2006-655: A SOLAR-POWERED DECORATIVE WATER FOUNTAIN HANDS-ON BUILD TO EXPOSE ENGINEERING CONCEPTS TO NON-MAJORS

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A Solar-Powered Decorative Water Fountain Hands-on Build to Expose Engineering Concepts to Non-Majors

A creative replicable hands-on activity is described which introduces the engineering design process and exposes undergraduate students to issues of energy sustainability. The activity can be used in a standard undergraduate science with lab requirement course as offered by physics or engineering faculty or can be incorporated into an undergraduate engineering curriculum. A fountain metaphor symbolizes the human need for water and energy and is used to sensitize the students to the global inequities in water and energy resources. By focusing on a technological issue that impacts both the global community and everyday life, relevance is used as the motivator to recognize energy technology as an accessible and tangible subject. The solar fountain combines a small DC water pump with readily available solar panels. Three unique fixtures were designed specifically to accommodate a wide range of shop skills. These fixtures help to maximize success and minimize frustration in populations with little to no background in tool handling. A successful laboratory experience helps to de-mystify the engineering process. The fountain design is left to the student who is encouraged to mix artistic sensitivity into an engineering process. The resultant fountain builds self-confidence and the activity is highly rated by students. The module was assessed on two levels: attitudinal and learning criteria with a group of female campers at the Science, Technology, and Engineering Preview Summer (STEPS) program 2005.

Background

Technology drives our society and our economy yet few non-engineering majors consider taking courses about technology. Energy is arguably one of the most important issues of the 21st century, yet many undergraduate students know little about energy production or our energy supply. Engineering a solar-powered fountain can introduce undergraduate students to renewable energy. It is designed to accompany lectures on energy, solar power and sustainability. Depending on the depth of these lectures, the described laboratory activity can be used in a general freshman level *'science with lab'* core course or can be incorporated into a sophomore level mechanical or electrical engineering course with additional advanced options.

A technology-literate population is a critical national asset in the global market, and it is necessary for every person in the U.S. to "be all they can be, technically".[1] In 2002, mechanical engineering positions were among the most numerous available to bachelor's degree students.[2] The cold facts are that few U.S. citizens are selecting technical careers, particularly engineering. Reasons for this lack of interest in engineering are systemic, starting with pre-college students and their teachers, who either do not know what engineering is or who avoid it based on their negative perception of what engineering is about.[3] Very few non-majors ever have the opportunity to take an engineering class because of the lengthy pre-requisites and the lack of available 'technology for non-majors' offerings. Many students do not see the relevance of engineering work to themselves or to society as a whole.[4] Thermodynamics, in particular, focuses on the abstract concepts of restrictions on energy transformations and energy conservation. Engines, power plants, and refrigeration seem inaccessible and sterile, separate from common human experience. In reality, thermodynamics deals with the application of energy towards useful work, yet the work, and its impact on the world, are seldom addressed explicitly. To many non-majors, energy technology seems huge, distant, foreign, and cold. In this laboratory activity, the successful building of a decorative fountain is used to explain energy transformation and make it more accessible and understandable.

Including an Environmental and Social Impact Lens

Talented high-school girls with the correct math and science pre-requisites tend to prefer health science to engineering[5], probably because they seek socially important or beneficial work.[6] The current solar-fountain laboratory was tested on forty 11th grade campers at an advanced STEPS summer program to see if teaching technology through socially impacting topics would result in a behavioral outcome; would the students actually change what they do as a result of their experience. At this point we only have data about participant intentions, but future surveys will follow up to measure actual academic choices.

The current paper focuses on incorporating a humanities approach to technology pedagogy. There have been calls to integrate humanities topics into engineering education. Isaacs and Tempei have published retention successes by de-emphasizing math and science, and emphasizing engineering with a humanitarian focus and social usefulness.[7] There have also been articles in the engineering education literature calling for change in educating engineers.[8,9] Specifically, engineers must become cognizant of technologies that minimize negative environmental and social consequences.[10] Although engineering is clearly interlinked with social and political activity, a sweep of the literature does not yield any specific attempts to include such topics in the curriculum or to use *personal or global* issues as the main vehicle to deliver technology topics.

Challenging Student Preconceptions

There has been evidence that people see engineering as a homogeneous group of men with narrow personality traits; a profession shaped by people who lack imagination and creativity[10]. Despite intensive efforts to recruit new people into engineering, little psychological data has been compiled focusing on changing the current stereotype. Isaacs[11] suggests educating people about what engineers actually do and challenging the negative perceptions of engineers. One objective of the solar fountain build activity is to emphasize that engineering design is a creative process and that there is more than one way to achieve an objective.

