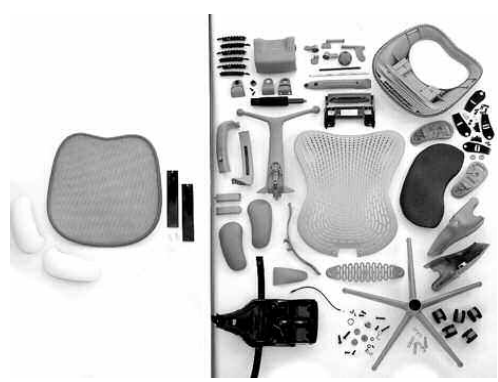


Figure 14.

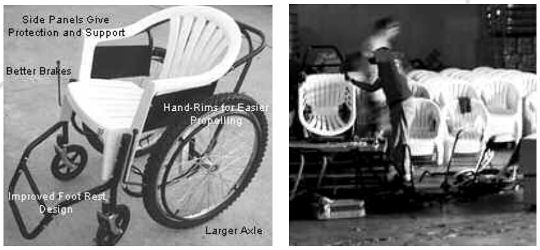


Figure 15.

The $50 wheelchair (actually $51.29) was designed by mechanical engineer Don Schoendorfer in 1999 and is distributed by his Free Wheelchair Mission (www.freewheelchairmission.org, Fig. 15). It utilizes many existing components in order to minimize tooling costs, and it helps to sustain the livelihood of people who otherwise would literally have to crawl from place to place.

The Tree bookshelf designed by Shawn Koh (www.designartist.co.kr, Fig. 16) reinforces the relationship between trees and books (paper comes from trees), encourages diverse reading through the use of diverse “shelf' shapes,” and inspires by making it fun to interact with books. Each of these designs illustrates social relevancy that can be achieved in designed, manufactured products.

Figure 16.

Pedagogy at MSCD

Sustainability and product life cycle assessment are among the design parameters for studio design projects. The principles are internalized as students devise practical design solutions that draw from myriad sources. This pedagogy requires students to consider and employ sustainability concurrently with product design/development, as opposed to a curriculum in which sustainability is taught isolated, in lecture courses. But we do offer specific information in an instructional format to facilitate students developing a background in the application of sustainability principles. These techniques include lectures and presentations about contemporary and historical models of sustainable design thinking; the use of required readings in the content area; discussions; workshops and presentations by outside experts; and the application of this information.

The goal of this instructional program is to enable students to make informed design decisions regarding sustainability issues for their product designs. In addition to this comprehensive goal, the department faculty has developed specific learning objectives. Upon completion of the Industrial Design program, major students should be able to:

1. Recall, discuss, and apply information about low-impact materials—renewable materials, awareness of material toxicity, and the relative embodied energy of materials.

2. Evaluate and choose design solutions that provide increased energy efficiency in transportation, consumer use of products, and manufacturing processes.

3. Identify and discuss components of life cycle assessment techniques and select design solutions for maximal product quality and durability.

4. Design products that facilitate their reuse or recycling at the end of their lifecycle.

5. Select product designs, materials, and processes that have a positive social impact.

Assessment is an important element of any instructional program. The evaluation of students in regards to the objectives listed above occurs in several ways. There is an embedded component in the evaluation/critique of student designs by faculty and professionals that occurs in studio classes. Sustainability concepts tied to the instructional materials are part of the overall assessment of student designs. There are embedded elements of assessment for these objectives in quizzes and tests for some courses where the specific instruction occurs, and an overarching component to the assessment of these objectives. The capstone design studio course and the senior internship are evaluated for a number of student performance categories reflecting sustainability objectives and overall learning objectives for students so they will be able to perform the practice of industrial design. This assessment is administered both by faculty and practicing professionals, and it provides key data for the ongoing evaluation of the program. These results direct faculty so they can continue to improve both curriculum and instructional practices so they will reflect the assessment data. The faculty believe that evaluating department students' ability to utilize informed sustainable design decisions should be addressed at the more global outcome level; this would allow for an assessment of the integrated whole of the lower level courses and objectives regarding sustainable design. Program-level assessment data regarding sustainable design is discussed in a later section of this article.

The Curriculum Model

Although the authors are aware of the interrelationship of the categories represented in the learning objectives, their curriculum isolates each one to make them easier to teach, explain, and assess. Working definitions of the topics included in the categories follow.

1. Low-impact renewable, nontoxic material selection with minimal embodied energy requirements.

The working definition in the curriculum describes low-impact renewable materials as those that can be derived from agricultural crops (grown for nonfood uses) and from other plant or animal sources. They are renewable because they can be used and replaced without irreversibly depleting reserves; this property also makes them a valuable resource in combating climate change. Nontoxic material considerations delineated in coursework are based on the premise that "toxicity" refers to a material's ability to harm living things and at what level of exposure (White, St. Pierre, & Belletire, 2007, p. 17), Issues of concern for designers in relation to product consumer use addressed in the curriculum are: out-gassing issues, the use of carcinogens-materials considered capable of causing cancer, mutagens or materials that induce genetic changes in the DNA of chromosomes, and teratogens, a material or agent that causes physical defects in a developing embryo (www.epa.gov/enviro/html/emci/chemref). An awareness of research methods into material toxicity issues, the use of material safety data sheets, and material toxicity concerns in the manufacturing process are also addressed.

As presented in course lectures, embodied energy refers to the quantity of energy required to manufacture, and supply to the point of use, a product, material, or service. Embodied energy considers the energy requirements for materials from the raw material extraction, to transport, manufacturing, assembly, to produce a service or product, and finally to bring about its disassembly, deconstruction and/or decomposition. (White, St. Pierre, & Belletire, 2007).

2. Efficiency in transportation, consumer use, and manufacturing of products.

Transportation issues are discussed and emphasized, including the use of flat-pack designs and ready-to-assemble products. Packaging for shipping container efficiency, and product weight considerations are addressed. Energy considerations in regard to the consumer use of products are addressed in design discussions. Possible design solutions that utilize hand-power options, low-energy-consuming bulbs, auto shut-off features, and others are encouraged.

Manufacturing processes are important topics in the curriculum because they require so much energy, comprising as much as 80% of industrial energy use. Manufacturing plays a big role in U.S. energy use. Industry accounts for around 30% of the total, and manufacturing is responsible for around 80% of industrial use (Halber, 2006). The ability to research the energy requirements for different manufacturing processes is developed through the coursework.

3. Life-cycle assessment (LCA)

A critical challenge for designers is to embrace the "material trail" of their work. Awareness of the true amount, type, and source of materials behind their designs is a good step toward understanding the challenges of ecological sustainability (Thorpe, 2007). The question, "Paper or plastic?" posed by the grocery store clerk, actually opens up myriad questions and concerns that experts are continuing to debate over. In the end, it is best to bring a reusable bag, and answer "neither."

Because of the multiple factors and complexities in making decisions about design based on LCA, there are most often no clear "correct" answers. Challenges and opportunities may be realized in comprehensive product life-cycle assessments, but at the undergraduate level such complex assessments are difficult to construct and evaluate. It is the authors' aim to introduce the guiding concepts behind such detailed analysis and make students aware of the complexities that contribute to truly sustainable industrial design.

4. Product design that considers reuse/recycle

An assumption that guides the curriculum in this category is that a potential route to an environmentally friendly design solution is to extend product life through designs that allow repair and reuse. When the product is no longer usable, the materials and components can be recovered through recycling. Reuse is the recovery of materials and/or components for similar or alternate end use. Recycling turns materials that would otherwise become waste into resources for remanufacture in new products.

Authors of Cradle to Cradle (McDonough & Braungart, 2002) have referred to recycling as down cycling, as it reduces the quality of a material over time (and increasingly over multiple recycles). In some cases using materials that were never designed for their new application, reprocessing them into a new form, may require as much energy—and generate as much waste—as employing virgin materials, but without reliable, known characteristics (McDonough & Braungart, 2002). The trend in U.S. industry, and the U.S. EPA, is toward preventing wastes before they are created instead of treating, disposing, or reprocessing them later (Ciambrone, 1997). This is an indication that currently in industry many are realizing that the impact their products have on the environment is not limited to the manufacture of a product.

5. Social relevancy of concept/product

It is good for designs to be thematically pointed toward solutions that have positive impact on people and society. Designers must work to replace semantically loaded expressions as “beautiful,” “ugly,” “cool,” “cute,” and so on, with words like “meaningful” (Papanek, 1973, p. 25). It is important for ecologically intelligent products to be meaningful and to be at the forefront of human expression (McDonough & Braungart, 2002). Many examples of new technology and devices have languished because they were ahead of their time, including pneumatic tires, the laser, and fluorescent light bulbs (Volti, 2006). It is not enough for sustainable solutions to simply exist. There must be a desire for them. Their end should elegantly glorify their means.

Specific Curriculum

Currently, multiple courses deal with the topics regarding the above sustainable design considerations. In analyzing the instructional coverage of these topics the department has found it beneficial to chart the courses that address each topic, and to what extent. A matrix was developed that indicates where the topics are introduced (I), where they are reviewed and reinforced (R), and where the students demonstrate (D) application of the concepts. While the specific pedagogy may vary from faculty to faculty as course assignments change, the matrix representing these instructional steps remains in place. Assessment results may indicate the need for change over time, but Table 1 illustrates the current curricular plan.

Examples of how we address a specific sustainable design topic through the curriculum

Information about renewable materials and associated considerations are introduced initially in the materials courses. Students are made aware of the renewable nature of certain materials and are given information on available “green” materials. For example, in the

Table 1.

Sustainable Design Topics in Required Courses	Materials Classes	Manufacturing Materials and Processes Class	Beginning ID Studio	Intermediate ID Studio	Design for Production	Advanced ID Studio	Professional ID Studio	Concept and Portfolio Design	Professional Internship
Renewable materials	I	R	R	R	R	R	D		D
Material toxicity	I	R	R	R		R	D		D
Embodied energy	I	R	R	R		R	D		D
Transport efficiency			I	R		R	D		D
Consumer energy use			I	R		R	D		D
Efficient manufacturing processes		I	R	R	R	R	D		D
Life cycle assessment			I		R	R	D		D
Re-use/recycle	I	R	R	R	R	R	D		D
Positive social impact			I	R		R	D	R	D

I= Introduced
R= Reviewed and reinforced
D= Demonstrates application/integration in design solutions

department's Introductory Woodworking classes students are introduced to the industrial materials available for wood-based designs as well as how to price, specify, and order those materials. As a part of these presentations the use of green materials, such as FSC certified lumber and alternative quick growing resource sheet materials (bamboo and Kirei sorghum-based board), and sources for recycled lumber are relayed to the students. These considerations of renewable material use are reviewed and reinforced as they pertain to manufacturing processes in the department's manufacturing materials and process class. The same concepts are addressed with prompting from instructors as students address design problems in the lower level studio sequence classes and also the design for production class in regards to material selection. Students are expected to demonstrate an ability to apply renewable material considerations in the capstone studio class and during their internship placements.

Program Assessment of Sustainable Design

Our department believes that sustainable design should be assessed at the more global, program outcome level. Assessing them at the course level downplays the value of true integration of sustainability into the wider pedagogy and curriculum. We seek to integrate rather than separate this important subject matter. This section reports on the program assessment results regarding sustainable design. The Industrial Design program utilizes three different data-collection methods, which are tied directly to the program's student learning outcomes, and it provides evaluators with an opportunity to provide input on all of them. The data-collection instruments are utilized by internship supervisors, faculty, and professionals observing senior presentations; student interns use it for self-evaluations regarding how well the program has prepared them. The three instruments evaluate students at or near the end of the program and thus can assess the integrated nature of the sustainability outcome. Although there are seven overall program-level learning outcomes, the instruments expand those outcomes into 22 elements for an improved ability to address specifics. Sustainable design is one of the 22 elements that are assessed each year as part of the regular program assessment process.

The department has instituted a minimum target score of 80% (or 3.2 on the 4-point scale) on the evaluation instruments. This is consistent with faculty expectations of meeting standards to succeed in the profession and represents what the faculty believe is an appropriate expectation for student achievement. The current data-collection instruments have been in place for two years. Though this report will include comments comparing this year's scores to last year's data, it is probably premature to identify clear trends from this limited sample. Figure 17 shows the current level of achievement regarding student knowledge and application of sustainable design concepts. The data show a trend toward improved scores for student achievement, over the relatively short time span of two assessment cycles.

Conclusions

An academic institution's approach to teaching sustainability will vary widely

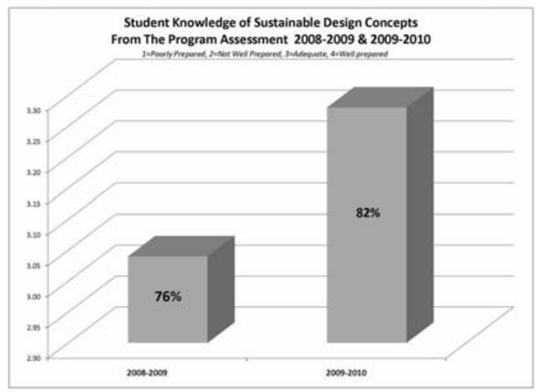


Figure 17.

depending on the clientele that it serves and the context in which the institution exists. Given our program's context and the nature of our student body, the most appropriate focus for our program is on the material, technical aspects of ecological solutions that may be readily applied. The department exhibits a commitment to the concept of sustainable design with ongoing work to educate students and encourage appropriate sustainable design solutions. The ongoing program assessment data will direct instructional and curricular adjustments to improve the current pedagogical strategies for this vital design imperative.

*This article is based in part on a conference paper presented at the NCIIA 13th Annual Meeting on March 19-21, 2009. Washington DC.

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Toward a Zero Energy Home: Applying Swiss Building Practices/Attitudes to U.S. Residential Construction

Daphene C. Koch, William J. Hutzel, Jason M. Kutch and Eric A. Holt

Abstract

This project evaluated typical U.S. and Swiss homes to identify construction practices that are most energy efficient and have economic payback. A net zero energy home (ZEH) produces as much energy as is consumed in it over time. Students in a College of Technology in a Midwest Indiana State University and a technical University in Switzerland resulted in developing models of homes that combined U.S. and Swiss standards. The project was completed in two phases: during the first phase of this project, construction costs, energy use, and economic payback was calculated for six homes that were designed using both Swiss and U.S. standards. During the second phase of the project, cultural norms that influence energy use were explored. A survey was used to compare U.S. and Swiss college students' lifestyles and energy habits. All homes had the same basic size and layout, but some used construction practices typical for the United States and others were designed according to Swiss guidelines for residential construction. The results of the study showed that a Swiss-style low-energy home is not cost effective for the Midwestern United States if energy costs remain low, but it could become attractive if energy rates escalate significantly. It was also recognized that technology by itself will not minimize energy consumption, a result of the second part of the project that explored cultural norms that influence energy use. From the survey of both U.S. and Swiss college students' lifestyles and energy habits, it was revealed with a high level of confidence that Swiss students are more energy conscious than their U.S. counterparts.

Introduction

This project evaluated typical U.S. and Swiss residential design to identify construction practices that are most energy efficient. The analysis reviewed current best practices in both countries along with an evaluation of attitudes toward energy use by individuals. In the United States an Energy Star system is being used to model homes. Energy Star is an umbrella of voluntary programs started in 1992, which ran as a joint program since 1996 with the U.S. Environmental Protection Agency (EPA) and the DOE to improve energy efficiency of homes (Banerjee & Solomon, 2003). The Swiss method of building a sustainable home is the Minergie System (Minergie, 2010). Zero Energy Homes (ZEH) have been built in Japan, Sweden, Germany, Norway, Austria, and the United States. Unfortunately, there is no real database to centralize information to globalize the adoption of successful homes worldwide (Charron & Athientitis, 2005). To add to the existing body of knowledge, this project reviewed the importance of moving toward ZEH homes, and the current practices and attitudes of the United States and Switzerland toward energy efficiency. The research modeled six variations of designs that incorporated the Energy Star and Minergie systems.

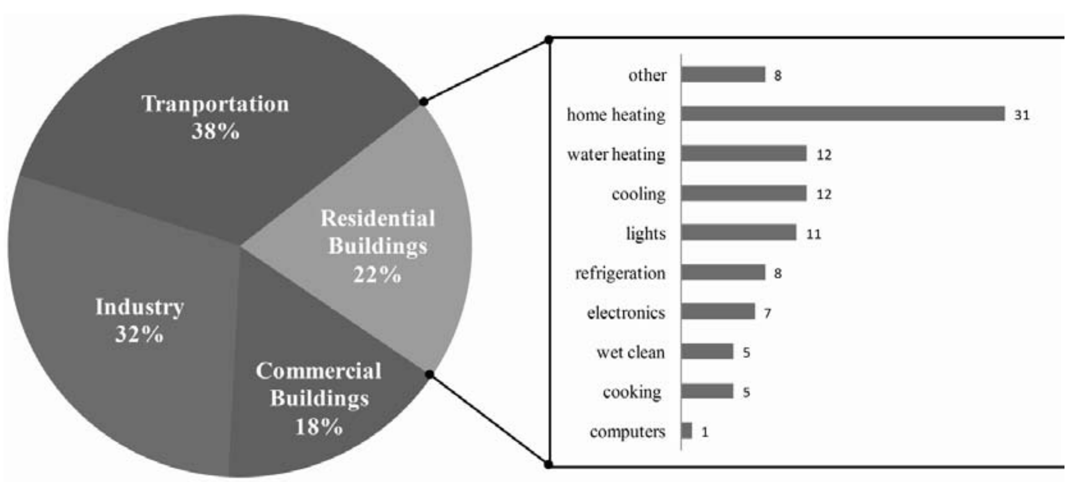

Figure 1. Energy Usage by Sector Including Detail for Residential (*Energy Star, 2010; Perez-Lombard, Ortiz, & Pout, 2008*)

Figure 2. Swiss Masonry Walls (left) and U.S. Wood-frame Walls (right) *(photos by authors)*

Significance of Energy Consumption

The International Energy Outlook (IEO) report projects that the world energy consumption is expected to expand by 50% in 2030 (Energy Star, 2010). Residential buildings account for 22% of the primary energy use according to the Energy Information Administration (EIA, 2008). Within residential buildings, space heating and water heating (both natural gas and electric) are the biggest opportunities for energy savings. Figure 1 details the exact usage of electricity in the home. It shows that most energy is used for heating (home and water), lighting, and cooling. These should be the initial targets to better design a home.

The Department of Energy (DOE) started a program, “Build America,” with a goal of reducing whole-house energy use for new home by 50% by 2015 and 95% by 2025 (Anderson & Horowitz, 2006). The Build America initiative targets significant improvements to the building envelope (the makeup of the walls, roof, and floor) through better insulation and sealants, and major reductions in electricity through using highly efficient appliances, lighting, and mechanical systems. The remaining energy for achieving net-zero will be supplied by a renewable energy source, such as solar or wind.

Residential Construction Standards in the United States and Switzerland

A detailed inspection of the Swiss and U.S. homes showed fundamental differences in construction techniques. Figure 2 shows photos taken by the students to document the typical systems used in each country. The Swiss building standards are more similar to U.S. commercial standards of building with heavy use of a thick masonry brick-type component. This creates more thermal mass than the typical U.S.-style wood-frame home. Significant attention in optimizing the building envelope in terms of insulation, air sealant, and efficient windows is a component of the Swiss system. The highly efficient mechanical systems included air-to-air heat recovery, radiant slab heating and cooling, and solar domestic hot water in Swiss homes, which is currently utilized in more commercial applications in the United States.