Different modes of instruction are needed to reach out to the varied learning styles of students. The introduction of hands-on group activities to freshman engineering classes has yielded increased interest,[12] and it is well documented that collaborative and active learning are effective pedagogical tools.[13,14,15] Successes have been documented in retaining engineering students by breaking up the monotony of lectures and by introducing team and cooperative learning[6]. Specifically, students find that the introduction of experimental tasks adds to their learning. Women in particular need a better balance in curriculum between the technical and social aspects (communication and interpersonal skills) of engineering.[6] The solar fountain build presents engineering as a team oriented activity based on a systematic process to create products that benefit humankind.

In a society where most of our 'gadgets' are not designed to be opened or fixed, fewer and fewer undergraduate students have had the opportunity to tinker with things in their childhood. Because technical disappointment and failure will negatively impact user satisfaction and perception of value,[16] every attempt was made to avoid frustrations generated by the lack of tool handling experience. Three unique fixtures were designed to accommodate a wide range of shop skills and maximize student success. All the participants created a working fountain with little to no frustration.

<u>Laboratory Process</u>

Brainstorming Session

At the beginning of the first lab session, the students were asked to diagram three design process charts in their lab notebooks (Table 1), the *Customer Requirements*, the *Engineering Specifications* and the *Quality Function Deployment Matrix*. This is an interactive activity led by the instructor and the charts are drawn by the students from the class discussion. The purpose is to emphasize to the students that engineers use a systematic, question-driven process to design new items. Though this seems quite intuitive, many students wrongly believe that engineering design exclusively involves difficult equations or mathematics, and thus is not comprehensible to the general public.

Table 1. Introduction of the engineering design process

Assignment	Answers the question	Examples
1. State project objective and customer.	What are you making? Why are you making it? For whom are you making it?	A fountain utilizing a renewable energy source.
2. Customer Requirements	What does the customer want?	Aesthetically pleasing; nice sound; reasonably priced; shoots up 15 cm, etc.
3. Engineering Specifications	Identify the required functions. List components required to accomplish the task. Describe the components in technical terms.	Pump needed to move 20 gallons per hour. Pump needs to have 6 V DC power to match solar panels. *most of this information is provided by the instructor with ample explanation. *Some in-class algebra based problems can be guided and solved in small groups.
4. Quality Function Deployment Matrix (QFD)	Are all objectives and requirements met?	A matrix with customer requirements on one axis and the engineering specifications

		on the other axis showing relation between components and functions.

Concept Generation

The brainstorming session may come up with an assortment of pump and solar panel requirements. However, in a course for non-engineering majors, it is easier to have the pump and panels pre-purchased and guide the students through a sizing exercise. If the activity is embedded into an engineering curriculum, the students can be asked to find the appropriate components, create a bill of materials and order the components themselves. After the students receive their pump and panels, ideas for fountain styles can be found from websites or print resources.[17] Students are then asked to draw a sketch of the proposed fountain in lab notebook and describe in detail component placement. The sketch should clearly show creative design thought with sufficient attention to pump and panel location. The final design may change, but it is important for the students to clearly indicate their thought process.

Build Phase

The build activity has three distinct sections:

1. Solar panel & pump assembly
2. Fountain composition
3. Panel holder

The required materials are listed in Table 2, tools are listed in Table 3 and the assembly instructions are listed in Table 4. The solar panel-pump assembly allows students to drill holes, add fasteners and solder wires. The drilling tool guide (Figure 2) was found to be an essential tool to avoid student frustration. A detailed metric drawing is in Appendix III and an English drawing can be found on the project website[18]. The tool guide enables the holes to be drilled through a masonite strip and the solar panels correctly (Figure 1). The wood scrap board was also found to be important to avoid drilling into the laboratory workbench. The design to have two panels held together by a masonite strip enables the instructor to introduce concepts such as photovoltaic (PV) panels in series, PV panels in parallel, total power, voltage and current, as well as basic energy units. The instructor introduces how a photovoltaic panel works as well as how it is manufactured. The instructor also can introduce wiring symbols and have the students draw a wiring sketch in their lab notebook and record the step-by step instructions. Finally, the students test the solar panel-pump assembly (Figure 3) by placing the pump in a bucket of water and a shining a bright light on the panels before moving to the fountain composition.

Figure 1. Mini solar panels

Figure 2. Drilling tool guide with masonite strip

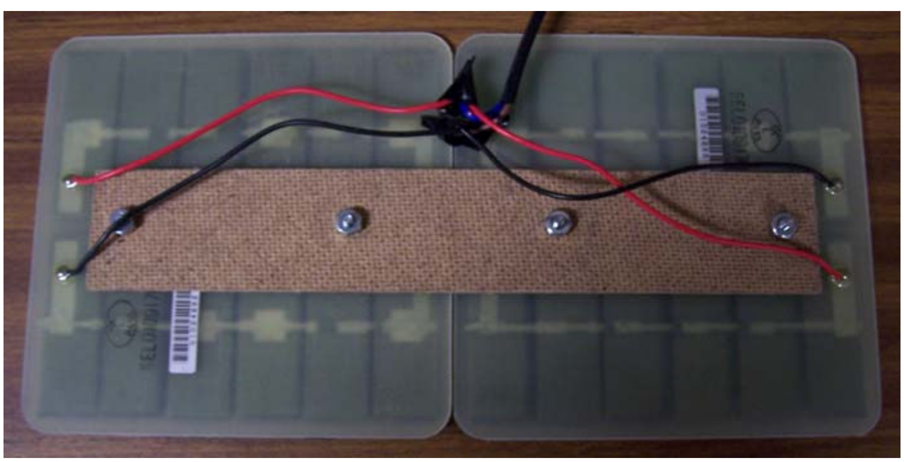

Figure 3. Pump-PV panel assembly.

During the fountain composition step (Figure 4) students learn to cut and bend tubing. Tube bending is surprisingly difficult for many beginners and it is important for the instructor to point out that tube benders accommodate different diameter tubes. The concept of inner and outer diameters of tubing and the differences between piping and tubing is introduced. To avoid student frustration, encourage simple bending shapes. The pump connects to the aluminum tubing (spout) using a small piece of vinyl tubing. The student must hide the pump and minimize the exposure of the power cord. The fountain composition uses the imagination and creativity of the students. It is explicitly pointed out to the students that there is no one right solution. Rarely do the pieces fit as originally sketched and some adjustment is necessary. It is important for the instructor to allow the students to engineer their own solution to help build self-confidence.

Figure 4. Fountain assembly

The final step is to make a solar-panel holder. A special foam holder (Figure 5) and hot wire Styrofoam cutter (Figure 6) were designed to ensure student success. The Styrofoam cutting is done with two students (Figure 7) and two stands can be made from one Styrofoam block. The construction of the hot wire cutter is described in the Appendix I. A detailed metric drawing of the foam holder is found in Appendix III and an English version of the fixture can be found on the project website.[18] The Styrofoam cutting enables a discussion about joule heating. The entire fountain can be checked with a light bulb or taken outside on a sunny day (Figure 8).

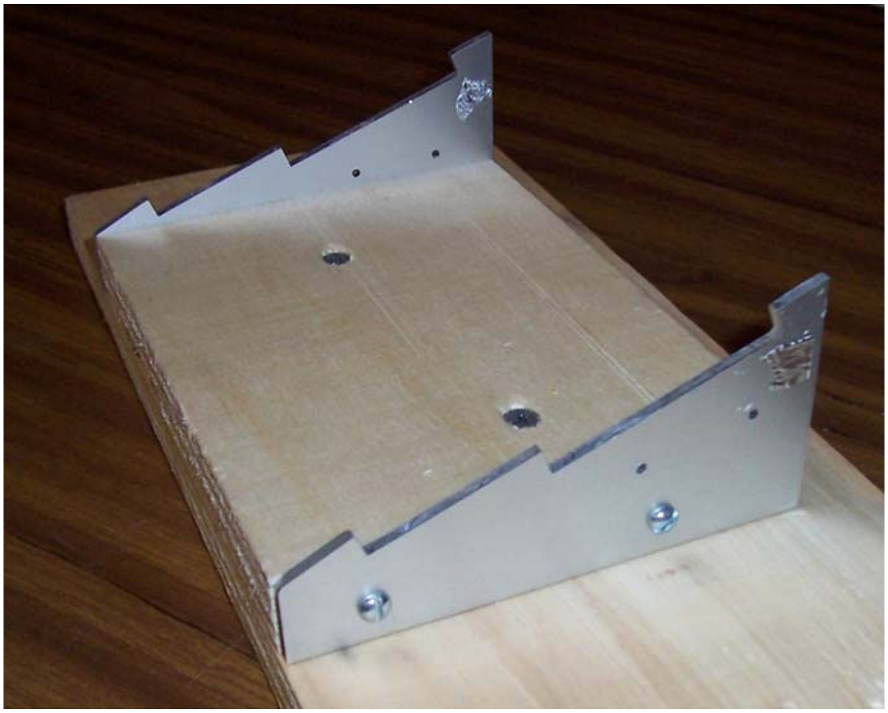

Figure 5. Foam cutting fixture.