Typical Swiss home are built using a masonry type of material, which does not exist in the United States. A Swiss home also typically costs more than $600,000 (U.S.) to purchase, and in Switzerland, most people do not own homes, but rather inherit them.
The U.S. has produced affordable housing using wood-frame construction. This vast difference in materials used for homes resulted in the development of a typical midrange U.S. home layout that was developed to be used for modeling the standards of Minergie and Energy Star. Figure 3 shows the standard home layout

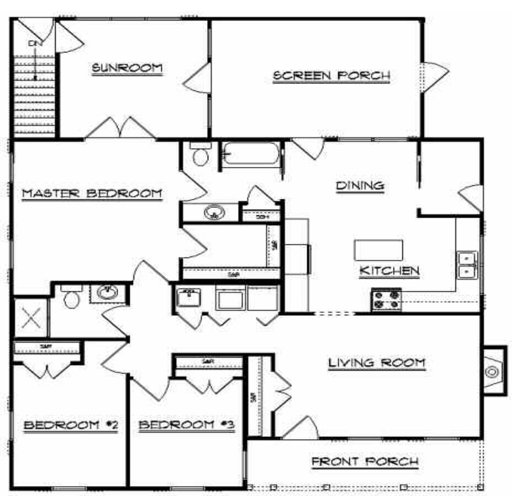

Figure 3. Floor Plan of Typical Midrange U.S. Home *(plan produced for research project)*

Table 1. Major Specifications for Six Residential Construction Models

Construction Category	Wall R-value (R_{SI})	Attic R-value (R_{SI})	Heating	Solar for Hot Water
Standard U.S.	11 (1.94)	30 (5.28)	Gas - 80% AFUE 80 MBtuh (23.4 kW)	No
Energy Star	19 (3.35)	50 (8.81)	Gas - 92% AFUE 80 MBtuh (23.4 kW)	No
Standard Swiss	19 (3.35)	38 (6.69)	GSHP - 5.0 COP 40 MBtuh (11.7 kW)	No
Minergie	30 (5.28)	50 (5.28)	GSHP - 5.0 COP 36 MBtuh (10.5 kW)	Yes
Hybrid Energy Star	19 (3.35)	50 (8.81)	GSHP - 5.0 COP 40 MBtuh (11.7 kW)	Yes
Hybrid Minergie	30 (5.28)	50 (8.81)	Gas – 92% AFUE 80 MBtuh (23.4 kW)	No

that was developed to standardize comparisons of different characteristics of homes.

A single-family home with one story and a conditioned unfinished basement was used because this type of construction is found in both countries. The floor plan included three bedrooms, two bathrooms, one walk-in closet, a living room, a dining room, a kitchen, a sunroom, a screened-in porch, and a front porch: it totaled 1,504 ft2 (139.7m2). Four exterior doors account for approximately 100 ft2 (9.3 m2) of surface area and the windows equaled approximately 237 ft2 (22 m2); the majority of the windows face south, which provides additional heating during the winter. The above-grade wall surface area is approximately 1400 ft2 (130 m2).

The basis of the project was to differentiate the Energy Star and Minergie building standards, but it was found that in the United States not all of the Swiss standards were realistically applied. Table 1 identifies six different combinations of residential construction identifying the wall and attic insulation, heating, and application of solar hot water heating. These are the major characteristics of the home that were modeled to evaluate using the standardized floor plan. The combinations range from the least energy efficient design, standard U.S. home, to the standard Minergie home of Switzerland.

The insulating value of the walls and attic in Table 1 is expressed in terms of an R-value. Two systems of units are shown. The U.S. customary R-value has units of ft2-°F-hr/Btu. The conversion to comparable SI units is 5.68 ft2-°F-hr/Btu equals 1.0 m2-°C/W. Table 1 shows the U.S. R-value first, with the SI version (labeled RSI) in parentheses. The exterior walls of the "Standard U.S." home have R-11 (1.94 RSI) insulation, whereas the attic has an R-30 (5.28 RSI). Heating is provided by a natural gas furnace rated at an annual fuel utilization efficiency (AFUE) of 80% with a capacity of 80 MBtuh (23.4 kW).

Modeling U.S. and Swiss Homes

A software tool, RemRate, was used to analyze energy use. RemRate is an easy-to-use computer program for residential construction that calculates heating, cooling, hot water, lighting, and appliance loads. Certified energy auditors use the program to determine whether a new home design meets the requirements for

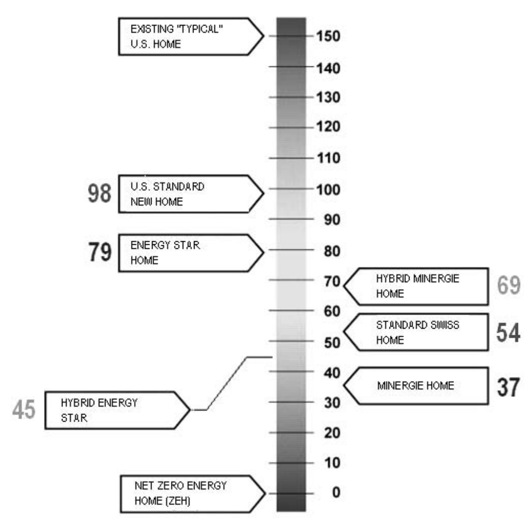

Figure 4. HERS Index Ratings for Research Model Homes *(developed by researchers)*

Table 2. Construction and Utility Costs for Each Category

Construction Category	Construction Cost ($)	Annual Energy Cost ($)
Standard U.S.	141,546	$2,356
Energy Star	144,848	$2,088
Standard Swiss	161,932	$1,838
Minergie	164,013	$1,242
Hybrid Energy Star	152,148	$1,475
Hybrid Minergie	156,713	$2,095

U.S. Energy Star certification. RemRate includes climate data for cities and towns throughout North America. The analysis for this project was conducted in a Midwestern city, which is classified as a cold climate according to DOE's Building Technologies Program (Polly et al., 2011). The winter design temperature used was -5 °F (-20.6 °C) and a summer design temperature is 93 °F (-33.9 °C).

The RemRate software also predicts annual utility costs when rates are provided.
This project assumed utility rates that are typical for an area, but low compared to the rest of the United States. Electricity was $0.10 / kilowatt-hour (kWh). Natural gas was $1.50 / hundred cubic feet (CCF). During the economic analysis, an energy escalation rate of 3% annually and a discount rate of 1% were used as the baseline. These assumptions are significant because different locations in the U.S. have different energy rates, potentially affecting the economic analysis. This case study is valid for this location.

RemRate also provides a Home Energy Rating System (HERS) Index for a given home (Energy Star, 2009). Figure 4 shows the HERS scoring for the model homes in this project. HERS is a scoring system in which a home built to the specifications of the HERS Reference Home (based on the 2006 International Energy Conservation Code) scores a HERS Index of 100, while a net-zero energy home scores a HERS Index of 0 (Judkoff & Neymark, 1995). The lower a home's HERS Index, the more energy efficient it is in comparison to the HERS Reference Home. There are no units intrinsic to the HERS Index; it is a relative scale between 0 and 100.

The standard U.S. home scored 98 with an improved score of 79 for the Energy Star home. In contrast, the Standard Swiss home scored a 54, whereas the low-energy (Minergie) version scored a 37. The Hybrid Minergie and Hybrid Energy Star homes scored a 69 and a 45, respectively. These numbers indicate that the mechanical systems in the Minergie home played a major role in reducing overall energy consumption. The impact of the Swiss building envelope was less important.

Payback Analysis

Estimates of energy consumption do not provide a complete picture of overall performance. An energy efficient home is not a worthwhile investment unless the utility costs are reduced by a corresponding amount over the life of the home. To calculate actual life cost analysis, an estimate of the construction costs of the six home models was conducted. Table 2 summarizes the costs for both construction and annual energy costs. The land is not included because it would be the same for each home category. The standard U.S. home has the lowest cost at $141,546, but it also has the highest energy costs $2,356. The Swiss Minergie home

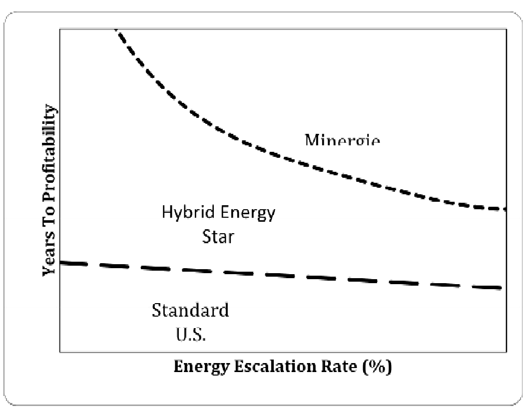

Figure 5. Economic Payback as a Function of Energy Escalation Rate

is more expensive ($164,013), but it would operate on an annual basis of only $1,242.

Figure 5 summarizes the results of a payback analysis that considered the costs for the various housing options as a function of energy escalation rate. The vertical axis of the graph is the time period in years where various housing options are most economical. A discount rate of 1% was assumed for all computations. Only three of the six possible housing options appear in Figure 5, because those are the ones that achieved the highest savings.

The Standard U.S. home would be the most cost effective option until year 13. The lower construction costs offset the larger energy expenditures for the first 13 years of home ownership. At that point, the Hybrid Energy Star would become cheaper and remain so until year 43. After year 43 the Minergie option would become the most cost-effective option. These examples show that more expensive and energy efficient housing options become attractive if energy rates increase sharply. As an extreme example, at a 10% annual energy escalation rate the more expensive Hybrid Energy Star home would become cost effective after 10 years. A Swiss-style Minergie home would be the best choice after 22 years.

Before the volatility of the real estate market began, people in the U.S tended to move frequently, so a home that is less expensive in terms of first cost is cost effective despite the higher energy costs. In contrast, a Swiss home is a once-in-a-lifetime investment, so it makes sense to invest in something that is cost effective over a much longer time period. It is also interesting that the Hybrid Energy Star option is cost effective between roughly 10 to 20 years of home ownership. This is the option that includes the building envelope of a U.S. Energy Star home with the mechanical systems of a Swiss Minergie home. This result shows that for this simplified analysis it was easier to justify the cost of improved mechanical systems as opposed to investing in a highly insulated building envelope.

Attitudes Toward Energy by Culture

Recognizing that technology by itself will not minimize energy consumption, a second part of the project explored cultural norms that influence energy use. A survey of U.S. and Swiss college students compared lifestyles and energy habits. Data was collected from students in comparable undergraduate thermodynamics classes at both a Midwestern U.S. university and a Swiss technical school. The survey included 58 U.S. students and 28 Swiss students. The difference in the size of the two student populations is directly related to the enrollment of the two academic programs.

The U.S. students were juniors; approximately 20 to 21 years of age, whereas the Swiss students were approximately 25 years old. The Swiss students were older because of a 4-year professional internship requirement before the formal academic training. This simple survey was not able to account for how differences in age and professional experience affect the results. One other potential flaw is that the survey was delivered in written English to both student populations. Although the Swiss students were generally fluent in both Swiss-German and English, there could be translation issues that the researchers were not aware of. The survey questions were kept simple, and visual cues were included on the survey form to make it easy to interpret. However, the survey did not specifically evaluate how proficiency in English affected the data.

Three broad areas were evaluated. One set of questions targeted basic expectations for housing in terms of size, style, cost, and so on. A second set of questions evaluated overall energy awareness and whether energy efficiency

Table 3. Sample Questions About Housing

Housing Options	Swiss		U.S.	
	Median	Mode	Median	Mode
What age (years) do you expect to be when buying your first	35	35	25	25
What is your expected price for your first home?	$600,000	$1,000,000	$150,000	$150,000

Table 4. Questions About Energy Awareness

Energy Awareness	Category 1	2	3	4	5
How important is it to shut off your computer at night before going to bed?	Not Important	Not Interested	Neutral	Interested	Very Important
How important is it to you to recycle (e.g., Glass, Paper, or Plastic)?	Not Important	Not Interested	Neutral	Interested	Very Important

is an integral part of a student's lifestyle. The third set of questions considered how energy awareness affected day-to-day decisions. The results of this brief survey revealed some substantial differences that begin to highlight how social norms can impact energy conservation.

The survey of Swiss and U.S. students included 21 questions. Many, but not all questions, were expressed as a 5-point Likert-type item. Table 4 is a sample of the survey results related to housing. These questions show how expectations for home ownership vary between Swiss and U.S. college students. The median age for achieving home ownership varied dramatically. Swiss students expected to buy their first home by age 35, whereas most U.S students expected to purchase their first home by age 25. Several Swiss students actually reported "never" in terms of home ownership, which supports the observation that long-term apartment living is relatively common in Switzerland.

Table 3 also shows that the student-reported median home price in Switzerland was $600,000, while the median was only $150,000 in the United States. As reported previously, the higher costs in Switzerland are driven by significantly different construction standards. A typical Swiss home is built for a design life of 100 years, much longer than one in the U.S. The striking cost difference is also in part because of the value of land in Lucerne, Switzerland, as compared to land in Midwestern United States. The Swiss culture dictates that a home is a significant once-in-a-lifetime investment, and homes are often passed down from one generation to the next. It makes good sense for the Swiss to wait until they are able to afford a substantial home purchase. In contrast, homes in the U.S. were a relatively short-term investment.

Table 4 is a sample of questions evaluating overall energy awareness. Students were queried about the importance of shutting off electrical appliances and recycling. For each question, students were asked to respond to a 5-point Likert-type item indexed from "not important" to "very important." The goal of these survey questions was to discern whether students have a personal commitment toward sustainability.

Table 5. Results Related to Energy Awareness

Energy Awareness	Swiss Median	Swiss Mode	U.S. Median	U.S. Mode
How important is it to shut off your computer at night before going to bed?	4	5	2.5	1
How important is it to you to recycle (e.g., Glass, Paper, or Plastic)?	4	4	3	4

Table 6. Sample Questions About Lifestyle Impacts

Lifestyle Impacts	Category 1	2	3	4	5
How willing would you be to walk 10 blocks during the winter or summer in order to save gasoline?					
How happy would you be to not have air conditioning at all in your residence during the summer?					

The results shown in Table 4 illustrate some of the reported behavior patterns. Swiss students ranked the importance of turning off a computer much higher than their U.S. counterparts. The median value for Swiss students was 4, and the median value for U.S. students was 2.5. The two student populations responded in a similar way to the survey question that dealt with recycling. The rankings by both Swiss and U.S. students suggest that this topic has become part of the student culture. It has been observed that most U.S. students have grown up with recycling programs in their homes and schools.

Table 6 is a sample of the survey questions that evaluated the lifestyle impacts of energy conservation. The goal was to discern whether students make a conscious effort to engage in activities or behaviors that conserve energy. Rather than a scale in written English, emoticons were used. The simple facial expressions used in the survey and shown in Table 6 convey the same categorical information while avoiding the subtleties of written English.

Table 7 shows some results from the part of the survey that targeted lifestyle impacts. The first lifestyle question showed that Swiss students were more amenable to the prospect of walking 10 blocks (on the order of one mile) to save gas. The median and mode responses were a 4 for Swiss students and a 3 for U.S. students.

The second lifestyle question explores the importance of air conditioning in the summer. Stark differences between Swiss and U.S. students were noted on this question. The median answer for Swiss students was a 4.5, which implies that summer air conditioning is not mandatory. The median response for their U.S. counterparts was a 2, meaning that summer air conditioning is an expectation for day-to-day living.

The air conditioning question reveals significant lifestyle differences. Many Swiss residences have a limited amount of air conditioning, due in part to a moderate climate noted in Table 1, but also because of differences in comfort expectations and regulations on residential electricity consumption. It is probably not a coincidence that many Swiss people take a month-long holiday in August, when apartment life without air conditioning could become very uncomfortable.

What is the overall message from this survey of Swiss and U.S. students? Is there an

Table 7. Results Related to Lifestyle Impacts

Lifestyle Impacts	Swiss Median	Swiss Mode	U.S. Median	U.S. Mode
How willingly would you be to walk 10 blocks during the winter or summer in order to save gasoline?	4	4	3	3
How happy would you be to not have air conditioning at all in your residence during the summer?	4.5	5	2	1

underlying theme that sheds light on differences in residential construction practices? An effort was made to consolidate the survey results by computing an "energy consciousness quotient." This is an informal term that combines the three major survey topics (housing options, energy awareness, and resulting lifestyle impacts) in order to directly compare Swiss and U.S. students in terms of lifestyle differences that impact energy use.

The results of selected survey questions were combined into a scale with a range from 0 to 100%. The mean value for this "energy consciousness quotient" for the Swiss students was 85.5%, with a standard deviation of 0.51. The mean for U.S. students was 71%, with a standard deviation of 0.83. Statistics were applied to see whether the difference between the two values was statistically significant. T-statistic calculations showed with 99.9 % confidence Swiss students have a higher "energy consciousness quotient" than their U.S. counterparts.

The "energy consciousness quotient" is an interesting parameter. Within the population surveyed it probably does a reasonable job of quantifying to what extent energy conservation has an impact on student lifestyles. It was encouraging to document that both student populations consider energy conservation as part of day-to-day living. It is not surprising that Swiss students rated higher in this regard, probably because of simple economics. Costs for fuel, electricity, and other energy resources are typically higher in Switzerland.

Conclusions

This research analyzed six different residential construction models using Swiss and U.S. metrics. It was found that a Swiss home built in Indiana would be more expensive, yet more energy efficient than the other homes in its neighborhood. Typical U.S. construction techniques are cost effective during the short term. However, Swiss low energy construction becomes a better investment after longer periods of home ownership. A brief survey of students noted cultural, lifestyle, and economic differences that might also help explain the differences in construction standards.

Changes in energy policy and technology could affect some of the trends noted in this article. In the United States, federal tax credits for investments in residential energy efficiency, such as windows or insulation, have been popular. Future research could be completed utilizing this as a method to review possible zero-energy and energy efficiency techniques. European countries have more historic data that could be applied to the research of energy efficiency in the United States in the future.

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Design, Operation, and Analysis of a Floating Water Fountain System Using Renewable Energy Technology

Hans Chapman, Eduardo Gomez, Nilesh Joshi, and Sanjeev Adhikari

Abstract

Engineering and technological applications of renewable energy installations, such as photovoltaic (solar) energy, are making important contributions toward the development of environmentally friendly products and processes for a more sustainable future. This article presents the design, assembly, and operation of a solar powered floating fountain system for analysis of aeration in stagnant water. The goal was to increase the level of dissolved oxygen in a body of water by harnessing solar energy for submerged aeration. The system is composed of six solar panels, a kit of batteries, a linear current booster, pressurized water tank, two pumps, an air compressor, and a float. The design factors for dissolved oxygen (DO) measurements were determined from depth of water, time of the day, location of fountain, and status of fountain (on or off). A Split Plot design was used to investigate the performance of the fountain, based on the changes in levels of DO in the pond. Statistical analysis showed a 120% gain in DO concentration during a 20-day period with significant destratification of the pond. This applied research will be of interest to engineers and technologists in various areas, including environmental development, green construction, and aquatic and energy conservation.

Keywords: Renewable Energy Technology, Solar Powered Fountain, Aeration, Dissolved Oxygen.