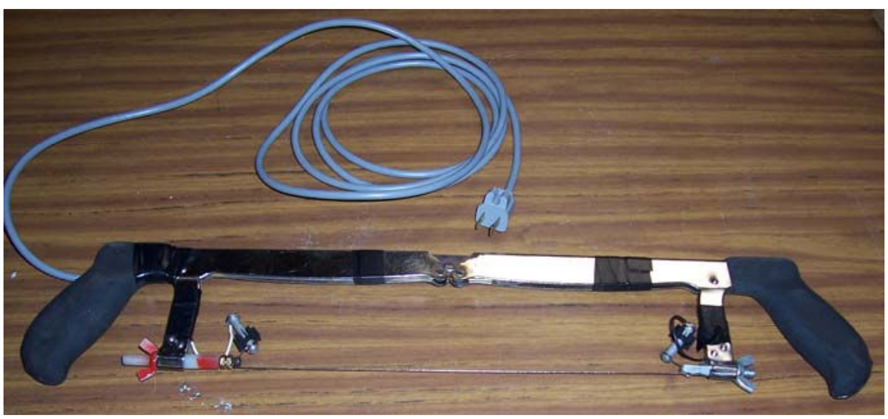

Figure 6. Hot wire Styrofoam cutter.

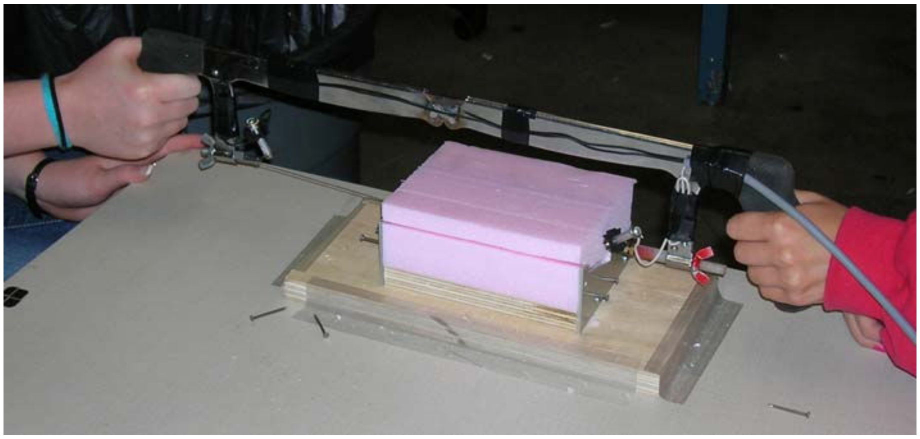

Figure 7. Cutting the PV-panel holder.

Table 2. Materials for assembly

Materials- Pump-panel assembly	***source***	***Approximate price***
2- solar panels (5.5" x 5.5"; 5.6 V, 225mA)	The Energy Alternative http://www.theenergyalternative.com/energy_efficient_products/index.html?item=412	(mini) solar panels available in bulk ($65/20)
1- aquarium pump (12 in lift, 26 gph, 6V DC pump) (figure 2)	Solarkey Technology Co. SP005-pump http://www.solar-fountain.net/product_details.asp?cid=13&mid=81	$15
masonite strip (9 in x 1 ½ in x 1/8 in)	Hardware store	2ft x 4ft piece~$6.5/60
4- 6/32 x ½ machine screws or 4- M3x12 machine screws	Hardware store	100/$2
4- 6/32 hex nuts or 4- M3 hex nuts	Hardware store	100/$1
Materials- Fountain composition	***source***	***Approximate cost***
Flower pot basin (approximately 12" diameter x 2" depth or 30 cm diameter x 50 mm depth)	nursery	$3.00
Rocks (marble, lava, river washed, etc.)	nursery	$4.5/sack; 7 students/sack
1 ft aluminum tube (5/16" OD) or 30 cm aluminum tube (8 mm OD)	Hardware store	$26/ 50 ft

6 in plastic tubing (7/16" OD x 5/16" ID) or 15 cm plastic tubing (11mm OD x 8 mm ID)	Hardware store	$2/10 ft
water-proof greenery/flowers	Craft shop or pet shop	$50/40 students
Materials- panel holder	***source***	***Approximate cost***
Block of 2" x 6" x 4 5/8" rigid Styrofoam	Home building supply	4ft x 8ft piece ~ $15/300