Introduction

Photovoltaic (PV) renewable energy systems offer new alternatives for consumers and businesses as to how power can be provided. PV systems react to light by transforming part of the radiant energy into electricity. PV cells require no fuel to operate, produce no pollution, require little maintenance, and are modular. These attributes permit a wide range of solar - electric applications (Markvart, 1999; Marshall & Dimova-Malinovska, 2002; Dunlap, 2010). Other advantages of PV systems include: unlimited input solar energy, reliable power output, flexibility in assembly, and easy installation (Boyd, 1997; Butler & Sinton, 2004).

Pumps are useful devices for the operation of water fountains. Fountains are installed on water bodies, like ponds, streams, and lakes, to prevent destratification of the water (Michaud & Noel, 1991; Lynch & Commer, 1994). Water pumping is one of the most competitive areas for PV power. PV pumping systems pump most water during the sunniest, hottest days of summers. PV pumping systems have, as a minimum, a PV array, a motor, and a pump. In addition to water pumping, PV systems can also be useful for aeration of water bodies.

Natural stream purification processes require adequate dissolved oxygen levels in order to provide for aerobic life forms. When pollution enters a body of water, plant and algae die and sink to the bottom, resulting in an overload of organic sludge. A lower form of life in lakes and ponds die and this debris eventually rots. Oxygen solubility has been shown to increase with decreasing temperature, salinity and pressure (Wieland & Kühl, 2006). When dissolved oxygen (DO) is at saturation level, the number of oxygen molecules leaving the water surface equals the number entering (no net movement) (Michaud & Noel, 1991). Below DO saturation, there is a net movement of oxygen from atmosphere to water. The greater the difference between the oxygen pressures in the water and the atmosphere, the larger the movement of oxygen from the atmosphere to the water.

System Design

The solar powered water fountain (SPOWF) was designed to enhance dissolved oxygen levels in a test pond at Innovation Park, Tallahassee, Florida. The three primary components for producing electricity using solar power are: solar panels, a charge controller, and batteries. Solar panels charge the batteries, and the charge regulator or linear current booster (LCB) ensures proper charging of the battery. The system was designed in two main parts (the fountain and the aerator). The water fountain adds oxygen to the water body by exposing the water to the external air. The aerator provides air bubbles into the body of

Table 1. Loads and Their Electrical Ratings for the Fountain

Description	Volts	Amps	Watts	Amp –hour /day
Submersible pump	24	4	96	48
Surface pump	24	6	144	72

water by using an air supply line from an air compressor. A different electrical circuit was designed for each part. The required solar panels and batteries were placed onshore and the loads were located offshore. The loads of the fountain include a submersible pump, a surface pump, and the air compressor.

Design of the Fountain

The fountain design consists of (i) solar array, (ii) deep cycle batteries, (iii) pumps, and (iv) pressure tank. The loads for the fountain are shown in Table 1.

The number of solar modules in parallel required was 3. It was also determined that 2 modules in series were required for the 24 Volts battery, making a total of 6 batteries.

Deep-cycle Batteries

The capacity of the deep-cycle batteries used for a total of 432 Amp-hours (assuming 3 days in the week without sun and a correction factor of 1.2) was determined to be 4 batteries in series.

Pumps and Pressure Tank

Two pumps were chosen:

- A positive displacement 3-chamber diaphragm submersible pump with a total vertical lift of 70 meters, a flow rate of 8.6×10^{-4} m^3/s, and a maximum pressure of 6.9×10^5 N/m^2.
- A surface pump with a vertical lift of 9.1 meters, a flow rate of 3.3×10^{-5} m^3/s, and a maximum pressure of 3.1×10^5 N/m^2.

Figure 1 is a schematic diagram of the fountain showing how the panels, batteries, actuator, and pumps are connected. Considering the pressure and flow rate of the pumps, a 0.13 m3 tank was chosen. Additionally, a "cut-in 2.1×10^5 N/m^2 / cut-out 3.4×10^5 N/m^2" pressure switch and a pressure gauge were attached to the tank.

Design of the aerator

The aerator is comprised of one item each from the following: 7.2 Amps solar panel, 6- Amp air compressor, 6.1 m #12 AWG wire, 15 Amps charge regulator, 12 Volts battery, and a plastic case. A 0.13 m diameter, 1.68 m long PVC pipe was chosen, and a 90˚ elbow was glued at the top of the pipe to transport the air bubbles from the bottom to the surface of the lake. Four radial holes were drilled six inches from the end of the pipe to hold the air stones in place, using plastic fittings. The air stones were interconnected to a 9.5×10^{-3} m flexible hose. The hose was connected to the air compressor located on top of the fountain as shown in Figure 2. The PVC pipe was then strapped with two 0.91 m x 0.04 m aluminum flat bars. One side was welded to the SPOWF aluminum structure, and the other side bolted to the pipe as showed in Figure 2.

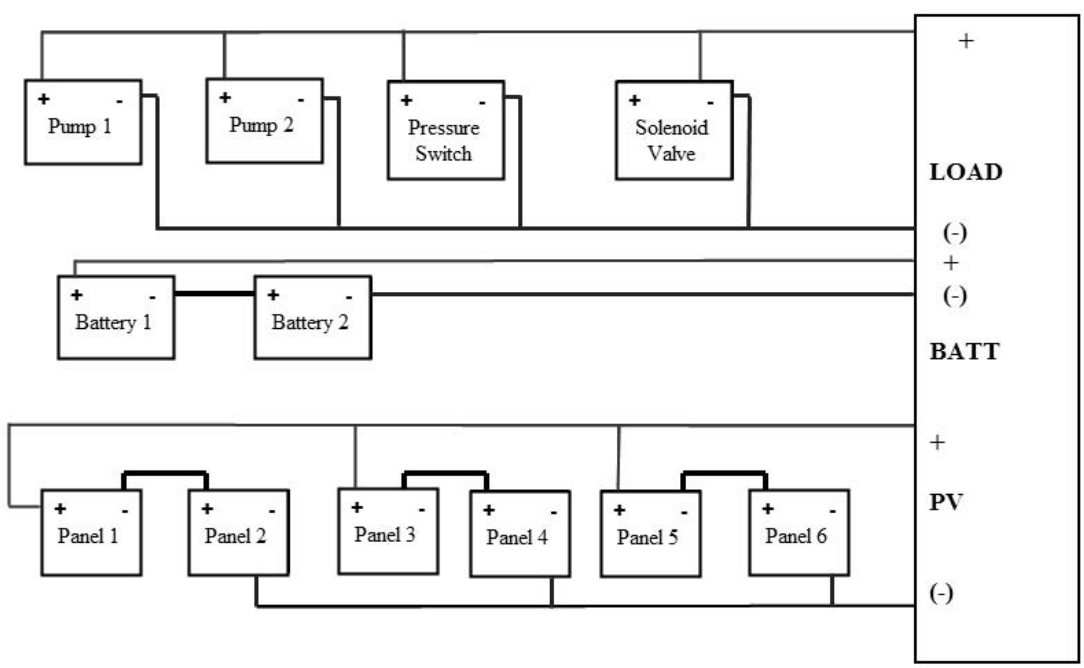


Figure 1. Schematic Diagram Showing the Arrangement of Pumps, Batteries, and Solar Panels in the Fountain Design

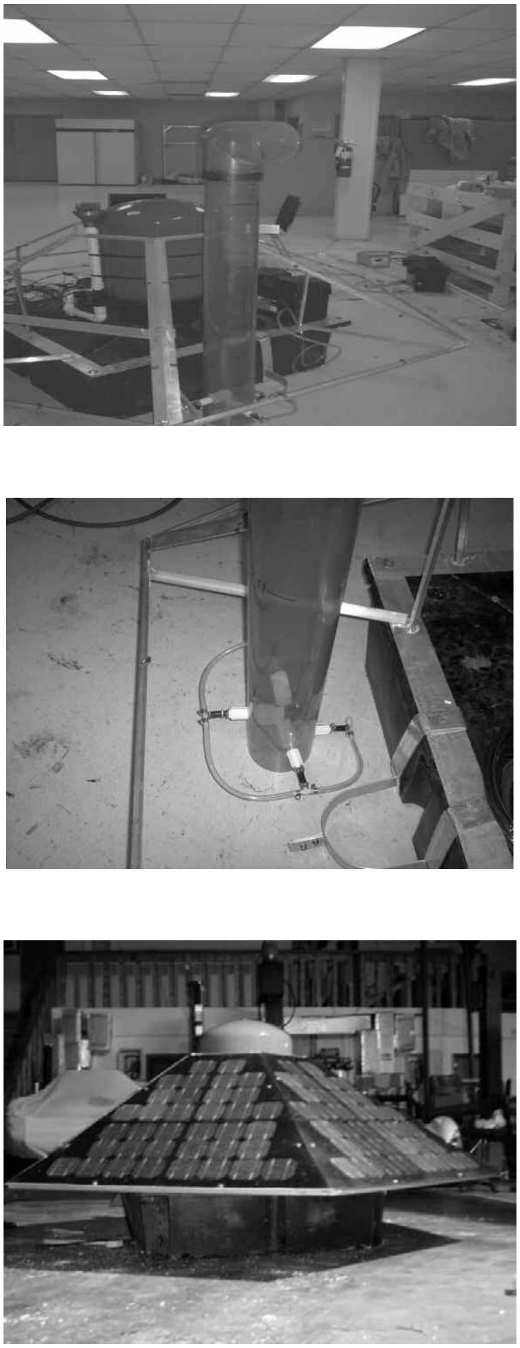


Figure 2. Photos of the Solar-powered Water Fountain (SPOWF) *[Top]: SPOWF unit under construction, showing the aeration system (vertical tube), blue water tank, aluminum frame, base float, and electrical wiring for connecting the panels, batteries, and actuator. [Middle]: Close-up view of the bottom part of the aerator, revealing arrangement of air stones. [Bottom]: Fully assembled SPOWF unit*

System Operation

When the SPOWF system is turned on, both pumps constantly pump water into the tank through the one-way valve. As the water flows into the tank, the pressure in the tank increases steadily to 3.44×10^5 N/m^2. At this critical pressure, water is jetted of the fountain through the nozzles. The flow stops when the pressure drops below 2.1×10^5 N/m^2, and the pressure switch shuts off to rebuild the pressure in the tank. This sequence is continued as long as there is enough current flow to power the loads (Braimah, 2004; Gomez, 2006).

The purpose of running both the fountain and aerator together was to maximize the daily water circulation. The voltage output of the PV panels is often too low to run the pumps under these conditions. To offset this limitation, it was necessary to operate an energy booster with the system. The linear current booster (LCB) works by enhancing the output current from two batteries, especially under low light conditions, cloudy days, and early morning or late evening.

System Analysis

Cause-and-effect diagram

A cause-and effect diagram was developed for the SPOWF system as shown in Figure 3. From this diagram, the factors were classified as design factors, factors held-constant, and nuisance factors. The design factors were: depth of the water, time of the day, location of the fountain, and the status of the fountain i.e., ON or OFF. The factors held-constant were variables that could modify the response, but for the purpose of this experiment, these factors were not of interest, so they were held at their specific level. Some of them were: filters, fountain, solar panels, and pumps. Nuisance factors, on the other hand may have a large effect that must be accounted for. The nuisance factors considered in this experiment were: barometric pressure, temperature of the water, cloudiness, and air temperature.

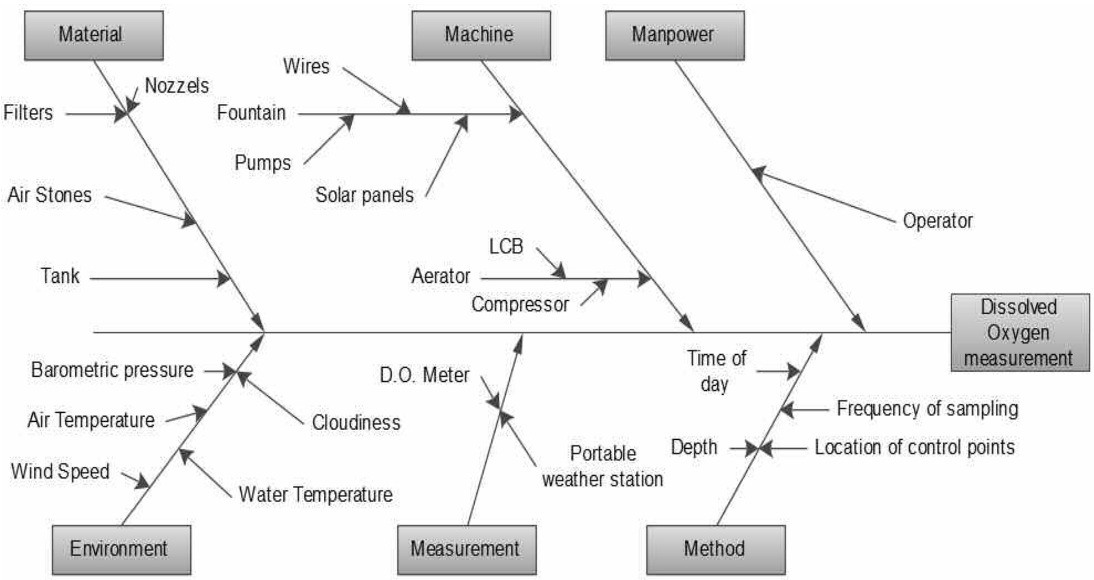
Dissolved oxygen measurement

The dissolved oxygen meter provided the reading of the concentration of dissolved oxygen as well as the depth and temperature of the water. Measurements were done every day at 7:00 AM and 1:00 PM during 20 consecutive days in October and November. Table 2 shows the data set after measurements were taken.

Estimated general linear relation for final model

The final estimated model equation in terms of coded units with all the statistically significant terms was determined for two scenarios, i.e., "Fountain Off" and "Fountain On" as indicated below:

Figure 3. Cause-and-effect Diagram for the Solar-powered Floating Fountain



Fountain OFF

DO = 4.63 **-** 0.5244 (Location) + 0.3569 (time of day) (7)

Fountain ON

DO = 6.0455 – 1.0238 (Location) + 0.7138 (time of day) (8)

Interactions between "fountain with location" and "fountain with time of day" are evident in the differing coefficient estimates for location and time of day for "fountain off" vs. "fountain on", respectively. A response surface analysis (Simpson, Kowalsky, & Landman, 2004) was performed and the results are shown in Figure 4.

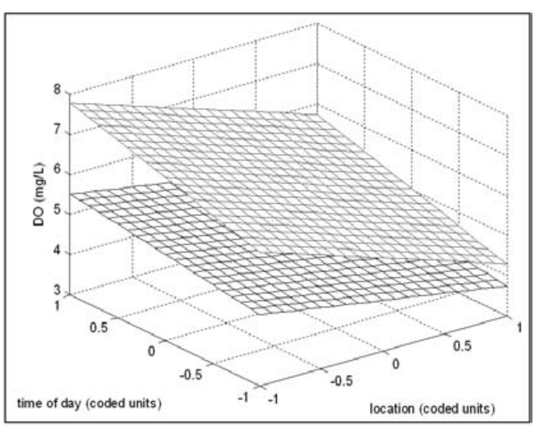


Figure 4. Response Surface for Dissolved Oxygen (DO) as a Function of Location and Time of Day, When Fountain is ON (top) and Fountain is OFF (bottom)

In order to accurately predict DO as a function of location and time of day, a transformation from natural to coded units (Myers & Montgomery, 2002; Montgomery, 2005) should be made prior to applying the model as shown in Eqs. 7 and 8, respectively.

In general,

$$\text{Coded units} = \frac{NU - [Min + Max]/2}{[Max - Min]/2} \quad (9)$$

Where, *NU* is the value in natural units

Min is the (-1) value of the factor in natural units

Max is the (+1) value of the factor in natural units.

Table 3 shows an example for calculating DO at a location, 3.7 m away from the fountain at 9:00 AM.

Final model charts

The first datum for the fourth subplot was collected again, after 12 days, with the fountain in the OFF status. It was observed that the aeration effect due to the floating fountain had disappeared. Consequently, the measured DO levels were at the original values as shown in Figure 5. This new information is valuable because it can be inferred that the experiment was time independent.

Table 2. Data Set Collected Indicating Factors and Response (*dissolved oxygen measurement*)

Day	Depth of water (meters)	Time of day (hours)	Location (meters)	Status of Fountain (On / Off)	Air Temp (°K)	Water Temp (°K)	Cloudiness (0 or 1)	Wind speed (m/s)	DO (mg/L)
1	0.3	13	1.52	Off	291	293	0	2.24	4.5
2	1.52	13	7.62	Off	291	291	1	0.45	4.7
3	0.3	7	7.62	Off	280	293	1	0	4.8
4	0.91	10	4.57	Off	291	292	0	1.34	4.6
5	1.52	7	1.52	Off	279	291	0	0.89	4.5
6	1.52	7	1.52	On	279	291	0	0.45	6.4
7	0.3	7	7.62	On	282	291	1	1.34	7.1
8	0.3	13	1.52	On	301	298	0	0.89	6.1
9	0.91	10	4.57	On	292	295	0	1.34	9.8
10	1.52	13	7.62	On	295	291	0	0.89	7.6
11	1.52	13	7.62	On	297	292	1	0.45	10
12	1.52	7	1.52	On	283	294	1	1.34	6.4
13	0.91	10	4.57	On	295	295	0	0.89	6.3
14	0.3	13	1.52	On	299	296	1	0.45	7.1
15	0.3	7	7.62	On	284	299	0	0.45	7.8
16	0.3	13	1.52	Off	300	302	1	1.34	4.6
17	0.91	10	4.57	Off	295	299	0	1.34	4.7
18	0.3	7	7.62	Off	285	299	1	1.79	4.6
19	1.52	7	1.52	Off	282	293	1	2.24	4.8
20	1.52	13	7.62	Off	295	296	1	2.24	4.5

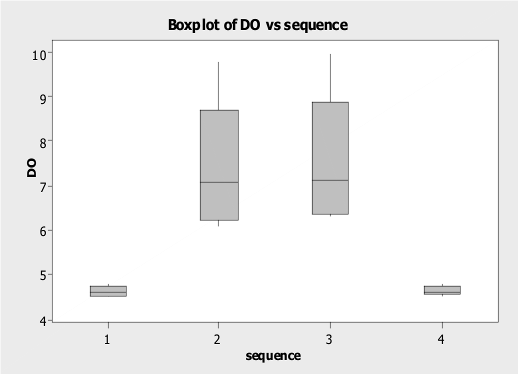


Figure 5. Box Plot of DO Concentration Showing Time Independent Effect

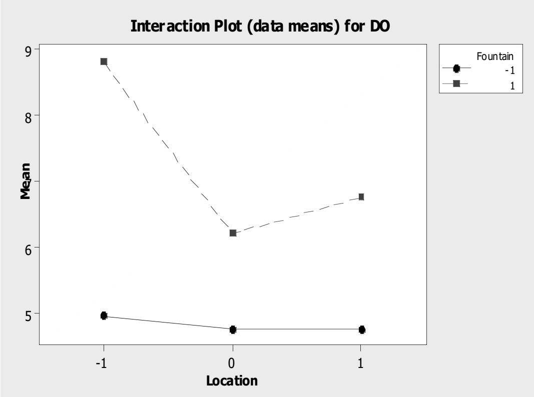


Figure 6. Interaction Between Fountain and Location Set Up at Two Levels

Table 3. Natural to Coded Units Transformation for Dissolved Oxygen Measurement, 3.7 m Away from the Fountain at 9.00 AM

Natural Units		Coded Units		DO (mg / L)	
Location	Time of Day	Location	Time of Day	ON	OFF
3.7 m	9:00 AM	-0.30	-0.33	6.1147	4.66

The interaction between the fountain and its location is shown in Figure 6. When the aeration system was in the OFF status, the DO concentration was observed to be 4.95 mg / L at 5 feet away from the fountain. At the same location when the aeration system was in the ON status, the value for DO was 8.8 mg / L. At the high level of location (7.6 m away from the fountain), the results were similar. When the fountain was OFF, the DO was 4.75 mg/ L and when the fountain was ON, the DO reached 6.75 mg/L. Note that there was a difference for the center point between fountain OFF and ON. The DO changed from 4.75 to 6.2 mg /L respectively.

Figure 7 shows the interaction between fountain and time of day. There was an increase in DO at different times of day whether the fountain was ON or OFF. However, the magnitude of the increase depended on the fountain status. When the fountain was ON, the DO value increased from 7.06 mg /L at 7:00 am to 8.49 mg / L at 1:00 pm. When the fountain was OFF, the DO value changed from 4.75 mg / L to 4.85 mg / L. As with the interaction between fountain status and location, the center point responded differently when the fountain was ON compared to OFF mode. The accepted minimum level of dissolved oxygen required for aquatic species is 6 mg/L (Hondzo & Steinberger, 2002). Results indicated that the floating fountain achieved the minimum desired level of dissolved oxygen.

Cost Analysis of the Floating Fountain

Table 4 lists the materials, labor and maintenance cost for the floating water fountain system. All cost items have been rounded to the nearest $50. Small-scale solar PV installations require minimum yearly maintenance, if any. Thus, a lifetime maintenance cost of $1,000 is included.

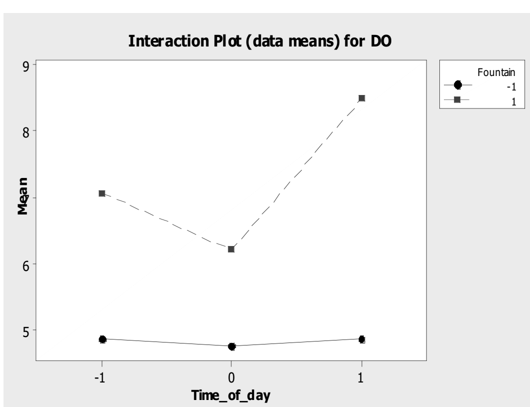


Figure 7. Interaction Between DO and Time of Day When the Fountain is ON and OFF

Total Cost = Materials Cost + Labor Cost + Maintenance Cost
= $6,600.00 (4)

On the other hand, assuming that the fountain is powered entirely by utility grid electricity, the total estimated amount of Kw used during operation of the Floating Fountain is as follows:

Fountain:
(24 V x 8.4 Amp) x 24 hours = 4.8 kw-hr/day (5)

Aerator:
(12 V x 6.4 Amp) x 24 hours = 1.8 kw-hr/day (6)

The Total usage is 6.4 kw-hr/day.

Thus, the estimated annual output in kw-hr/year is equivalent to 2340 kw-hr/year

If the cost of electricity (utility)
= $ 0.2175 / kw-hr (for Tallahassee, FL)
= approximately $500 / year

(*assuming no inflation and no increase in electricity tariffs*)

The use of grid electricity will require all the materials listed in Table 4, with the exception of the PV modules and batteries.

Table 4. Materials, Labor and Maintenance Cost of the Floating Fountain

Description	Cost ($)	Subtotal ($)
Materials		**5,000.00**
Modules	3,000.00	
Pumps	300.00	
Structure	500.00	
Tank	300.00	
Plumbing	100.00	
Compressor	200.00	
Batteries	200.00	
Hoses and fittings	150.00	
Linear current booster	150.00	
Wiring	100.00	
Labor	600.00	**600.00**
Maintenance	1,000.00	**1,000.00**
Total		**6,600.00**

Since the cost of solar PV modules and batteries is $3,200, the above analysis yields a payback period of 3,200 / 500 = 6.4 years, which is economically profitable, considering that the useful life of photovoltaic modules is 20 – 30 years. There is also the added environmental benefit of using solar energy.

Conclusion

Solar-powered appliances present unique advantages over traditional devices. The Solar-Powered Water Fountain (SPOWF) system manufactured and tested in this work achieved its main function, i.e., aeration of a selected water body with the aid of the aerator and fountain. Consequently, the dissolved oxygen (DO) concentration was increased significantly from a low level of 4.5 mg/L to a high of 9.95 mg/L, an increase of about 120%. Statistical analysis of the data (DO measurements) was conducted using a Split Plot Design. This mathematical model described a linear relationship between the primary operating factors, location of the aerator and time of the day, and the output, DO.

Economic analysis conducted using a payback period approach, by comparing the solar generated power with the utility grid electricity, yielded a payback period of 6.4 years. Considering that photovoltaic systems have a useful life of between 20 to 30 years, this payback period is profitable both economically and environmentally, considering the enormous benefits of the aerator / fountain unit to aquatic life.

The SPOWF system has immense potential commercialization opportunities. Possible consumer markets include environmental, building and construction, parks and gardens, private homes, estate developers, aquatic, and energy conservation.

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Innovative Rotary Displacer Stirling Engine: Sustainable Power Generation for Private and Fleet Vehicle Applications

Phillip R. Foster

Abstract

The Stirling cycle and related terminology is defined. Selected contemporary research involving the cycle in environmentally friendly applications is cited. Three conventional engine configurations that utilize a reciprocating power piston and crank shaft (the Alpha, Beta, and Gamma) are characterized, in terms of minimum number of components, advantages, and disadvantages. A new type of Stirling engine that employs a segmented rotary displacer and other related design improvements is presented along with preliminary findings from engine test runs.

Keywords: Stirling engine, electric power generation, renewable energy

Robert Stirling, in 1816, developed and patented the air engine that bears his name. The steam engines of the early 19th century had a reputation for unreliability, particularly regarding boiler explosion, and the Stirling cycle engine was thought by some as a possible substitute. Fascination regarding the potential for the Stirling cycle can be seen in the prolific development of Stirling cycle engines. Although this cycle provides several distinct advantages over other engine cycles currently in widespread use, there are some noteworthy disadvantages that technology has been hard pressed to eliminate. Thus, most innovation in Stirling engine design has not been adopted. Despite its shortcomings, the Stirling cycle engine is once again under study, but for entirely different reasons.

Worldwide concern over global warming and depletion of nonrenewable energy sources has renewed interest in the Stirling cycle being used for generating green or sustainable energy. Hsu, Lin, and Chiou (2003) reported on what is believed to be the first study of the Stirling cycle, fueled by waste energy, to generate electricity. The heat source was an incinerator. Experimental hardware included a free-piston Stirling engine coupled to a linear alternator. The researchers selected the free-piston Stirling because crank-driven Stirling engines "… presented some challenging design problems, including power modulation, leakage of working fluid, isolation of lubricants, etc." (Hsu et al., p. 61). Their findings demonstrated the difficulty in simulating actual engine performance, but on a larger scale, these authors pointed the way for other researchers to pursue the topic. In 2008, Snyman, Harms, and Strauss investigated applying the Stirling engine to energy generation through waste heat recovery. Their work focused on the utilization of three design analysis methods for simulating the optimization of a Beta configuration Stirling engine utilizing waste heat. Also included in their research was an experimental setup, using an instrumented Beta Stirling, which was powered by exhaust gases from the combustion of propane. The experimental setup replicated the simulation conditions. The authors' findings indicated that actual engine performance could be predicted by the simulation analysis. Chang and Ko (2009) also studied waste heat recovery for electricity generation utilizing the Stirling cycle. The renewable heat source used in their research originated from a waste incinerator. Leu (2010) studied the viability of biomass as a heat source for small-scale electrical generation using the Stirling engine. In this application, solid biomass fueled a fixed-bed gasifier with a combustor. Flue gas from the combustor provided the energy input for the Stirling engine-generator set.

The Stirling Cycle and Related Terminology

Stirling Cycle

All modern engines encountered in day-to-day use operate on a well-known cycle characteristic of their operation. For example, four-stroke reciprocating internal combustion engines utilize spark ignition. These function according to the Otto cycle. Engines that utilize compression ignition adhere to the Diesel cycle. These are mechanical cycles in which the working fluid, a fuel-air mixture, does not undergo a thermodynamic cycle involving cooling to the initial state. They are not reversible. Rather, after combustion imparts work to the mechanism, the remains of the working fluid are expelled from the engine and replaced with fresh mixture. A complete cycle may require one or two 360° revolutions (Cengel & Boles, 1998; Howell & Buckius, 1992; Wood, 1991).

The Stirling cycle is a reversible thermodynamic cycle consisting of four phases: heat addition (isovolumetric heating), expansion (isothermal expansion), heat rejection (isovolumetric cooling), and compression (isothermal compression). The four phases, which constitute one complete cycle, are completed in a single 360° revolution. A displacer alternately shuttles the working fluid from the cold to the hot workspaces of the engine in synchronization with the power piston. When in the hot workspace, the working fluid is heated, its pressure increases and it expands, thus moving a power piston and doing work. When the displacer shuttles the working fluid into the cold workspace, it is cooled, its pressure is reduced, and the power piston compresses the working fluid back to its original volume (Beale, 1984; Biwa, Tashiro, & Yazaki, 2008; Gras, 2011; Woodbank Communications, Ltd., 2011).

The positive attributes of the cycle have been well known since its inception. They include quiet operation, high thermal efficiency, safe operation, ease of operation, and the ability to function on any form of thermal energy (including both traditional combustion and non-polluting sources, such as biomass, solar energy, and geothermal energy). Shortcomings of the Stirling cycle have hindered its wider application in competition with steam, electric, and internal combustion. These shortcomings include the complexity of design and a relatively low power output per size and weight (Beale, 1984; Der Minassians & Sanders, 2009; Karabulut, Yucesu, & Koca, 2000; Snyman et al., 2008).

Selected Stirling Engine Terminology

A basic knowledge of selected Stirling engine terminology will help the reader understand the narrative pertaining to contemporary engine configurations. Further, it is essential to an understanding of the major objectives of this article, that is, the discussion of an innovative rotary displacer Stirling engine. The following terms are defined: phase angle, dead space, regenerator, working fluid, workspace, displacer, and volume compression ratio.

Phase angle (α). The displacer piston always moves in advance of the power piston. Both pistons are mechanically connected to a common flywheel and crankshaft. Typically, the phase angle is 90° (Senft, 2002; Snyman et al., 2008).

Dead space (dead volume). Conduits, passageways, internal heat exchangers, and similar features for conveying the working fluid that is not directly shuttled by the displacer make up the dead space. Some dead space is inevitable, but it must be minimized because it is detrimental to the indicated work of the cycle (Senft, 2002).

Regenerator. A feature consisting of layers or coils of heat-absorbent material located on the internal surfaces of working fluid conduits or passageways. This feature is used to increase the efficiency of the cycle by (a) accumulating excess heat from the expanding working fluid, which can then be transferred to the fluid during subsequent cycles, and (b) reducing the amount of heat that must be accommodated by the external heat sink through the cold workspace (Snyman et al., 2008).

Working fluid (working gas). The design of Stirling engines is such that the internal spaces contain a gas that is alternately heated and cooled during the cycle but is unable to escape from the mechanism. This gas, referred to as the working fluid or working gas, is commonly air. However, gases with lighter molecular weight (i.e., helium or hydrogen) provide thermodynamic advantages over air. The working fluid is not consumed in the cycle (Snyman et al., 2008).

Workspace. The interior volume of the displacer housing, excluding the displacer itself and any engine dead space, constitutes the workspace. This area contains the bulk of the working fluid and has provisions for the addition and rejection of heat. These provisions subdivide the workspace into the hot workspace and the cold workspace, areas that are thermally insulated from each other.

Displacer. The displacer is a reciprocating piston that moves along the axis of the displacer housing, thus alternately communicating the working fluid to the hot and cold workspaces of the engine (Beale, 1984; Der Minassians & Sanders, 2009).

Volume compression ratio. Any given engine has a maximum volume and a minimum volume. The former is the sum of the displacer volume plus the power piston cylinder volume. The latter is the displacer volume alone. The ratio of the maximum engine volume to the minimum engine volume is referred to as the volume compression ratio (Senft, 2007).

Conventional Commercial Stirling Engine Configurations

Three related engine configurations have persisted over the years and these are most commonly used in contemporary commercial applications: the Alpha, the Beta, and the Gamma. All of these configurations utilize the conventional piston, crankshaft, and cylinder arrangement, but two of the three (i.e., Beta and Gamma) use them in conjunction with a uniquely Stirling cycle addition, the displacer. The following sections characterize the three prevalent reciprocating piston-type Stirling cycle engines. Descriptions and figures are generic interpretations of these configurations. No attempt has been made to describe or render the complexities associated with actual working engines.

Characteristics of the Alpha Stirling Engine

The Alpha Stirling engine consists of two power pistons, each with a separate cylinder and connecting rod. One power piston and cylinder represents hot workspace, the other cold workspace. The connecting rods join a common journal on a single flywheel/crankshaft. This arrangement is shown in Figure 1. As the figure depicts, the hot and cold workspaces are physically separated from each other. This feature provides excellent thermal isolation for the two workspaces. The conduit that joins the two workspaces, however, adds to the dead space associated with this design.

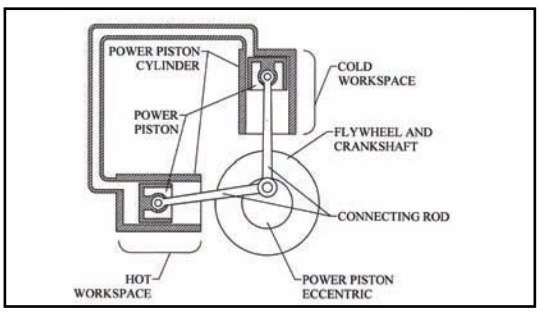

Figure 1: Alpha Configuration of Stirling Engine

The Alpha then, in its simplest form, utilizes four reciprocating parts and one rotary part. This configuration requires a close tolerance fit between each power piston and its respective cylinder. This is not an issue for those components operating within the cold workspace. The hot workspace piston and cylinder do represent a problem with regard to maintaining a reliable seal in an environment with high heat coupled with sliding friction. Seals on this piston can be subject to early failure due to these operating conditions. Techniques that alleviate piston seal failure may also increase engine dead space. The Alpha is known for its high power-to-volume ratio.

Characteristics of the Beta Stirling Engine

The Beta Stirling engine included design features that eliminated the hot seal failure issues of the Alpha. The engine utilizes a power piston with a connecting rod, similar to the “cold” power piston of the Alpha, but the “hot” power piston is replaced by a displacer with a connecting rod. The displacer represents a major improvement. The power piston and the displacer both share a common cylinder and a common flywheel/crankshaft. This arrangement is shown in Figure 2. Unlike a piston, the displacer does not require a tight tolerance seal along its surfaces. Its function is to simply shuttle working fluid within the hot and cold workspaces. This insulates the power piston from the high temperatures that exist in the hot workspace. Also, dead space is minimal.

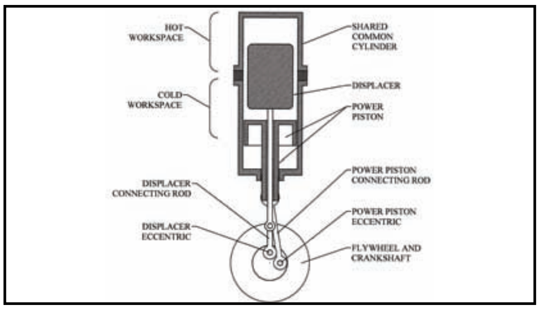

Figure 2: Beta Configuration of Stirling Engine

A design in which there is sharing of a common cylinder presents thermal conduction issues not encountered in the Alpha. The junction of Beta hot and cold workspaces must include an additional thermal barrier to reduce conduction and maintain efficiency. The Beta, in its simplest form, consists of four reciprocating parts and one rotary part.

Characteristics of the Gamma Stirling Engine

The Gamma Stirling engine is similar to the Beta it that it utilizes the same type of moving parts. It has one major difference. The Gamma power piston does not share a common cylinder with the displacer. Its design employs two distinct cylinders, a feature evident in Figure 3. However, the hot and cold workspaces of the displacer cylinder require the addition of a thermal barrier. Therefore, in its simplest form, the

Gamma configuration also consists of four reciprocating parts and one rotary part. The Gamma shares the same advantages as the Beta and also holds the potential for being mechanically simpler. Gammas are particularly suited to multicylinder applications.

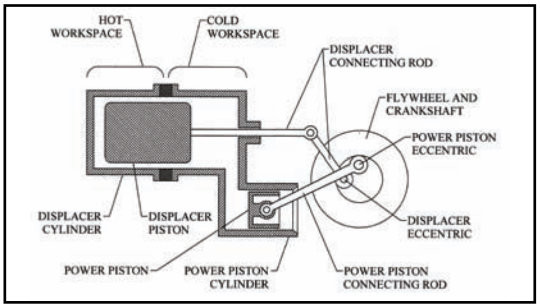

Figure 3: Gamma Configuration of Stirling Engine

In the preceding explanation, the reciprocating and rotating part count was always prefaced by the phrase "in simplest form." The reality of conventional commercial Stirling design seldom if ever adheres to the simplest form. Contemporary engines display a range of mechanisms, some fairly complex, to change linear motion into rotary.

Summary of Conventional Stirling Configurations

Certain generalizations can be made from the preceding sections. There is a renewed interest in the Stirling cycle for sustainable and/or environmentally friendly electrical generation. Reciprocating piston-type Stirling engines, particularly the Alpha, the Beta, and the Gamma, have been harnessed in these applications and have been reported to be effective. These engine configurations, in their simplest form, utilize four reciprocating parts and one rotary part (per power cylinder). Actual commercial engines are typically more complex (i.e., have more moving parts per power cylinder).

Genesis of the Stirling With Attitude (SWATT) Engine

The author was convinced that the cycle could be effectively achieved with fewer than five moving parts per power cylinder. A reduction in parts, particularly reciprocating parts, would contribute to mechanism longevity while reducing complexity. It was proposed that the cycle be represented by three moving parts, two reciprocating and one rotary. The reciprocating parts included the power piston and connecting rod assembly. The rotary part was the displacer. Integrated into the displacer were the crankshaft/flywheel and a valve mechanism. The crankshaft/flywheel also incorporated provisions for teaming engines to provide greatly simplified, multipower cylinder configurations.

The following parameters were selected as a starting point for initial engine design: liquid cooling, power cylinder bore and stroke = 1.000" X .625" (volume = .491 in3), phase angle 90°, and volume compression ratio 1.244. The power cylinder specifications and the volume compression ratio established the volume of the rotary displacer at 2.009 in3. Materials selected included stainless steel for all major structural components, graphite for the piston, titanium for the connecting rod assembly, and polymer for the rotary displacer. The following sections address design features of major components, specifically, the individual displacer segments, the rotary displacer assembly, the displacer housing, and a rotary valve mechanism.