Table 3. Tools for assembly

Tools-Pump-panel assembly
drilling tool guide *** see Figure 2 and assembly drawing*
Screwdriver
cordless drill w/ drill bit 5/32
scrap wood to place on workbench
Solder, soldering iron & its holder
wire stripper
utility knife (or razor blade)
electrical tape
Tools-Fountain composition
Hot melt glue and glue gun or super glue
tube bender
tube cutter
Tools-panel holder
Variac
Hot wire cutter – ** *see Figure 6*
Four nails
Foam holder ** *see Figure 5 and assembly drawing*

Table 4. Assembly procedure of solar fountain

Assembly instructions -Pump-panel assembly
1. Put masonite strip into drilling tool guide and drill 4 holes **drill straight up & down Note: drilling tool guide will eliminate student frustration and build confidence
2. Drill corresponding 4 holes onto the solar panels, (outer two holes) Use scrap wood on your bench to avoid drilling into the bench.
3. Attach the 4 machine screws onto the solar panels and masonite strip, fix with hex nuts, fasten with screwdriver. Make sure hex nuts are on the back side of the solar panels.
4. Plug in the soldering iron, place on its holder
5. Remove plug from aquarium pump wire with utility knife (discard the plug)
6. Slit the cord in center & remove black plastic insulation
7. Strip off outer wire plastic on the pump cord (about 1/4")

Careful with stripper, cut gently and pull off plastic; practice with pump wire!
8. Strip off outer wire plastic on the solar panel wires (about 1/4")
9. Twist the two solar panel wires together clockwise(the two reds together and the two blacks together)
10. Twist the blue wire from the pump with the red solar panel wires and twist the brown wire to the black solar panel wires (positive to positive, negative to negative)
11. Solder the twisted wires together* *apply the soldering iron onto the twisted wire for about 15 seconds (have students count to 15) apply the solder, make sure it looks shiny take away the solder take away the iron
12. Apply a small piece of electrical tape to the joint after it has cooled down
13. Unplug the soldering iron. Put away your tools & straighten up your work area
Assembly steps- fountain composition
1. Cut aluminum tube from large roll with tube cutter
2. Cut plastic tubing from large roll with utility knife on scrap wood
3. Bend aluminum tube to some shape as designed by the student *Be sure you put it in the correct notch in the tube bender *To avoid student frustration, encourage simple bending shapes
4. Attach plastic tube to pump and to aluminum tube
5. Place in basin and put in rocks **place as little cord as possible in the basin
6. Adjust décor
Assembly steps- panel holder
1. Plug in hot wire cutter
2. Set variac to 8-9 volts
3. Put foam block into holder, secure with two nails (insert into small holes in the foam block holder)
4. Cut the Styrofoam stand with two students holding the hot wire cutter
Final Assembly
1. Add water
2. Put panel under light bulb or take assembly outside

Figure 8. Final solar fountain.

More advanced students can add a rechargeable battery (Figure 9), an on-off switch, or a water-proof housing for the PV panels.

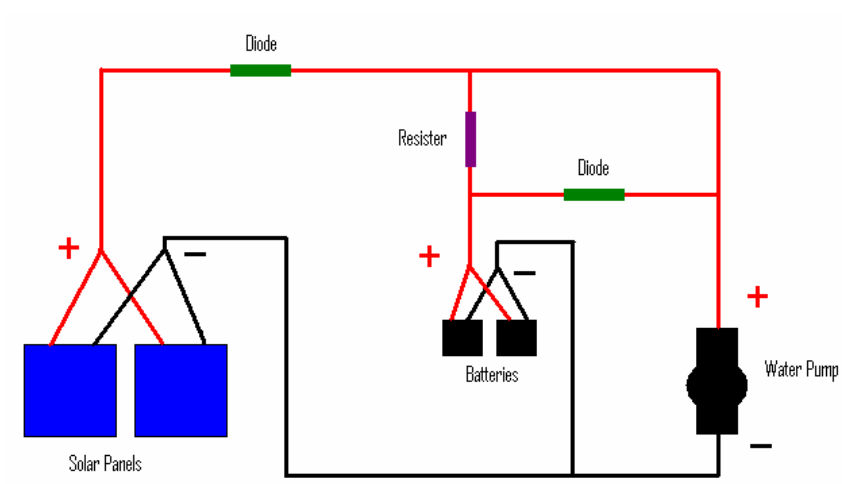

Figure 9. Optional rechargeable batteries

Additional Materials would require two rechargeable battery packs connected in parallel (Panasonic P-P504,3.6 volts, 600 mAh, charge rate of 14 hours); two diodes – IN751A, a resistor 240 hm_5%, and an optional on/off switch.