Individual Displacer Segments

The displacer of the subject engine is not of one-piece construction. Rather, it is made up of 16 polymer segments, 14 of which are virtually identical. Individually balanced, each has a stepped profile along about 180° of the outer circumference (see Figure 4), which is evident along the lower half of the segment in the figure. The same profile is mirror imaged in the internal surfaces of the two-piece stainless steel displacer housing. This design feature increases the surface area of the hot and cold workspace, enabling a more rapid isovolumetric heating (expansion) and cooling (compression) of a larger volume of working fluid. The six holes adjacent to the stepped area balance the segment by removing a mass equivalent to that removed in the creation of the stepped profile.

Figure 4: Typical Rotary Displacer Segment

The balancing holes, in the fully assembled displacer, are filled with an expanded foam insert that has a very low mass coupled with a high temperature resistance. If left unfilled, balancing holes would add substantially to the engine's dead space. The axial hole with keyway locates the segment along the assembled displacer's long axis while preventing rotation about it. Individual segments are kept in position through two retaining rings, one on either side of each segment. One of these rings is shown in Figure 5.

Using a segmented displacer that had a stepped profile that could enhance the heat transfer area was possible because the displacer was rotary. This permitted the use of one of several relatively new engineered polymers. PolyEtherEtherKetone (PEEK) has mechanical and thermal properties that make it ideal for this application. These include: tensile strength of 16 ksi, compressive strength of 20 ksi, maximum operating temperature of 480°F, thermal conductivity of 1.75 BTU-in./ft.2-hr.-°F, and a coefficient of thermal expansion, 2.6 X 10-5in./in./°F (Boedeker Plastics, Inc., 2011, pp. 2-3). Thus, PEEK is a very good insulator that will neither absorb nor transmit too much thermal energy. It is also strong for a polymer and has a high operating temperature ceiling. Like most polymers, however, it "grows" when heated, and this growth is more than that encountered with most metallics. The type of stainless steel used in the water-cooled displacer housing is AISI 304, which has a much lower coefficient of thermal expansion, 9.6 µ in./in..-°F (Oberg, Jones, Horton, & Ryffel 2004, p. 472). Because the displacer segments are individually located along the axis of the housing using retaining rings, their relatively large coefficient of expansion is of consequence for a relatively short lateral dimension, their individual thickness. This expansion is easily accommodated in the sizing of the corresponding workspace for a given segment, even though the stainless "grows" very little by comparison.

The Rotary Displacer Assembly

Adoption of a rotary displacer over a reciprocating one provided two significant advantages. These are reduced cycle power needs and increased design flexibility. Each will be briefly discussed.

Reduced cycle power needs. Reciprocating displacers waste energy. In the 360° rotation representing one complete cycle, the displacer changes direction twice. The displacer is accelerated from rest at 0°. It achieves maximum velocity at 90°, followed by deceleration and rest again at 180°. It is again accelerated achieving maximum velocity at 270°, followed by deceleration as it approaches 360° in its return to starting point. Energy is consumed in both acceleration and deceleration. A rotary displacer, however, never changes direction. Therefore, no engine energy is consumed in the constant acceleration-deceleration associated with the reciprocating arrangement. Further, its mass contributes to that required by the flywheel/crankshaft assembly that is essential to the Stirling cycle.

Increased design flexibility. Reciprocating displacers limit the design options available for optimizing engine operation. This is because minimizing reciprocating mass must take precedence over other factors. Minimizing mass influences material selection, which can result in compromises in thermal and mechanical properties. For example, high stiffness, low weight, low thermal conductivity, and high thermal resistance are also very desirable displacer material characteristics. Unfortunately, it is difficult to identify a cost-effective material selection that offers such diverse characteristics and is, at the same time, low mass. Also affected are the physical design, the axial orientation (vertical vs. horizontal), and displacer surface topology (i.e., its axial cross-section). Surface topology includes design features intended to increase the displacer surface area that is available for heat transfer. Minimal surface area for effective heat transfer has been cited as an issue. Senft (2007, p. 64) wrote "[i]n many real engines the expansion and compression processes for the most part occur in engine spaces that have relatively little heat transfer area." Mechanism wear must be controlled to maintain an adequate service life. For the same reasons that they waste energy, reciprocating displacers load other components (e.g., bearings and linkages), requiring more robust design of these components.

A rotary displacer, at operational speed, exerts radial and thrust loads only. These are the normal loads placed on bearings, and they do not adversely influence engine design in other areas. A rotary displacer also opens up design options in other ways. Because mass is not an issue, there are novel design opportunities for the displacer. The rotary displacer can be long, can incorporate features for increased surface area, and can still function from ambient to operating temperature within the close confines of the stainless housing.

Figure 5 shows the fully assembled, segmented rotary displacer. The top surface of the displacer creates the hot and cold workspaces of the engine; this is in concert with the hot and cold sections of the displacer housing. The lines appearing along the circumference, indicating the sides of each segment, also represent the physical space between segments. This space allows for the thermal "growth" that is

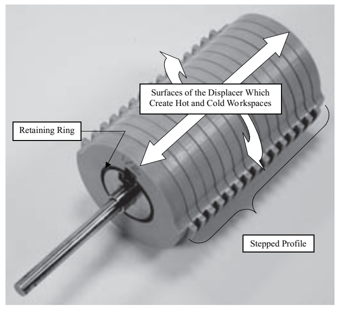

Figure 5: Complete Segmented Rotary Displacer

inevitable as the segment warms from close proximity with the hot workspace. Each segment is restricted in its lateral movement associated with this "growth," by two retaining rings. The maximum extent of this movement, either left or right, always coincides with the width of the corresponding radial groove in the housing.

The Displacer Housing

The displacer housing consists of four major components, all of type 304 stainless steel. The hot and cold workspaces are achieved through two partial cylinders that are joined along their edges to form a complete cylinder. A PEEK seal is located along their linear joints to prevent thermal conduction between the hot and cold workspaces. Their internal configuration, as previously noted, is a mirror image of the rotary displacer. The ends of the housing contain the bearings and provisions for liquid cooling. Additionally, the right-hand end contains features that contribute to the rotary valve mechanism as well as the means for the hot and cold workspaces to communicate with the power piston. The internal ends of the housing are faced with PEEK seals to prevent thermal conduction. Clearances between the rotary displacer and the housing are tight to minimize dead space but sufficient to ensure no contact. Figure 6 shows a single displacer segment in a partial assembly with half of the displacer housing. In this figure, the housing shown is that of the cold workspace (note the coolant manifold connections at the lower left). A single displacer segment is shown here to clarify the internal configuration of the housing, the cold workspace. One segment retaining ring also appears clearly.

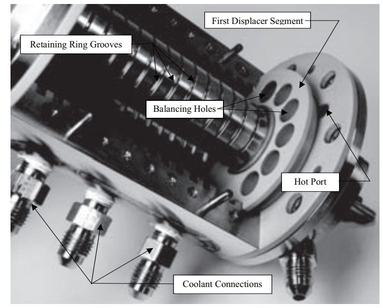

Figure 6: Open Displacer Housing Showing Cold Workspace and Partially Assembled Rotary Displacer

Each of the radial grooves along the inner surface of the cold workspace corresponds to one of the 15 segments not yet in the displacer assembly. The internal configuration of the hot side of the displacer housing is identical to that of the cold side.

Rotary Valve Mechanism

Another design feature that is possible because of the rotary displacer is a rotary valve integral with the first displacer segment and the adjacent portion of the housing. This arrangement does not add additional moving parts, but it effectively directs the working fluid in the following way. The power cylinder has two ports, one in communication with the hot workspace through the hot port (see Figure 6) and one in communication with the cold workspace through the cold port. The cold port is not visible in Figure 6; it is obscured by the segment. Regardless, it is situated 180° from the hot port and lies on the same circular centerline in the side of the displacer housing. These ports are positioned immediately adjacent to the stepped profile groove occupied by the first displacer segment. Recall that the stepped profile of the segments exists for about 180° only (see Figure 3). Hot and cold ports connect to the power cylinder through passageways. The cold port and its passageway represent a heat sink in that they are kept cold by the engine's liquid cooling system. These areas are also insulated from the hot workspace. The hot port and its passageway represent thermal energy input, being in communication with the hot workspace. When the displacer rotates through its cycle, it alternately blocks and opens the hot and cold ports. During isovolumetric heating (expansion), therefore, the hot working fluid is inhibited from moving through the cold passageway, even though pressure throughout the engine is the same. Similarly, during isovolumetric cooling (compression), the cold working fluid is inhibited from moving through the hot passageway.

Preliminary Findings From Initial Running of SWATT Engine

This engine has been under development for approximately 10 years, and much of this time has been spent on design and fabrication. Figure 7 shows the assembled engine from the perspective of the cold workspace. Major subassemblies have been identified.

In order to run the engine, various auxiliary units must be connected. These include a propane gas burner, connections for the liquid cooling, and various instrumentation components. To facilitate collection of engine performance data, a test bed was constructed to hold the engine and auxiliary units. The complete setup has been operable for about two years and has accrued data from about 120 hours of run time. It is instrumented with five externally mounted surface contact type K thermocouple probes. These are located at various positions to collect temperature distribution data. Two probes monitor hot workspace (thermocouple locations 1 and 3), two monitor cold workspace, and one monitors power cylinder temperature, also representing cold workspace (thermocouple locations 2, 4 and 5, respectively). Thermocouple probes are connected to two Fluke 52 II and one Fluke 51 II digital thermometers. This instrumentation displays data that provides the mean hot workspace temperature, the mean cold workspace temperature, and the resulting difference in temperature (ΔT). A noncontact laser photo tachometer, an Extech Model 1PX61, is also mounted on the test bed. This instrument displays the engine's RPM. Because there is a patent pending on the engine, it is now possible to release some design and performance information.

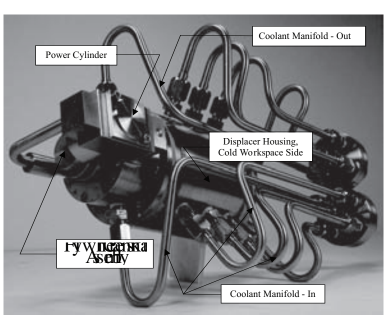

Figure 7: Assembled SWATT Engine

Although its appearance is radically different from Alpha, Beta, or Gamma Stirling engines, the SWATT engine definitely functions on the Stirling cycle (i.e., the nonconsumed working fluid is alternately heated and cooled but always returns to its initial state with each revolution). Although work on the design parameters it still under way, some unexpected findings regarding one, the phase angle, have come to light. The ideal phase angle was found to be remarkably different from that typically attributed to either Beta or Gamma engines, which operate with a phase angle of approximately 90°. As previously noted, the SWATT engine was initially designed and built with this angle. Initial engine runs, however, indicated ceiling RPM of about 400, which was less than anticipated. By varying the phase angle on the flywheel/crankshaft assembly, it was possible to experimentally determine an ideal phase angle through observation of tachometer readings.

Determination of the Ideal Phase Angle

Eccentrics

The flywheel/crankshaft assembly consists of several components, one of which serves as an eccentric. A cylindrical piece, the eccentric is bored through its longitudinal centerline to connect to the rotary displacer axle. When assembled, only one orientation is possible. A crank pin, which engages the power piston connecting rod, screws into the eccentric. The distance from the eccentric centerline to that of the crank pin establishes the stroke of the engine. The radial displacement of the crank pin, in relation to that of the rotary displacer, establishes the phase angle. Eccentrics were constructed to enable engine operation with phase angles of 75, 80, 85, 115, 120, 125, 130, and 135 degrees. Phase angles on either side of 90° were selected because it was not known whether an ideal angle was less than or greater than 90°.

Engine Performance Log

An engine performance log was developed to standardize data collection during phase angle testing. The log provided for manual recording of the time of an observation, the temperatures at the five thermocouples, and the RPM. Also recorded were the mean hot workspace temperature, the mean cold workspace temperature, and the temperature difference (ΔT) between each. The last three quantities are calculated and recorded post test. A representation of this form is depicted in Table 1. This contains test data for the 90° phase angle.

Table 1 90° Phase Angle Performance Log Showing RPM and Temperature in °F

	Thermocouple Locations (1-5) and Recorded Temperatures (°F)					Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
Time (h:m)	T_1	T_2	T_3	T_4	T_5				
4:00	77	77	77	77	75	N/A	N/A	N/A	N/A
4:05	182	80	181	79	76	182	78	104	576
4:07	197	81	185	80	77	191	79	112	577
4:09	197	82	169	81	78	183	80	103	420
4:11	198	82	169	81	79	184	81	103	484
4:13	198	82	168	81	79	183	81	102	428
4:15	190	82	156	81	80	173	81	92	368
4:17	198	82	174	81	80	186	81	105	511
4:19	204	82	179	81	81	192	81	111	407
4:21	198	83	164	81	81	181	82	99	382
4:23	193	83	158	81	81	176	82	94	364
4:25	193	82	159	81	81	176	81	95	392
4:27	194	83	159	81	82	177	82	95	408
4:29	194	82	160	81	82	177	82	95	418
4:31	194	82	161	81	82	178	82	96	426
μ	195	82	167	81	80	181	81	100	440

Note that the first data row, highlighted in red, shows only time and thermocouple temperatures at the start of the test. Calculation of mean hot and cold workspace temperatures as well as the engine workspace temperature difference (ΔT) are irrelevant at this point. At the bottom of the table, means are provided for temperatures taken at all thermocouple locations, grand means for the hot and cold workspaces, mean temperature difference, and mean RPM for the duration of the test run.

Phase Angle Testing Procedure

Experience running the engine has demonstrated that it needs approximately 20-23 minutes of initial run time to stabilize operation. The term stabilize implies that engine RPM is at or very near maximum, and minimal burner adjustment is necessary to maintain that RPM. This condition is termed steady state, and once achieved, heat input and RPM output remain relatively consistent over the duration of the engine test run.

During the initial 20 minutes of operation, however, constant adjustment of the burner is required. Thus, temperature and RPM data collected during this time display fluctuations that necessarily differ from test run to test run. This is evident in first 11 rows of temperature data for thermocouples monitoring hot workspace (T1 and T3) and the respective RPM figures shown in Table 1. The magnitude of fluctuations is dependent on how aggressively heat is applied. Both excessive heat and insufficient heat are detrimental to maximal RPM. Though high temperatures and RPMs can occur during this time, they do not characterize sustainable operation. These initial temperature and RPM figures are useful, even essential, in stabilizing operation, but that is the extent of their utility. For this reason, it was decided that all test runs in the phase angle study would be 31 minutes in duration with a 23-minute stabilization period, during which collected data would not be utilized to assess the effectiveness of a given angle. Only the last 8 minutes of the test would be used to collect data representing the performance of a given phase angle. The temperature and RPM sampling interval for a complete test run was set at 2 minutes with the exception of the initial reading, which was 5 minutes from the commencement of the test (the engine requires an approximate 3-minute warm up prior to running). All temperatures were recorded in degrees Fahrenheit (°F). Temperatures and RPMs were recorded to the nearest integer and standard rounding practice was used.

Findings: Phase Angles 75°, 80°, and 85°

The 75° phase angle was tested first. It was not possible to start the engine. The same results occurred with the 80° phase angle. At the 85° phase angle, the engine started, but it proved very difficult to stabilize, and the test run was aborted. Therefore, there is no performance data for the first three tests. Lack of run data, however, did provide valuable insight. Because the initial engine configuration successfully employed a 90° phase angle, the difficulties encountered with angles of 75°, 80°, and 85° demonstrated that if there were potential for improved engine RPM performance through phase angle manipulation, that manipulation would involve phase angles of 90° or more.

Findings: Phase Angle 90°

An eccentric having the 90° phase angle suggested by the literature was initially built with the engine. It was effective when the engine was first run, but empirical evidence characterizing the extent of its effectiveness had yet to be collected. Therefore, the fourth phase angle test was based on 90°, and, as previously noted, findings are shown in Table 1. This table, however, can be condensed through the elimination of the run data accrued during the 23-minute stabilization period. This reformatting (see Table 2), which will be used in the discussion of remaining phase angles as well, makes it possible to compile means for temperatures and RPMs that are not influenced by startup fluctuations.

Table 2 90° Phase Angle Performance Log Showing RPM and Temperature in °F after Engine Stabilization

	Thermocouple Locations (1-5) and Recorded Temperatures (°F)					Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
Time (Minutes into Run)	T_1	T_2	T_3	T_4	T_5				
25	193	82	159	81	81	176	81	95	392
27	194	83	159	81	82	177	82	95	408
29	194	82	160	81	82	177	82	95	418
31	194	82	161	81	82	178	82	96	426
µ	194	82	160	81	82	177	82	95	411

Table 3 115° Phase Angle Performance Log Showing RPM and Temperature in °F after Engine Stabilization

	Thermocouple Locations (1-5) and Recorded Temperatures (°F)					Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
Time (Minutes into Run)	T_1	T_2	T_3	T_4	T_5				
25	194	80	163	77	81	179	79	100	713
27	196	80	164	78	82	180	80	100	709
29	197	80	163	78	82	180	80	100	696
31	197	80	162	78	82	180	80	100	685
µ	196	80	163	78	82	180	80	100	701

Findings indicate a high level of consistency for virtually all temperature readings. The consistency of cold workspace temperatures (taken from locations T2, T4, and T5,) indicates sustainable, effective cooling (grand mean of 82°F). This is characteristic of steady state operation. A similar statement can be said of hot workspace temperatures taken from locations T1 and T3 (grand mean of 177°F). The 90° phase angle also rendered a mean ΔT of 95°F and an RPM of 411.

Findings: Phase Angle 115°

Contained in Table 3 are findings from the 115° phase angle test. Again, temperatures display consistency. Cold workspace temperatures had a grand mean of 80° F, whereas hot workspace temperatures indicate a grand mean of 180°F. This, in conjunction with consistency in RPM, indicates the engine is functioning near steady state. The mean ΔT was 100°F and the mean RPM was 701. The RPM statistic represents a major improvement over that obtained with the 90° angle suggested by the literature.

Findings: Phase Angle 120°

Table 4 contains the findings for the 120° phase angle test. Temperatures remained consistent at a given thermocouple over time. Cold workspace temperatures had a grand mean of 82° F, whereas hot workspace temperatures indicate a grand mean of 179°F. These values are similar to those derived from the 115° phase angle data. The ΔT, at 97°F, dropped slightly from that encountered with the previous phase angle, but the average RPM recorded during the test increased to 712.

Findings: Phase Angle 125°

Table 5 contains the findings for the 125° phase angle test. Individual hot workspace thermocouples (T1 and T3) indicated temperatures that remained consistent, but to a somewhat lesser degree than the previous test. Individual cold workspace temperatures, as measured by thermocouples at locations T2, T4, and T5, displayed the same high level of consistency as seen in previous tests.

Table 4 120° Phase Angle Performance Log Showing RPM and Temperature in °F after Engine Stabilization

	Thermocouple Locations (1-5) and Recorded Temperatures (°F)					Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
Time (Minutes into Run)	T_1	T_2	T_3	T_4	T_5				
25	194	82	163	81	82	179	82	97	729
27	195	83	163	81	82	179	82	97	720
29	195	83	162	81	82	179	82	97	708
31	195	83	162	81	82	179	82	97	691
µ	195	83	163	81	82	179	82	97	712

Table 5 125° Phase Angle Performance Log Showing RPM and Temperature in °F after Engine Stabilization

	Thermocouple Locations (1-5) and Recorded Temperatures (°F)					Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
Time (Minutes into Run)	T_1	T_2	T_3	T_4	T_5				
25	194	75	160	71	81	177	76	101	776
27	192	74	157	71	81	175	75	100	800
29	191	74	156	71	81	174	75	99	798
31	191	74	157	71	81	174	75	99	782
µ	192	74	158	71	81	175	75	100	789

Cold workspace temperatures had a grand mean of 75° F, whereas hot workspace temperatures indicate a grand mean of 175°F. The average ΔT returned to 100°F. The average RPM recorded during the test increased to 789, the highest yet obtained.

Findings: Phase Angle 130°

Contained in Table 6 are findings from the 130° phase angle test. Again, temperatures remained consistent. The mean ΔT was 100°F, but the RPM dropped to 738.

RPM dropped to 700 (see Table 7). This is the second consecutive drop in RPM, and it represents a substantial loss from the peak RPM value obtained with a 125° phase angle.

Summary of Findings Regarding the Ideal Phase Angle

The SWATT engine is a Stirling, however, it functions best with a phase angle that is significantly different from other Stirling engine configurations. It is not possible, at this time, to speculate as to why. What can be said is the ideal phase angle for SWATT is near 125°.

Table 6 130° Phase Angle Performance Log Showing RPM and Temperature in °F after Engine Stabilization

Time (Minutes into Run)	Thermocouple Locations (1-5) and Recorded Temperatures (°F) T_1	T_2	T_3	T_4	T_5	Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
25	193	81	163	79	80	178	80	98	794
27	193	81	164	79	80	179	80	99	795
29	194	81	165	79	81	180	80	100	751
31	195	81	166	79	81	181	80	101	610
μ	194	81	165	79	81	180	80	100	738

Findings: Phase Angle 135°

This was the last phase angle tested. Findings indicate consistency in all cold workspace temperature readings (grand mean of 82°F). Data from thermocouples monitoring hot workspace temperature (T1 and T3), however, display some variability that was not evident in previous tests. The hot workspace temperatures indicate a grand mean of 176°F. The average ΔT was 94°F, and the

The mean ΔT has been reported in the discussions of phase angle tests. This has been provided for information purposes only. Although it seems to cluster around or at 100°F, it is not speculated that this has any relationship whatsoever to a maximized RPM for a given phase angle. Had the test procedure specified temperature measurements in °C, the derived values for mean ΔT would not have appeared so "calculated."

Table 7 135° Phase Angle Performance Log Showing RPM and Temperature in °F after Engine Stabilization

Time (Minutes into Run)	Thermocouple Locations (1-5) and Recorded Temperatures (°F) T_1	T_2	T_3	T_4	T_5	Mean Hot: $(T_1 + T_3) \div 2$ (°F)	Mean Cold: $(T_2 + T_4 + T_5) \div 3$ (°F)	ΔT: (Mean Hot – Mean Cold) (°F)	RPM
25	192	83	159	81	82	176	82	94	704
27	187	83	154	81	82	171	82	89	700
29	191	83	161	81	82	176	82	94	739
31	193	83	164	81	82	179	82	97	658
μ	191	83	160	81	82	176	82	94	700

Contained in Table 8 is a brief summary of findings that support a phase angle of 125°. Other performance characteristics have been observed during the initial running of the engine. The mean ΔT from ambient at which initial running occurs is 70°F with a corresponding RPM of about 550. From this point, the engine gradually heats to a mean ΔT of 99°F and the sustained 800-850 RPM. This represents steady state and the performance remains basically unchanged for the length of an individual test run (maximum to date of about six hours). This performance is based on the previous indicated parameters while using air as the working fluid, atmospheric buffering from below, and no regenerator. The mean ΔT at initial start is noteworthy. It has been documented on all engine tests utilizing the 125° phase angle.

Table 8 Summary of Phase Angle Study Findings

Phase Angle	ΔT (°F)	RPM
90°	95	411
115°	100	701
120°	97	712
125°	100	789
130°	100	738
135°	94	700

The Direction of Future Research Regarding this Engine

Commercial Stirling engines utilize noble gasses, such as hydrogen or helium, as the working fluid. These have superior thermodynamic properties. The SWATT engine was also designed for pressurized helium, which requires a gas-tight enclosure surrounding the flywheel/crankshaft and power piston/cylinder assemblies. The fabrication of this enclosure is incomplete at this writing. Once the enclosure is complete, the research will commence with optimization of selected traditional Stirling design parameters (e.g., volume compression ratio). The really significant optimization, however, will focus on the configuration of the rotary displacer itself. This is believed to be the key feature in terms of simplicity, reliability, and, hopefully, increased power output. Of particular consequence is the configuration of the first displacer segment. This controls the opening and closing of the hot and cold ports and also the duration of same as well as any overlap, during which times both ports are simultaneously open.

Implications of this Technology for an Energy Conscious World

The idea of using the Stirling cycle in hybrid electric applications is not new. Recent research provides ample evidence. Obtaining reliable, sustained engine operation coupled with reasonable power output, however, constitutes the real problem. When this becomes reality, there will be myriad applications.

The initial application of this technology, as far as the author was concerned, was in association with the small electric-powered vehicles that were recharged from the grid during non-operational periods. The storage batteries used by these vehicles provided sufficient charge for intra-city commuting for up to four hours, after which recharging was necessary. The vehicles could operate somewhat longer, however, failure to recharge at this point would shortly cause a condition known as deep discharge. Deep discharge always required excessive grid time recharging and could also be potentially damaging to the batteries. An on-board Stirling engine, operating on environmentally friendly fuels, could act as an auxiliary recharger in the field, thus extending the vehicle's range and lessening required charging time on the grid.

A similar concept involves fleet use. In this application, a larger Stirling-powered generator in a stationary configuration, would be harnessed to recharge batteries of small, electric-operated fleet vehicles. This would eliminate the added cost of individual on-board Stirling engines and would enable the use of exclusively electric propulsion without extra demands on the power grid.

On a broader scope, this engine could find application in electric generation through waste heat recovery. Early research in this area, as cited in the introductory sections of this paper, indicates a potential contribution.

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Impact of Climate and Geographic Location on Moisture Transport in Wood Construction Walls and Implications for Selecting Vapor Retards

Kennard G. Larson

Abstract

This research effort studied two similarly built homes in two different geographic locations in an attempt to demonstrate the affect that climatic conditions have on the selection and installation of appropriate vapor diffusion retarders to control moisture transport in wood-framed structures. Much misinformation and suppositions exist regarding which vapor diffusion retarder to use, where to place it within the structure, and whether it is even necessary. As a result, uncontrolled moisture transport is often a significant factor in the premature degradation of a structure; this also adds to poor indoor air quality resulting from the growth of mold and mildew. Nine climatic values of temperature, humidity, and air pressure were recorded at 20-30 minute intervals at various locations within the wall cavities and the outside of both test structures, for a 12-week period from January to March. These data allowed the researchers to perform calculations to predict the potential for growth of mold or mildew within the structure. Ultimately, these data were further compared for moisture transport behavior with the simulation software WUFI ("Wärme und Feuchtigkeit Instationären), a PC program developed by the Institute for Building Physics in Germany and the Oak Ridge National Laboratories in Tennessee for calculating coupled heat and moisture transfer in building components.

Keywords: wood-framed house, sheathing, fiberglass insulation, moisture barriers, vapor barriers, intelligent vapor diffusion retarders, vapor diffusion retarders, moisture-thermal properties

Introduction

Moisture in buildings in the United States is considered one of the single, largest factors limiting the service life of a building (Lstiburek, 1991). In addition to the obvious liquid water, or rain, that can permeate the building envelope, the infusion of water vapor is of equal or greater concern because it is not visible or readily recognized. Water vapor can be controlled by placing the proper vapor diffusion retarder at proper locations within the wall components. A vapor diffusion retarder is typically, and less accurately, referenced in most literature as a "vapor barrier." However, a vapor retarder does not prevent all moisture from passing through as does a barrier (U.S. DOE, 2011).

Problem Statement

Incorrect use of vapor diffusion retarders ranks high on the list or controversial techniques and incorrect applications in construction (Laliberte, 2008). Much misinformation exists about which kind of vapor diffusion retarder to use, where it should be located, and if it is necessary. Illustrating this point, an Internet search at a do-it-yourself construction website revealed the following post: "Everything I've read says to put up a vapor barrier between the insulation and the drywall. They mention plastic sheeting, but nothing tells what (thickness) to use." The answers varied from: "Any plastic sheeting will provide a substantial barrier. The cheaper the better," to more accurate, scientific solutions (Tribe, 2007). Not only must vapor diffusion retarders limit moisture from getting into the construction, they also must let moisture out if indeed it does permeate the construction (Lstiburek, 2011). As such, the "plastic sheeting" mentioned in the blog as a solution, is not suitable in many climates. The goals of this research effort were to determine (a) the moisture transport activity in exterior walls of wood-framed construction, (b) the extent that geographical elevation above sea level affects the climatic and moisture transport behavior in similarly designed and constructed buildings, (c) if there is a preferred position/location for various types of vapor retarders (i.e., on the interior or exterior surface of the wood frame), and (d) which of the tested vapor retarder materials, if any, provides an adequate level of moisture control to inhibit the development of mold or fungus.

The test structures for this research were residential, single-family homes typical to the Midwest region in the United States. The Energy Efficient Building Association (EEBA) classifies this region as a "Heating Climate" region (Lstiburek, 2011) and recommends different moisture control methods for specific regions. Figure 1 shows Test Structure 1, later referenced as the Kearney Project, located in Kearney, Nebraska, with latitude 40° 44' N, elevation 652 meters above sea level. Figure 2 shows Test Structure 2, later referenced as the Laramie Project, located in Laramie, Wyoming, with a latitude 41° 3' N, elevation 2193 meters above sea level. Because the EEBA does not differentiate for elevation values above sea level, it was of interest to see if elevation and the impact of atmospheric air pressure may be a factor in potential for mold growth.

Figure 1. Kearney Test Project

Figure 2. Laramie Test Project

Wall Construction and Material Combinations

As is typical in most North American wood-frame construction (ICC 2006), the material assemblies of the exterior wall frames of both structures were constructed according to Table 1. The types of construction materials that comprise the wall assemblies are listed from exterior to interior, and the thicknesses (t) of various building components is listed in millimeters. In both test structures, the walls that were tested faced north. All measurements referenced in this paper are listed in metric equivalent values. The materials used in the construction of the walls of both test structures were identical with the exception of a kraftpaper vapor retarder and hardboard siding in the Kearney project versus a nonpermeable polyethylene vapor barrier and fiber cement siding in the Laramie project. Because the influence that climate had on mold development was the variable in question, these material differences were insignificant. Figure 3 and Figure 4 illustrate the different vapor retarders at the location of the measurements.

Figure 3. Kraftpaper Vapor Retarder, Kearney

Research Methodology

Data were collected using a “data logger” capable of capturing and storing nine measurement values every 20 to 30 seconds in the computer memory. All data were recorded in metric units, and this collection continued for at least three months at each location. Data were downloaded to a spreadsheet to generate graphic

Table 1. Sizes and Material Types of Wall Layer Components of the Test Structures

Layer		Kearney		Laramie
	t [mm]	material	t [mm]	material
Exterior paint		prepainted		1 coat latex primer 2 coats latex topcoat
Siding	10	"lapped" hardboard "Masonite Colorlok"	10	"lapped" fiber cement "Hardiboard"
Wind and water retarder		"Tyvek" (58 Perm)		"Tyvek" (58 Perm)
External sheathing	13	OSB	13	OSB
Insulation	89	R-11 Fibre glass batt	135	R-19 Fibre glass batt
Vapor retarder		kraftpaper	0,15	PE-foil (6 mil)
Internal sheathing	13	gypsum board (drywall)	13	gypsum board (drywall)
Interior paint		1 coat latex primer 1 coat latex topcoat		none

Figure 4. Polyethylene Vapor Retarder, Laramie

Figure 5. Data Logger and Interior Climate Sensors, Kearney

impressions of what was occurring within the walls regarding the development of moisture and the consequential potential for mold growth. Ultimately, anticipating the relative humidity (RH) on the inside surface of the oriented strand board (OSB) exterior sheathing was of interest due to the potential for mold growth at levels

Figure 6. In-Wall Temperature and Humidity Measurement Devices, Laramie

above 60% RH. For the Kearney project, the climatic data were collected for 12 weeks during winter 2006. For the Laramie project, the climatic data were collected for 12 weeks during fall 2004. For consistency, the measuring instruments were arranged in identical fashion in both structures, as illustrated in Figures 5 and 6. Care was taken to ensure that the same distances from reference surfaces were maintained.

Figures 7 and 8 illustrate location details and various positions of the sensors relative to the interior cavity of the wall and exterior atmosphere of the structure. The exterior temperature/moisture sensor is visible in Figure 7, while the Ahlborn data-logger, interior temperature/moisture sensor, and air pressure sensor are visible in Figure 8.

Table 2. Figure Code, Channels, Sensors, Values, Units, and Location of Sensors

Figure Code	Measure Channel	Sensor Type Temp	RH	Measured Values	Units	Location
i	M04	PT 100	Cond.	temperature and rel. humidity	°C %	air interior
i1	M00	Coup.		temperature	°C	air interior
i/e 0,0	M01	Coup.		temperature	°C	inner surface of drywall
i/e 0,5	M02	Coup.		temperature	°C	in insulation at 60 / 80 % away from ext. sheathing
i/e 0,8	M03	Coup.		temperature	°C	in insulation 40 / 50 % away from ext. sheathing
i/e 1,0/150	M05	PT 100	Cond.	temperature and rel. humidity	°C %	inside of the ext. sheathing and 150mm from ceiling
i/e 1,0/ 350	M06	PT 100	Cond.	temperature and rel. humidity	°C %	inside of the ext. sheathing and 350mm from ceiling
e	M07	PT 100	Cond.	temperature and rel. humidity	°C %	air exterior
pA	M08			air pressure	haPa	interior of room

Figure 7. Location of Exterior Climate Sensor

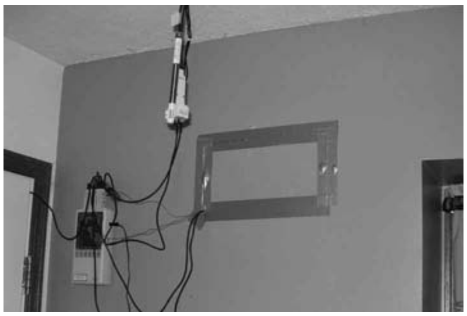

Figure 8. Room Climate Sensors and Sealed Cavity with Interior Sensors

Recording and Measuring Equipment

An Ahlborn data-logger, model 2590-9 recording instrument, allows logging of up to nine data inputs on channels 00 through 08. The data-logger was calibrated to record at 20-minute intervals for the Kearney project and 30-minute intervals for the Laramie project. The shorter interval was used to improve the accuracy of the measurements taken at Kearney in order to determine if the output graphic data might be easier to view. However, there appeared to be no significant difference. A typical display of the data-logger is observed in Figure 9. The nine channels recorded temperature, air pressure, and relative humidity at various locations on the structure.

The data sensors located throughout the construction included four PT100/condensator combination sensors to measure temperature and relative humidity, four thermocouple (Coup.) bimetallic temperature sensors, and one atmospheric pressure sensor. Table 2 describes which sensors were connected to respective channels, the variable that the sensor measured, the units of measurement, and the location of the sensors. The "Figure Code" column identified in Table 2 is for the purpose of viewing the "daily mean" values, relative to their location in the structure, in Figures 10 through 13. Rows of data in Table 2 are listed beginning with interior

Figure. 9 Ahlborn Data-Logger

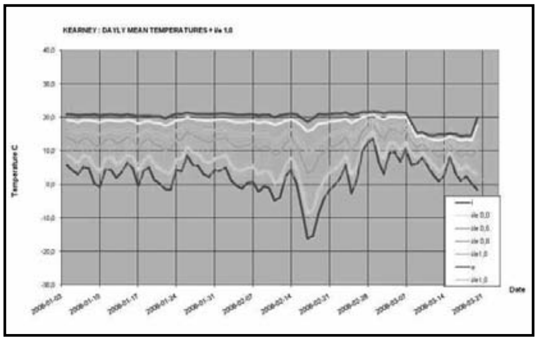

Figure 10. Temperature (C) from Interior to Exterior, Kearney

room measurement locations, moving throughout the wall, and ultimately to the exterior of the structure. The figure code column correlates to the "Location" column to observe where the sensors were placed in the assembly. For example, the sensor "i" was located in the interior of the room and measured temperature (degrees Celsius) and relative humidity (percentage) on channel M04 with a PT100 condensator instrument. In contrast, sensor "i/e 0, 05" was in the insulation but closer to the interior wall surface and only measured temperature (degrees Celsius) with a thermocouple on channel M02.

Measurement Results

After the data were collected, they were downloaded from the logger to a spreadsheet to generate the following figures. Figure 10 illustrates the daily temperatures for the Kearney project. The red line is the room interior temperature; subsequent colors measured temperature at increasingly further distances from the interior, progressing to the blue line, which represents the exterior temperature. The interior room temperature remained relatively constant with the exception of an extremely cold period beginning on Feb. 17, shown by the dark blue line. In contrast, the drop in interior room temperature beginning on March 7, shown by the red line, is attributed to the owner setting back the thermostat 7 degrees C (12 degrees F) during a two-week spring break.

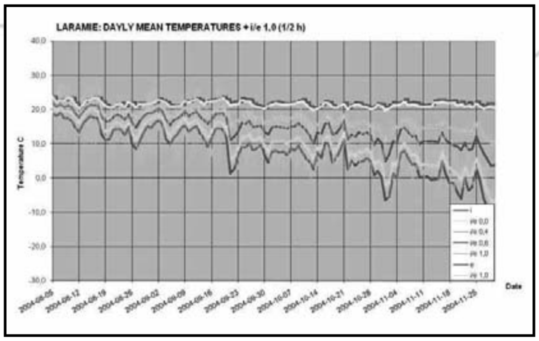

Figure 11. Temperature (C) from Interior to Exterior, Laramie

Figure 11 shows similar results with the exception of a somewhat higher and more variable indoor temperature. Possible explanations include perhaps the occasional use of an auxiliary heating device, such as a space heater or fireplace—they could also be the result of solar heat gain on sunny days.