Assessment of Module

It is important to measure the effectiveness of the hands-on activity. Effectiveness can be measured on multiple levels: attitudinal, learning, behavior, and organizational outcomes[19]. We measured effectiveness of the solar fountain project on two of these levels via an e-mail survey sent several weeks after completion of the STEPS program. Ten of the 40 surveys were returned, for a response rate of 25%. The survey is included in Appendix II.

Attitudinal criteria measure student impressions about activity content and delivery. This level of measurement assesses whether students liked the activity, as well as their comfort level and self-reported understanding of the material, and whether the experience affected their interest in engineering. Feedback from this type of measurement can be used to modify module content or presentation if necessary. The responses of STEPS participants were very positive. All responding students enjoyed the solar fountain project; with nine of the ten responding *strongly agree*. Regarding the statement “I am more confident in my science abilities now that I have built the solar fountain”, the average response on a scale from 1 (strongly agree) to 7 (strongly disagree) was a three, and all responses were a four or less. In response to the question “Building the solar fountain helped me understand the idea of renewable energy” the average response was a two on the same 1-7 scale. Eight respondents indicated that the project increased their interest in engineering. The remaining two respondents said the project maintained their interest in engineering.

Learning criteria measure the cognitive impact of a course. In our case, students responded to questions about content after course completion. While there was no traditional test given at the end of the STEPS program, we asked several questions on the survey that reflect the goals of the program. These goals were to help students understand the finite nature of water and energy resources, that there is no single correct answer to an engineering problem, and that engineering combines artistic creativity with empirical science. Participant responses indicated that the goals of the program were achieved. Specifically, on a scale ranging from 1 (art) to 7 (science) the average response to the question “Engineering is…” was a four. This indicates that participants understand that engineering balances creativity and science. Also, for the question “For any engineering question there is one correct answer” the average response was a six on the scale of 1 (strongly agree) to 7 (strongly disagree). This suggests that the students understand that there are many possible correct solutions to a problem.

Behavioral criteria measure if people actually change what they do as a result of their experience. At this point we only have data about participant intentions. Specifically, participants were asked whether this experience will impact their choice of high school courses, selection of colleges/universities, and the major they intend to pursue. Eight of the ten respondents indicated that the fountain project impacted the types of courses they will take in high school. Examples of the courses these students hope to take include soldering, wiring, mechanics, biology and more science in general. Half of the participants thought they would change where they apply for college, with some specifically mentioning that they will be looking at schools with good engineering programs. Four of the respondents indicated that the project influenced the major they intend to pursue (changing to majors such as engineering, environmental management, and science). Future surveys can follow up to measure actual academic choices.

Conclusion

A laboratory activity is presented that uses social relevance and an artistic hands-on build to introduce engineering design and process to a group of non-major female students. A follow-up survey measured increased awareness in energy issues and an increased interest in technology topics.

Acknowledgements

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Appendix I

Construction of the rigid Styrofoam cutting tool.

1. Disassemble two hacksaws. (drill out the rivets if necessary)
2. Discard the part of the saw without the handle.
3. Bolt or weld the two saws together end-to-end. (see Figure 6)
4. Fabricate an electrically non-conducting threaded rod to replace one of the saw blade tensioning screws.
5. Use 18 gage 2-conductor wires for the power-cord and attach one end to the non-conductive tensioning screw and the other end to the electrically conducting tensioning screw.
6. Connect the tensioning screws with 22 gage nichrome wire. (available from omega.com)
7. Secure all loose ends with electrical tape
8. Connect power cord to a variac and test at low voltage (5-10 V AC)

Wire should never be red-hot, use only enough voltage to melt through the rigid Styrofoam. Re-tension the nichrome wire as needed. Use in a well-ventilated area.

Appendix II - Assessment Survey

Please take a few minutes to complete this survey. The questions are specifically based on your experience with the **solar fountain project**.

For the following questions, please mark the scale with a checkmark or an X.

1. Engineering is
art : _____ : _____ : _____ : _____ : _____ : _____ : _____ : science

2. For any engineering question there is one correct answer.
strongly agree : _____ : _____ : _____ : _____ : _____ : _____ : _____ : strongly disagree

3. I enjoyed building the solar fountain.
strongly agree : _____ : _____ : _____ : _____ : _____ : _____ : _____ : strongly disagree

4. I am more confident in my science abilities, now that I built the solar fountain.
strongly agree : _____ : _____ : _____ : _____ : _____ : _____ : _____ : strongly disagree

5. Building the solar fountain helped me understand the idea of renewable energy.
strongly agree : _____ : _____ : _____ : _____ : _____ : _____ : _____ : strongly disagree

6. Based on your experience with the solar fountain project, please provide a brief statement about the availability of energy resources (e.g. finite, unlimited, etc.).