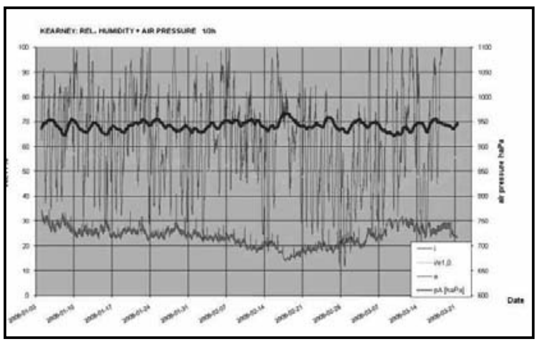

Figure 12. Relative Humidity and Atmospheric Pressure, Kearney

The critical consideration for mold potential is located at the interior surface of the OSB sheathing. Figure 12 graphs relative humidity (RH) levels at three locations: interior of room (red line), the interior surface of the OSB exterior sheathing (light blue line), and the exterior (dark blue line). In addition, atmospheric pressure (magenta line) was recorded in the interior of the room because of its influence on RH. Although the extremes in outdoor RH (dark blue) in the exterior atmosphere were great as noted by the wide range of readings, the RH within the wall construction (light blue), specifically on the inside surface of the OSB sheathing, was generally between 50% and 60%. At this low level of RH, no condensation would be expected, and therefore the development of mold would not be expected. A further observation is the relatively low RH within the living space of the room. It is likely that the lack of air tightness of the structure would explain this phenomenon by which moisture would escape via the high air exchange rate of the structure. Hagentoft (1996)

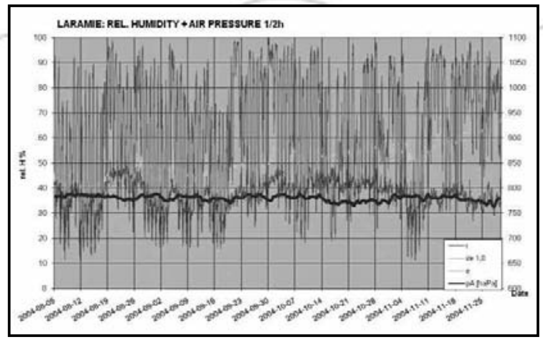

Figure 13. Relative Humidity and Atmospheric Pressure, Laramie

concluded similar results regarding air leakage carrying moist air into the construction that leads to unacceptably high values even for moderate indoor moisture levels.

Figure 13 demonstrates that low RH rates in the Laramie project at the interior surface of the OSB sheathing are attributed to the low air pressure (magenta line, ave. 750 haPa) at the relatively high elevation of 2193 meters above sea level. The low atmospheric pressure would lead to a high evaporation rate resulting in the low RH levels. Of special note is the increase of the RH from 40% in fall to 70 % at the beginning of winter. This would explain the appropriateness of using the nonpermeable PE vapor retarder at the much higher elevation without a concern for trapping moisture.

Simulation Models with WUFI

In an effort to determine if similar results could be attained through computer simulation, the researcher utilized the PC program WUFI (“Wärme und Feuchtigkeit Instationären Übertragung,” loosely translated “Unsteady Heat and Moisture Transfer”). The program allows the selection of different types of vapor retarder materials, the location/position of the vapor retarder within the construction, warm or cold climate conditions, and geographic conditions including longitude, latitude, and elevation. The advantage of using such simulation is that it eliminates the need to physically install sensors within wall cavities, thus reducing corresponding damage to the wall surfaces. Simulation also allowed the researcher to conduct a full one-year calculation in a matter of minutes.

Tests were conducted using common types of vapor retarder scenarios, including no vapor retarder, kraftpaper, polyethylene film (PE), and “intelligent” film (PA) on the inside surface of the insulation. Tests were also done to determine if exterior air barriers, such as “Tyvek” or kraft-paper, would influence the results. Intelligent vapor retarders are made of polyacetate or nylon and have a variable permeability rate that allows moisture to pass through the film depending on temperature and moisture conditions. PA allows the material to keep most moisture vapor out, but it also allows moisture vapor to dry out if a high level does infiltrate the wall cavity. As would be expected in standard construction, the vapor retarders that were tested were located directly under the interior gypsum board and on the interior surface of the OSB sheathing. A cold Test Reference Year (TRY) was calculated for Laramie, but for Kearney both a cold TRY and a warm TRY were calculated because of the higher humidity and the concern for potential mold development in summer. A TRY represents a time period beginning January 1 and concluding December 31.

Though TRY climatic data for either Kearney or Laramie does not exist in the WUFI (North American version), climate data were available in the WUFI for Omaha, Nebraska, and Casper, Wyoming, respectively. These available climate data were deemed adequate because Omaha and Casper represent a more severe climate for potential mold growth than either Kearney or Laramie, respectively. The preferred indoor climate was designed at a temperature 20°C and a relative humidity of 30% and 50%.

Three typical examples of the 24 simulations are presented in Figures 14 through 16. These sample simulation graphs were selected because they represent the exact construction materials of the Kearney and Laramie projects assuming a cold climate, with the additional simulation for Kearney in a warm climate. Two monitor positions (measuring points) were installed to record the temperature and the relative humidity at the exterior (position 3: red) and interior (position 4: blue) sides of the insulation. In Figures 14 through16, the Y-axis represents the temperature C and RH% (Feuchte), while the X-axis represents time (Zeit) over one TRY or 1-365 days. In Figure 14, the crucial summer months from day 125 to day 250 show the RH values well below 50%, thus showing no risk of mold growth in Kearney. For a very short period beginning on day 92, the RH may increase up to 100% at the inside of the OSB, but this risk is minimal because the Kraftpaper is relatively vapor open.

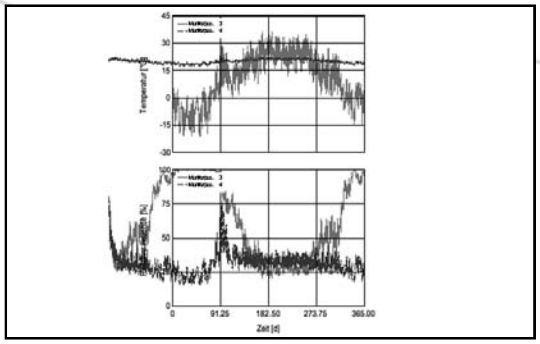

Figure 14. Kearney, Warm TRY with Kraftpaper Vapor Retarder and Indoor RH 30%

The simulation allowed the substitution of PE for kraftpaper in the Kearney project to see the how the results might vary. Thus, Figure 15 shows that even though PE foil would be an adequate vapor retarder in the winter (days 1-90 and days 275-365), during the summer the the PE foil would allow a higher RH of 50%-85% on both sides of the insulation, which would be a minor concern for mold damage. Therefore, kraftpaper is the recommended vapor diffusion retarder for the Kearney climate. It is relatively inexpensive and provides adequate potection without any risk of mold.

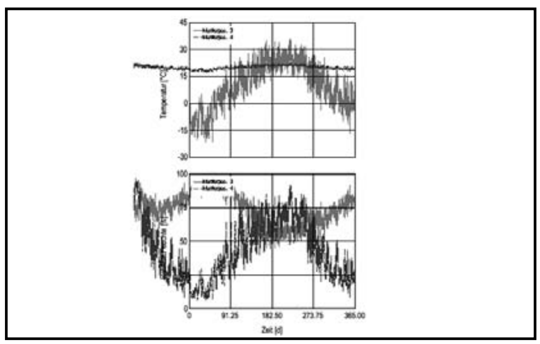

Figure 15. Kearney, Cold TRY with PE Foil Vapor Retarder and Indoor RH 50%

Figure 16 shows that PE foil is an acceptable vapor diffusion retarder for the Laramie climate, which has RH values below 50% in the

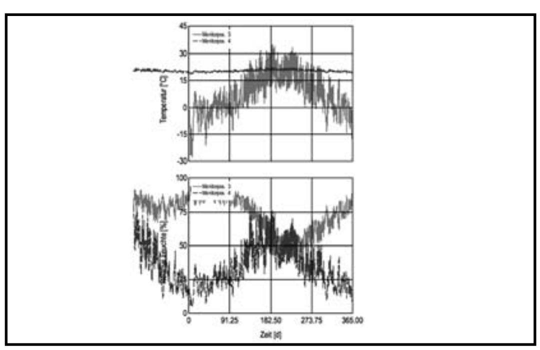

Figure 16. Laramie, Cold TRY with P.E. Foil Vapor Retarder and Indoor RH 50%

winter. Though in the summer the interior RH values can be above 50%, the high elevation and the associated low atmospheric pressure promotes rapid evaporation/drying and thus there is little concern for mold. This appears to be compatible with Lstiburek's recommendations (1991) for a maximum 35% indoor RH at 70 degrees F (20 C) during heating periods and when using PE foil as a vapor retarder.

The results of the WUFI simulations studies are shown in Table 3. It represents the results of the 24 simulations adjusted for the variables selected for the study. Data in the table are indicative of water per square meter (units in kilograms) (kg/m2) that could be expected on the interior surface of the OSB sheathing, depending on the type of vapor retarder. An assumption is made that values of less than 1 kg/m2 would be of little concern regarding mold development or condensed water. Values with an underscore are greater than 1kg/m2 ; they indicate that a particular vapor retarder would not be acceptable. Values in bold indicate the maximum result recorded for that test. Table 3 also illustrates that either in Laramie or Casper, there is little chance for mold to develop, regardless of the type of vapor retarder or whether a vapor retarder is even used. In contrast, it is apparent that while the type of vapor retarder used either in the Kearney or Omaha climate is of little consequence, not using a vapor retarder would be a genuine risk for mold. Regardless of the location of the vapor retarder or whether the climate data used was cold or warm, when using some type of vapor retarder, values were well within the acceptable limit of 1 kg/m2. Similarly, Levin and Gudmundsson (1999) concluded that when moisture loads are low, perhaps a vapor retarder is not necessary. However, indoor moisture conditions that exceed 2 kg/m3 will cause condensation on the inside of the external sheathing and high relative humidity in the insulation. This poses a significant potential for mold growth, structural damage, or both resulting from the degradation of the materials. Elevations above sea level are indicated in meters for all four cities. The data suggests that if an exterior air and moisture barrier, such as Tyvek or kraftpaper, was not used, then perhaps a vapor diffuser would not be necessary, explaining why many older homes without exterior air barriers do not have mold problems. Yet it is important to note that the advantage of exterior air and moisture barriers in reducing energy costs and preventing the exterior sheathing from becoming wet cannot be ignored.

Conclusions

The issue of mold growth and the consequential negative effect it has on structural damage to homes (e.g., wood members) as well as the impact mold can have on indoor air quality has become an increasing concern to builders and homeowners alike. This research concludes that the selection of proper vapor retarders to minimize the extent of damage is dependent on

Table 3: Need for Vapor Diffusion Retarders in Kearney and Laramie

Mineral Wool Insulation		**Values**		**Omaha**	Kearney	Insulation		**Casper**	Laramie	Insulation	
Water content				298 m El.	652 m El.	8,9 mm		1612 m El.	2293 m El.	12,5 mm	
[kg/m_]		**maximum**	start calc.:	0.16				0.24			
		interior VaporRetarder		none	kraft p.	PE	PA	none	kraft p.	PE	PA
Test Reference Year	warm	exterior Air Bar.	none	0.18	0.17	0.04	0.05	0.62	0.5	0.06	0.06
			(Tyvek)	**1.63**	**0.96**	**0.16**	**0.16**	**0.79**	**0.6**	**0.24**	**0.24**
	cold	exterior Air Bar.	none	0.19	0.17	0.04	0.03	0.53	0.43	0.05	0.06
			(Tyvek)	**1.96**	**0.96**	**0.16**	**0.16**	**1.1**	**0.78**	**0.24**	**0.24**
			none	0.19	0.17	0.04	0.05	0.53	0.43	0.05	0.06
			kraftp.	**1.96**	**0.97**	**0.16**	**0.16**	**1.1**	**0.78**	**0.24**	**0.24**

geographic location, elevation, and the choice of appropriate vapor retarders. It appears that the risk of mold is minimal at high elevations (such as Laramie) because of the rapid evaporation of moisture as a result of low atmospheric air pressure. It is apparent that a kraftpaper vapor retarder is adequate to control condensation within the walls of structures in geographic locations similar to Kearney; this can be accomplished with a minimal financial investment. In contrast, not to include a vapor retarder would pose a significant potential for mold growth in the Kearney climate. In any case, a vapor retarder at the inside surface of the insulation using foils that are open to vapor diffusion (e.g., kraftpaper or PA) is recommended. To conclude, during the winter, the temperatures in the Midwest United States are similar to those in Scandinavia. In contrast, during the summer, the United States has a tropical climate, very much unlike Scandinavia. Thus, the question of the location of the vapor retarder could not be directly correlated to previous studies from Scandinavia, some of which are cited in this article.

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Leveraging Green Computing for Increased Viability and Sustainability

Dominick Fazarro and Rochell McWhorter

Abstract

Greening of computing processes is an environmental strategy gaining momentum in the 21st century as evidenced by increased virtual communications. Because of the rising cost of fuel to travel to meetings and conferences, corporations are adopting sophisticated technologies that provide a "personal" experience for geographically disbursed colleagues to interact in real time. This article highlights several companies and academic professional organizations that utilize video conferencing, virtual classrooms, and virtual worlds to create digital spaces for collaboration. The article compares the impact of face-to-face collaboration that includes business travel expenses to the impact of the same activity in a virtual space. The human side of technology is also examined through virtual human resource development that increases employees' learning capacity and performance improvement. As advances in technology continue, it is expected that meetings will become more lifelike with the improvement of holographics. Corporations must continue to integrate green strategies to satisfy both environmental concerns and financial viability.

Keywords: green communication, virtual communication, virtual human resource development, sustainability

Leveraging Green Computing for Increased Viability and Sustainability

Introduction

Economic recession and soaring fossil fuel prices have affected the *viability* of many privately held companies and public and nonprofit organizations. To remain competitive and achieve their goals, organizations are increasingly leveraging sophisticated communication technologies so that individuals and workgroups at a distance can collaborate (Bingham & Connor, 2010).

Concomitantly, there is a movement toward more environmentally friendly *"green"* products and processes to increase *sustainability* (Witkin, 2011). According to Hasbrouck and Woodruff (2008), the importance of environmental issues has trickled down the supply chain and "permeated the awareness of consumers, regulatory bodies, OEMs, and others over the past few years" (p. 39), bringing with it new ways of conducting business. Further, in a 2008 survey, more than 80% of polled U.S. workers agreed that it was important to work for a company or organization that makes the environment a top priority (Kauffeld, Malhotra, & Higgins, 2009).

The purpose of this article is to highlight current trends that organizations use for collaboration and organizational learning that increase their viability and digital footprint. This article will also seek to demonstrate that these virtual communications are a *green computing* initiative for the sustainability of the environment.

The term *green computing* refers to the "study and practice of using computing resources efficiently" (Childs, 2008, p. 1); it is comprised of many facets, including the design, manufacture, use, and disposal of computer hardware and software (Lo & Qian, 2010). For this article, the authors will focus on the efficient use of computing resources for collaboration that reduces travel time and cost, increases organizational efficiency, and addresses environmental concerns.

Virtuality as Green Strategy

Technology is permeating both professional and personal lives as never before (McWhorter, 2010). Hopper and Rice (2008) discussed the benefit of "digital alternatives to physical activities" (para.7) as a way to reduce the impact of travel and the use of fossil fuels. They offered examples, such as electronic versions of newspapers, music downloads from the Internet, and online shopping. Likewise, collaboration with colleagues can be conducted via digital space.

The history of the Internet depicts users who have *connected to, through*, and *within* technology (Kapp & O'Driscoll, 2010; McWhorter, 2010). Figure 1 depicts these three distinct phases of the evolution of information and communication technology that are conducive for the greening of technology. In the 1990s, PCs became popular and employees and learners began *connecting to* technology to access useful data. In sharp contrast to earlier generations, the advent of new technologies, such as Web 2.0 tools, moved the user to the next step, *connecting through* technology to collaborate with others. The technology has now evolved so that it enables users to *connect within* the technology in immersive meeting spaces. Such environments allow for advanced collaboration and co-creation of user-made organizational content (Gronstedt, 2008) where users establish a virtual co-presence (the feeling of being present in the same digital space).

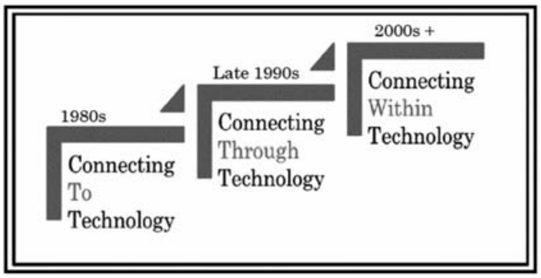

Figure 1. Evolution of Enabling Technologies for Green Computing (Source: McWhorter, 2011; adapted from Kapp & O'Driscoll, 2010)

Ted Nelson coined the term *virtuality* to describe the conceptual nature of an object (see Xanadu.com). Here the term *virtuality* is used to encompass synchronous (in real time) collaboration of learners and workers at a distance facilitated by integrated computing technologies. These synchronous collaborative "meetups" utilize integrated technologies, such as video conferencing, virtual classrooms, and virtual world platforms, so that colleagues can collaborate with each other although in geographically disbursed locations. In the context of green computing, each of these technologies will be discussed followed by the best practices of virtual collaboration for green computing.

Video Conferencing as Collaborative Green Spaces

The U.S. Travel Association reported that 31% of business travelers used videoconferencing in 2008 to replace at least one business trip (Bell, 2011). Video conferencing utilizes synchronous desktop media, such Skype™, Facetime™, or Yahoo Messenger™, to collaborate via text chat, voice, and video (through built-in or external webcam and microphone). According to Aamoth (2011), Skype™ was recently acquired by Microsoft, which opens the door to embedding it within Microsoft's many software applications.

For higher end video conferencing, companies can invest in a life-sized high-definition (HD) system, such as Cisco's TelePresence™, to conduct business with others at a distance (Kozubek, 2010) for truly "you are there" (p. 36) *telepresence* (technologies that make individuals feel they are meeting in the same space). This technology can connect team members face to face in virtual meetings transmitting full HD video to up to 48 locations globally. Viewing participants in HD appears to break down cultural barriers because participants can view common material on their computer screens and can see facial expressions and gestures.

Green computing also encompasses new trends in video conferencing, such as increased integration and portability. Smaller devices, such as smartphones (e.g., the iPhone™ and Blackberry Storm™) and digital tablets (e.g., the iPad ™ and HP TouchPad™) (Hiner, 2011) can be loaded with video conferencing software that requires smaller electrical loads. Such portable devices with video conferencing capabilities facilitate student learning, employee training, project management, and the broadcasting of organizational events (Toperczer, 2011).

Virtual Classrooms as Collaborative Green Spaces

A useful virtual classroom environment is formed by integrating voice over Internet Protocol (VoIP), a webcam, text chat capability, and the ability to share applications, such as a virtual whiteboard. In this digital space, users

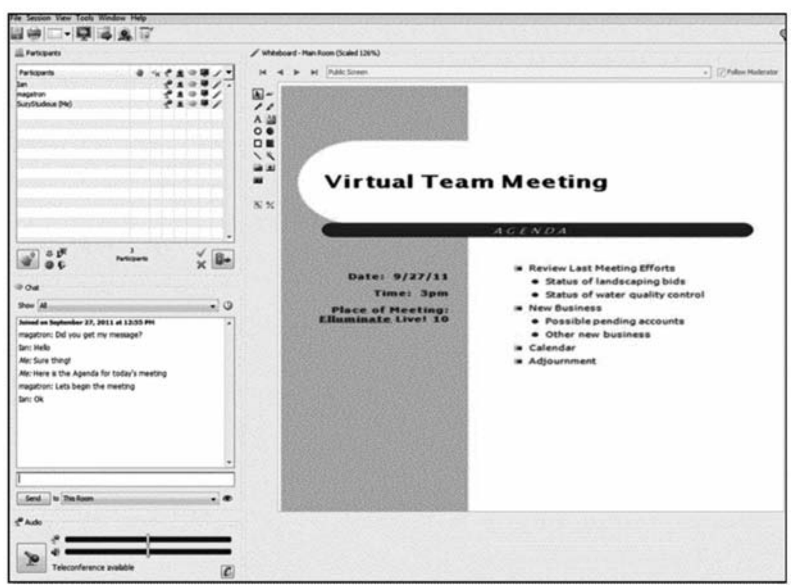

Figure 2. Screenshot of a Virtual Team Meeting using Elluminate Live! 10® (Top Left: List of Participants, bottom left: Instant Text Messenger, Right: Meeting Agenda)

can collaborate in real time through Internet technologies. An example of a virtual classroom environment is the Elluminate Live! 10 platform® that can be either a stand-alone product or one embedded into an organization's learning management system. This platform combines an interactive whiteboard, breakout rooms, two-way audio, multipoint video, desktop and application sharing, rich media, and session recording capabilities (Elluminate.com, 2011). See Figure 2 for a screenshot illustrating a virtual team meeting among three geographically disbursed colleagues.

Virtual Worlds as Collaborative Green Spaces

A virtual world has been defined as "a synchronous, persistent network of people, represented as avatars, facilitated by networked computers" (Bell, 2008, p. 2). According to KZero Worldwide (2011), approximately 42 million registered users (aged 25 and up) take part in various virtual worlds. These 3D virtual worlds are used for both entertainment and professional activities, including training and development (Chapman & Stone, 2010).

A recent study into the media-rich interactive environment of Second Life™ found it conducive for adult learning endeavors (Mancuso, Chlup, & McWhorter, 2010). Highly effective for simulations and collaboration, these green virtual spaces provide real-time opportunities for virtual teams and events (Bingham & Conner, 2010; Raisor & McWhorter, 2011). As a case study, Fazarro, McWhorter, and Lawrence (2011) described how nanotechnology safety training could be taught effectively in such an environment. Through avatars (graphic representations), users can interact with one another using local text chat, voice chat, and instant messaging via user-user or user-groups. Figure 3 depicts collaboration between two colleagues as they examine a 3D model of a Sulfuric Acid Plant; this exemplifies the *meeting within* (McWhorter, 2010) context of technology, and it saves organizations time and money and is beneficial to the environment because fossil fuels are not expended for unnecessary travel.

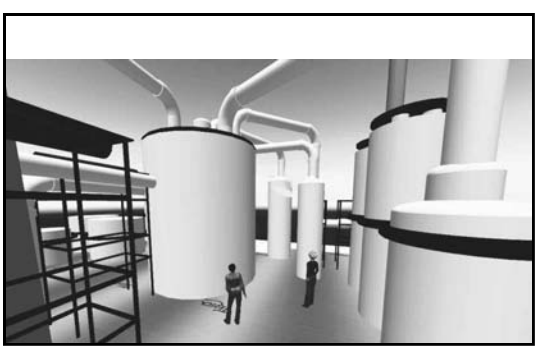

Figure 3. Virtual World Collaboration at a Sulfuric Acid Plant Source: Photo Courtesy of KR Virtual Designs

Greening of Professional Conferences: Adding the Virtual Component

A relatively new trend that buttresses the green computing concept is the addition of a virtual component to professional conferences. A number of professional organizations are now adding this option for members who cannot travel because of time or financial constraints. For a reduced conference cost, members can view the Keynote Address, a number of top presentations, and more. One example of a conference with a virtual component is the IEEE Nano Council's *Nano 2011* Conference in Portland, Oregon. If unable to attend, a member could participate in the post conference, including the conference program, full proceedings on a USB flash drive, and online access to narrated slides, which the organization noted would be "saving travel, hotel and meal expenses" (IEEE Nano 2011 ¶3). A sample of other national conferences that offer a virtual or online component includes The Society for Human Resource Management, the American Society for Training and Development, the American Library Association, and the National Board for Professional Teaching Standards. Figure 4 depicts a virtual meeting area where attendees can examine an online exhibitor hall that includes information about various products and services.

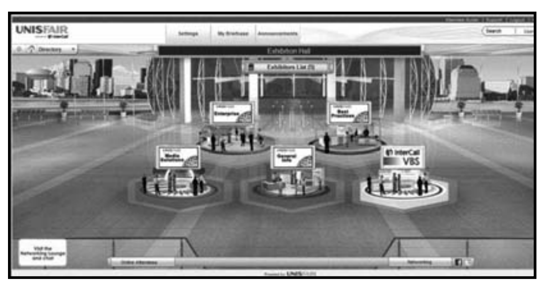

Figure 4. Exhibit Hall at a Virtual Conference
Source: http://events.unisfair.com

According to Bell (2011), virtual conferences are becoming more numerous. Some organizations offer a virtual conference component to their face-to-face (F2F) annual or semi-annual conference; however, some organizations are opting for the virtual-only conference, a true green computing initiative that benefits the environment and increases their viability.

Data has not been collected on either the number of individuals who attend virtual conferences or their feedback on the experience. However, a clue to market growth can be seen in the number of companies who offer support and services for virtual conferences. For instance, a recent search for virtual conference vendors revealed 40 companies that offered these services to organizations (Bell, 2011).

When contemplating a virtual conference as a hybrid component to a F2F conference or as a stand-alone event, organizations must consider the advantages and disadvantages afforded by each venue. Table 1 examines several dimensions, such as cost, convenience, and participation when comparing a F2F conference to a virtual conference.

Best Practices of Virtual Collaboration for Green Computing

Trevarthen (2008) and Räsänen, Moberg, Picha, and Borggren, (2010) provided the following best practices for using virtual communication within organizations:

1. Be mindful of the appropriateness of using virtual communications instead of F2F (need to know when and how to use it).

2. Determine the extent of executive and managerial buy-in using virtual technologies.

3. Establish goals and outcomes for using virtual communication.

4. Establish rules of engagement (protocols) with stakeholders.

In addition, Soule and Applegate (2009) established best practices for successful virtual project teams through virtual communications that included leaders adapting to technology. This is particularly important when organizations move from F2F meetings to virtual technologies.

Also, it is imperative that organizations spend adequate time and resources before they expect that members or employees will be

Table 1. Comparison of Face-to-Face Conferences to Virtual Conferences

Dimension	Face-to-Face (F2F) Conference	Virtual Conference
Cost to Attend	Conference Registration and Travel Expenses	Normally free or reduced conference registration; no travel fees required, but must have connectivity to access
Cost for Hosting	Typically very costly due to meeting spaces and food costs	Typically more cost-effective by paying a virtual conference vendor rather than F2F hotel venue
Convenience	Typical time required for travel and conference attendance	Can connect to virtual conference via desktop, laptop, or mobile device (contingent on chosen platform)
Global Participation	Attendees must spend greater travel costs and time expenditures to participate internationally	Although time zones are an issue, technology allows global real-time participation online
Networking	Connecting with colleagues and networking typically easier in F2F environment	Real-time collaboration is becoming available through integrated technologies such as virtual chatting, social media connections
Technology Integration	WiFi often unavailable to attendees in conference meeting rooms	Participation relatively easy with a reliable internet connection
Immersion	Easier to remove distractions and focus on the conference experience	More likely to be distracted by other tasks and daily routines
Post-Conference Experience	Follow-up normally done by organization in written format such as conference proceedings, newsletter and website reporting	Virtual conference can be fully archived through multimedia for asynchronous online access at attendee convenience

Adapted from: Bell (2011); Roberts and McWhorter (2011 effective with the new technology. Along with the greening of their collaborative efforts, organizations must enact virtual human resource development (VHRD) efforts to develop individuals' virtual technology literacy. VHRD is "the process of utilizing technologically integrative environments for increasing learning capacity and optimizing individual, group, community, work process, and organizational system performance" (McWhorter, 2011, p. 3).

These identified best practices are a sample of those that contribute to effective virtual communication. As technology improves, people must adapt and effectively use various technology-enabled collaborative techniques to maintain viability in the global marketplace and sustainability for the environment. The financial and environmental impact of using green computing will be discussed next.

What is the Impact?

According to LaBrosse, (2010): "The explosion of concern about the environment and the emerging business imperative for companies of all sizes to become sustainable presents a challenge for all managers" (p. 87). When introducing green computing within organizations, managers/leaders must first examine the cost benefits of the technology over the long term.

The impact of face-to-face collaboration involving geographically disbursed individuals and groups is costly from both the financial and environmental standpoints. For example, conventional travel to conferences requires using ground transportation, aircraft, or both, and these involve expensive fossil fuels and provide a massive output of CO2 (thought by a number of researchers in the scientific community to be very dangerous for the environment, and its impact is being investigated in many studies).

It is estimated that the average passenger automobile, for example, produces 8.8 kg of CO2 per gallon of gasoline with an average fuel efficacy of 20.3 miles per gallon (Environmental Protection Agency, 2005). Aircraft CO2 production varies by flight distance, and it is between .279 kg of CO2 per mile to .187 kg of CO2 per mile, depending on the length of the flight (Environmental Protection Agency, 2008). By comparison, videoconferencing makes use of equipment already available in the office, with the possible addition of a webcam. The savings made by decreasing travel for meetings that can be reasonably accommodated through modern technology have benefits that far outweigh any possible increase in energy used during videoconferencing.

In the 21st century, videoconferencing is an important activity of many businesses and organizations. One example of cost savings through videoconferencing follows. Ira Wainstein, partner and senior analyst of Wainhouse Research, focused on quality and speed of decision making and the development of more effective work teams and lower operation costs (Kozubek, 2011). Verizon Business™ (2011) designs videoconferencing technology to enhance the productivity of business meetings. Illustrated in Table 2, Verizon Business developed a cost comparison of four people attending a business meeting versus this meeting held via videoconferencing.

Corporations are facing uncertainty about the economy and the environment; however, companies are creating out-of-the-box approaches for viability and sustainability. Corporations that practice continuous improvement will provide new and innovative ways for cost and environmental savings both now and in the future (De Geus, 2002). Thus, ideas about the future of green computing will be discussed next.

Table 2. Cost Comparison with Videoconferencing Versus Business Travel for Four Employees

	Mode of Conference	
	Business Travel*	Videoconferencing*
Round Trip Flight, Transportation, Food, & Hotel Costs	$3,963.96	$1,320.00
Personnel Costs (i.e. meeting participants)	$1,233.54	$ 380.69
Total Time Spent for Conference	53.24 hours	16.29 hours
Total Costs	$5,197.50	$1,700.69
Money Saved		**$3,496.31**

**Note:* total costs. Adapted from Verizon Business (2011)

What does the Future Hold?

It can be speculated that in the year 2020, through the advancement of nanotechnology, processing speeds for computers will be tenfold compared to speeds in 2012. Also, the commitment to green communication will likely be commonplace for corporations that conduct business globally. In the future, advanced technology for conducting meetings may consist of full-scale virtual people to assist virtual communications. Figure 5 illustrates graphical interfaces for such collaboration in real time during the next decade.

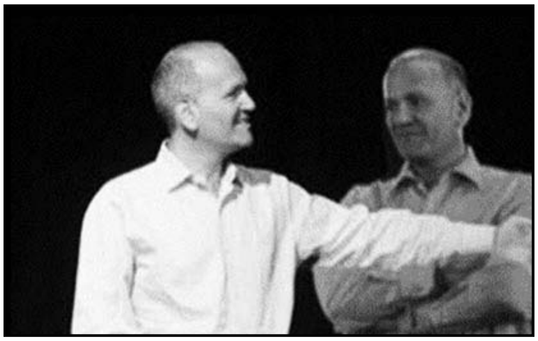

Figure 5 Real and Holographic Image Source: Barras (2009)

In fact, this depiction may be the optimal approach for virtual communication. For example, a CEO or an executive can conduct formal meetings using 3D high-definition holographic/virtual-world technology that projects an image of a person from any place on the planet to a place at the table. Furthermore, with sensors embedded in the holographic image, the image will have the tactile abilities that allow colleagues to shake the holographic hand of the person at the other worksite or event. For example, a full-scale *holodeck* might be used for a person to travel to London to attend a meeting without leaving the office. This technology has been researched for years with the concept derived from the science fiction show, *Star Trek: The Next Generation* (Grover, 2006).

This depiction may seem like science fiction, but with greater flexibility and capabilities formed through technology, virtual communications will likely become the main mode of conducting business. It is expected that the way people conduct business will likely be radically different during the next decade as they use increasingly sophisticated technologies.

Conclusion

The green technology movement is burgeoning as organizations are taking responsibility for the environment and embracing more efficient technology-enabled resources (Williams, 2007). This article has highlighted examples of cost savings and increased efficiency through the utilization of videoconferencing, virtual classrooms, virtual worlds, and virtual professional conferences. In addition, best practices for using sophisticated virtual technologies and future trends have been offered. These virtual initiatives provide a context for saving organizations time and money; they also benefit the environment by discontinuing unnecessary travel.

Organizations need to be cognizant of ways to achieve optimal savings regarding both financial and environmental impact and become savvy as they leverage technology in meaningful ways. Organizations should consider additional outcomes, such as recruiting new members through virtual conferences as these provide increased access to a global market.

Green computing allows for greater connectivity and customer service through efficiency of use. In the current lean status of organizations, technology should be considered for increasing membership, forming collaborative partnerships to share resources, and offering professional development. In addition, organizations should help their leaders and members to become more technologically astute.

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The 2010 Paul T. Hiser Exemplary Publication Award Recipient

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Criteria

1. The subject matter of the manuscript must be clearly in the domain of one or more of the professions in technology.

2. The article should be exemplary in one or more of the following ways:
    - Ground-breaking philosophical thought.
    - Historical consequence in that it contains significant lessons for the present and the future.
    - Innovative research methodology and design.
    - Trends or issues that currently influence the field or are likely to affect it.
    - Unique yet probable solutions to current or future problems.

A $300 award recognizes the recipient(s) for the year and is presented during an Epsilon Pi Tau program at an annual professional association conference.

GUIDELINES FOR
The Journal of Technology Studies

A refereed publication of Epsilon Pi Tau the international honor society for professions in technology.

The Journal of Technology Studies (JOTS) is the flagship, peer-reviewed journal of Epsilon Pi Tau, an international honor society for technology professions. One printed volume per year is mailed to all active members of the society as well as to subscribing academic and general libraries around the globe. All issues (begining wih 1995 to the current year), both print and those published in electronic format, are available online at scholar.lib.vt.edu/ejournals/jots.

The journal is indexed in Current Index to Journals of Education, the International Bibliography of the Social Sciences, and by VOCED, the UNESCO/NCVER research database for technical and vocational education and training maintained by NCVER in Adelaide, Australia (www.voced.edu.au).

SUBJECT FOCUS

The JOTS welcomes *original* manuscripts from scholars worldwide focused on the depth and breadth of technology as practiced and understood past, present, and future. Epsilon Pi Tau, as perhaps the most comprehensive honor society among technology professions, seeks to provide up-to-date and insightful information to its increasingly diverse membership as well as the broader public. Authors need not be members of the society in order to submit manuscripts for consideration. Contributions from academe, government and the private sector are equally welcome.

An overview of the breadth of topics of potential interest to our readers can be gained from the 17 subclasses within the “Technology” category in the Library of Congress classification scheme (lcweb.loc.gov.catdir/cpso/lcco/lcco_t. pdf). Authors are strongly urged to peruse this list as they consider developing articles for journal consideration. In addition, JOTS is interested in manuscripts that provide:

- brief biographical portraits of leaders in technology that highlight the individuals’ contributions made in dis tinct fields of technology or its wider appreciation within society,
- thoughtful reflections about technology practice,
- insights about personal transitions in technology from formal education to the work environment or vice versa, • anthropology, economics, history, philosophy, and sociology of technology,
- technology within society and its relationship to other disciplines, • technology policy at local, national, and international levels,
- comparative studies of technology development, implementation, and/or education,
- industrial research and development,or
- new and emerging technologies and technology’s role in shaping the future.

The immense diversity of technology, along with its applications and import, requires that authors communicate clearly, concisely, and only semi-technically to readers from a diverse set of backgrounds. Authors may assume some technical background on the part of the reader but not in-depth knowledge of the particular technology that is the focus of the article. Highly technical articles on any field of technology are not within the purview of the journal.

Articles whose focus has been extensively explored in prior issues of the Journal are of potential interest only if they (a) open up entirely new vistas on the topic, (b) provide significant new information or data that overturn or modify prior conceptions; or (c) engage substantially one or more previously published articles in a debate that is likely to interest and inform readers. Syntheses of developments within a given field of technology are welcome as are metanalyses of research regarding a particular technology, its applications, or the process of technical education and/or skill acquisition. Research studies should employ methodological procedures appropriate to the problem being addressed and must evince suitable design, execution, analysis, and conclusions. Surveys, for example, that exhibit any or all of the following characteristics are of no interest to the journal: (a) insufficient awareness of prior research on this topic, (b) insufficient sample size, (c) improper survey design, (d) inappropriate survey administration, (e) high mortality, (f) inadequate statistical analysis, and/or (g) conclusions not supported by either the data or the research design employed. The JOTS is neutral in regards to qualitative, quantitative, or mixed method approaches to research but insists on research of high quality.

GUIDELINES FOR The Journal of Technology Studies (Continued)

GUIDELINES FOR SUBMISSION

Articles must conform to the current edition of the *Publication Manual of the American Psychological Association.* All articles must be original, represent work of the named authors, not be under consideration elsewhere, and not be published elsewhere in English or any other language. Electronic submissions in either rich-text format or Microsoft Word formats are required. E-mail submissions should be sent to the editor at jots@bgsu.edu.

Manuscripts should be no more that 25 double-spaced and unjustified pages, including references. Abstracts are required and should be no longer than 250 words. Also required is a list of keywords from your paper in your abstract. To do this, indent as you would if you were starting a new paragraph, type *keywords:* (italicized), and then list your keywords. Listing keywords will help researchers find your work in databases.

Typescript should be 12 point *Times New Roman* or a close approximation. Only manuscripts in English that conform to American usage will be accepted. Figures, tables, photographs, and artwork must be of good quality and conform to the *Publication Manual of the American Psychological Association, specifically complying with the rules of Style®* for form, citation style, and copyright. The Journal of Technology Studies seeks to maintain the highest standards of academic integrity and asks all contributors to apply proper due diligence in manuscript preparation.

REVIEW PROCESS

Articles deemed worthy for consideration by the editor undergo anonymous peer review by members of the JOTS editorial board. Authors who submit an article that does not merit review by the editorial board are informed within approximately three weeks of receipt of the article so they may explore other publishing venues. A rejection may be based solely on the content focus of the article and not its intrinsic merit, particularly where the topic has been extensively explored in prior JOTS articles. Articles that exhibit extensive problems in expression, grammar, spelling, and/ or APA format are summarily rejected. Authors of articles that have been peer-reviewed are informed within about two to three months from the date of submission. Anonymous comments of reviewers are provided to authors who are invited to submit a revised article for either publication or a second round of review. The editor does not automatically provide reviewer comments to authors whose articles have been rejected via the peer review process. However, such feedback may be provided if the editor determines that the feedback might prove helpful to authors as they pursue other publishing opportunities.

PUBLICATION

Accepted articles are published in the on-line version of the journal (http://scholar.lib.vt.edu/ejournals/JOTS/) as the manuscript exits the layout and proofing process. Currently, JOTS articles also appear in a print issue at the end of the calendar year. Authors co-retain rights to the published article along with Epsilon Pi Tau. When requested, the editor will supply information about an accepted article that has not yet appeared on-line or in print for faculty undergoing tenure review.

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