7. Based on your experience with the solar fountain project, please provide a brief statement about the availability of water resources (e.g. finite, unlimited, etc.).

8. What was the most important concept you learned from the solar fountain project?

9. What was the most challenging part of the solar fountain project?

10. What part of the solar fountain project taught you the most?

11. Please rate the following equipment and processes:

	very easy to use/do	somewhat easy to use/do	unsure	somewhat frustrating to use/do	very frustrating to use/do
drilling tool guide					
foam cutting fixture					
hot wire styrofoam cutter					
tube bender					

soldering tool					
lectures					
other:					

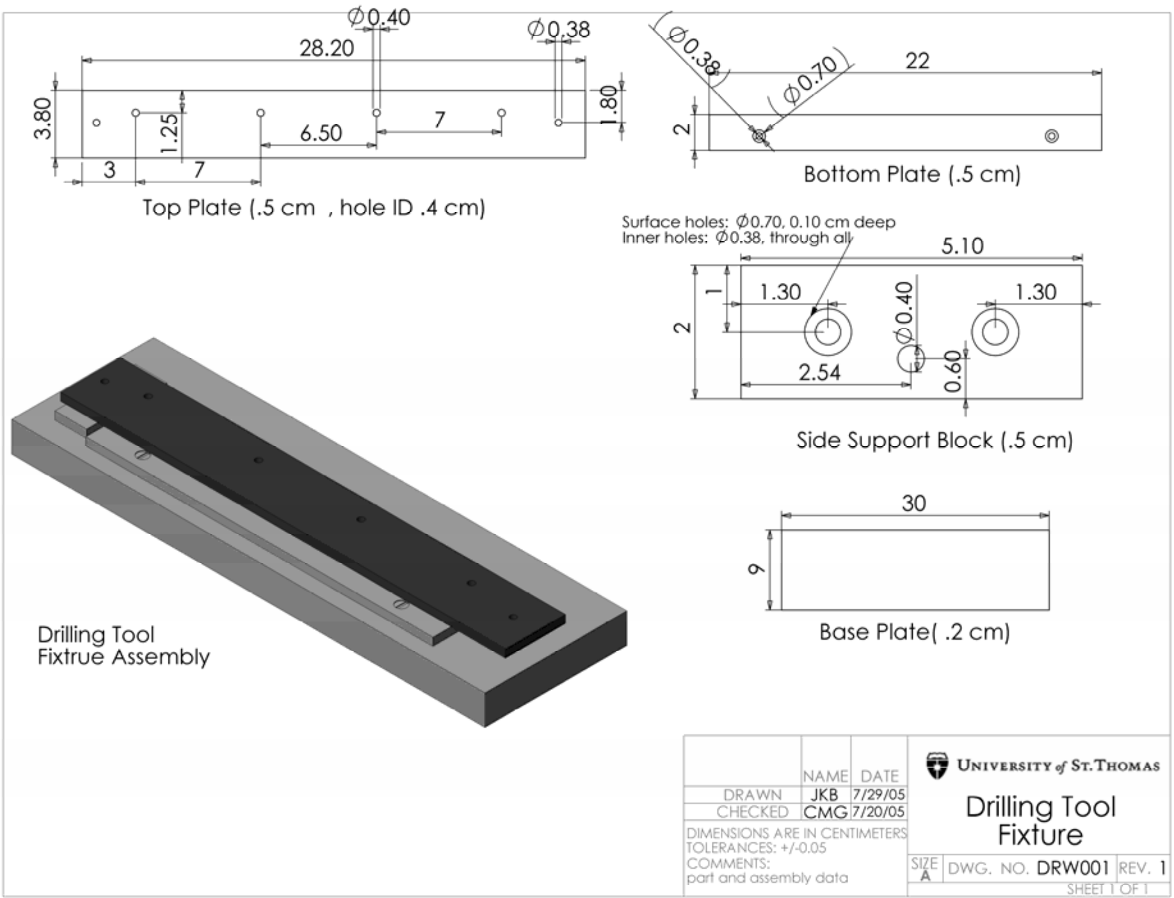
12. Making the solar fountain has INCREASED/MAINTAINED/DECREASED my interest in engineering.

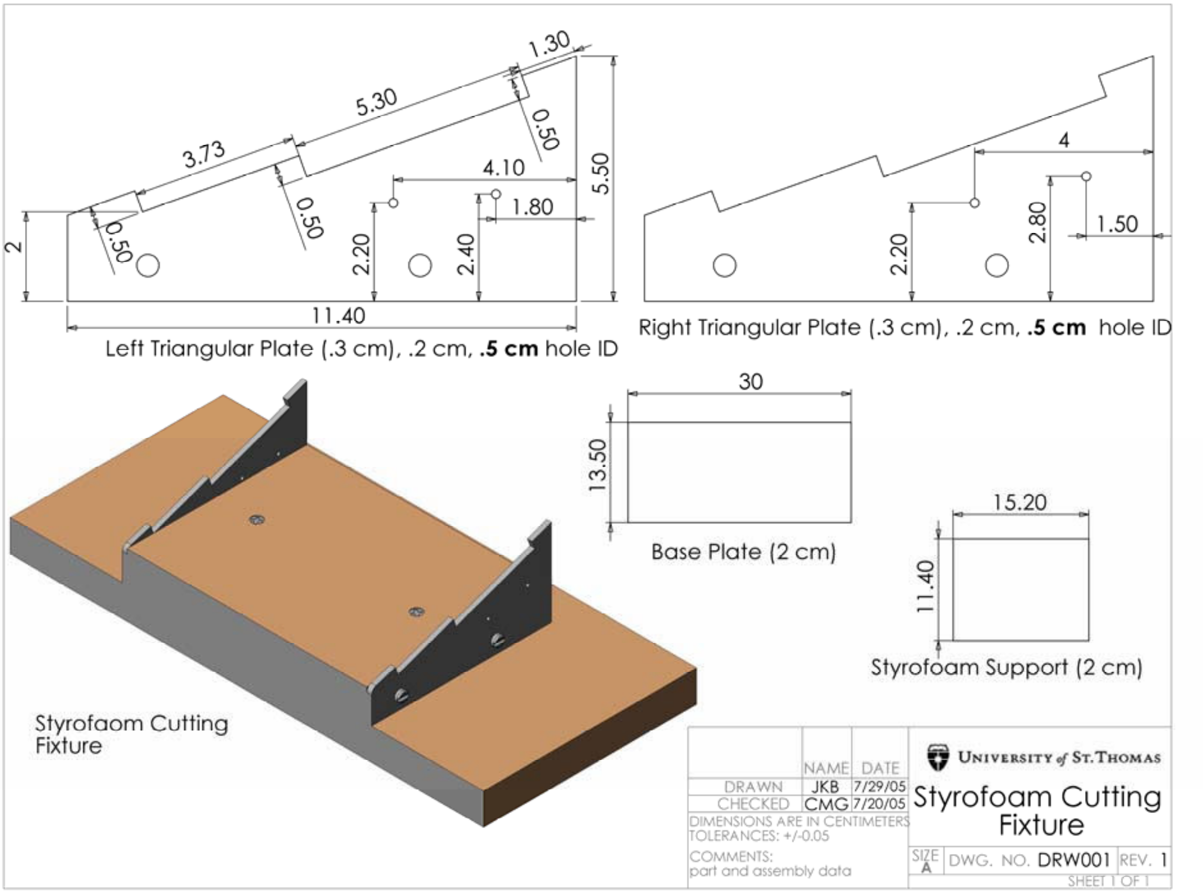
13. Please indicate if/how the solar fountain project has affected the following:
    - High School courses you will take
    - College/university you will apply to
    - The major you intend to pursue

14. What suggestions do you have for improving the solar fountain project?

15. Other comments:

Appendix III – Metric Fixtures




1.30
5.30
3.73
0.50
0.50
0.50
4.10
1.80
2.20
2.40
5.50
2
11.40
Left Triangular Plate (.3 cm), .2 cm, .5 cm hole ID
4
2.20
2.80
1.50
Right Triangular Plate (.3 cm), .2 cm, .5 cm hole ID
30
13.50
Base Plate (2 cm)
15.20
11.40
Styrofoam Support (2 cm)
Styrofaom Cutting Fixture
NAME DATE
DRAWN JKB 7/29/05
CHECKED CMG 7/20/05
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES: +/-0.05
COMMENTS:
part and assembly data
UNIVERSITY of ST. THOMAS
Styrofoam Cutting Fixture
SIZE A
DWG. NO. DRW001
REV. 1
SHEET 1 OF 1