AC 2009-1335: A MICROPROCESSOR-BASED CONTROL SYSTEM PROJECT FOR AN INTEGRATED FRESHMAN CURRICULUM

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Microprocessor-Based Control System Project for Integrated Freshman Curriculum

Abstract

A project has been developed and implemented in which the temperature and salinity are controlled in a small volume of water which is circulated using a small pump. A conductivity sensor measures salinity, and a Resistance Temperature Device (RTD) monitors temperature, providing data to a BASIC Stamp controller. Two relays are used to operate solenoid valves that release either fresh or salty water into the system, and a third relay is used to activate a heating element used to control temperature. A cascaded switching arrangement utilizing transistors allows the BASIC Stamp to drive these high-current devices. A DC motor-driven pump continuously circulates water through a fluid loop into which the conductivity sensor is integrated. Students fabricate an inline conductivity sensor (using a 555 timer), the RTD (using photolithography), a heating element (using a high-wattage resistor) and a wooden platform to which all of the components are mounted. The students develop programs to accomplish closed-loop control of the system, as well as provide a user interface where key system parameters are displayed. As part of our integrated freshman curriculum, this project provides hands-on experience to accompany traditional approaches to teaching science and engineering fundamentals including conservation of mass and energy, basic salt-water chemistry and electric circuitry. Assessment of the skills imparted through this project is provided using before and after survey data measuring student confidence in designing, fabricating and testing a working electro-mechanically controlled system.

Introduction

Engineering educators who are concerned with the future needs of the engineering profession have realized for a long time that a hands-on, project-based approach fosters the development of students who are confident in their ability to accomplish real achievements with their learning[1]. The project-based freshman curriculum revolution was born in the 1990s in the United States; with the key driving force arising from the National Science Foundation Engineering Education Coalitions[2-5]. More and more universities in the United States are implementing freshman programs with significant design and fabrication components[6-8].

At Louisiana Tech University, a sequence of three two-hour courses that spans the freshman year has been implemented with the aim of fostering the ten attributes defined by The Engineer of 2020[9] in our students. As the students move through the sequence, a steadily increasing level of independence is required from the students as they design and build projects with a steadily growing degree of complexity. In their first course, freshmen undertake a centrifugal pump project[10]. In the second course, the pumps are used to circulate salt water in a "fishtank"- a system (see Figure 1) in which the students use a microcontroller to control the temperature and salinity of a small volume of water using temperature and conductivity sensors that they make and calibrate as part of the course content. The final course of the freshman year requires the students to complete an open-ended innovative design project where they conceive, design and fabricate a "smart product" based on a "bug list" that they compile over a period of several weeks.

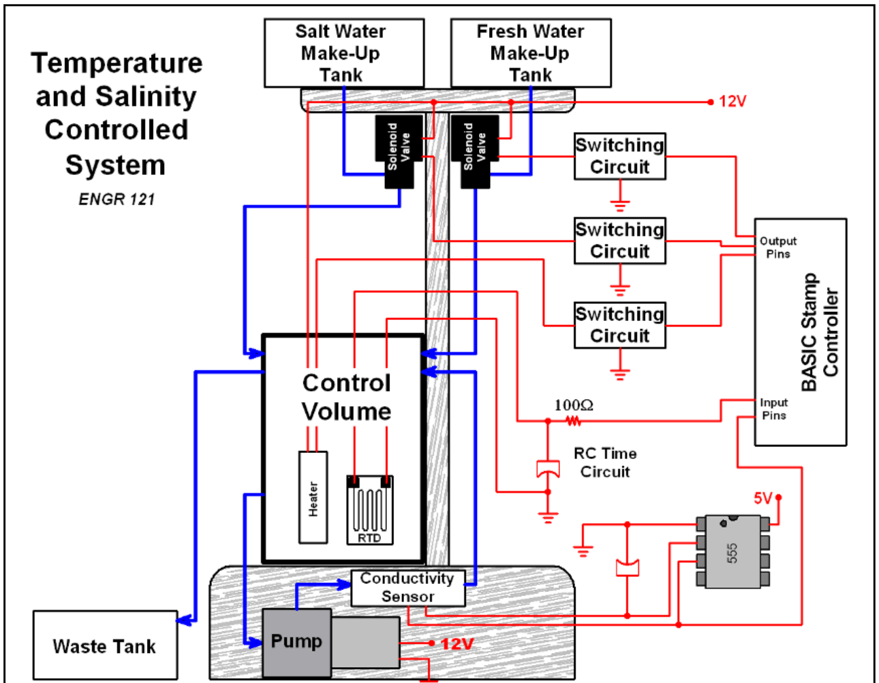


Figure 1 – Temperature and Salinity Controlled System

The temperature and salinity controlled system that is the focus of the second course in the freshman sequence is also the focus of this paper. The system consists of a control volume with a flow loop in which the temperature and salinity is to be controlled. There is a conductivity sensor inline in the flow loop that feeds information regarding the salinity of the water to a BASIC Stamp – the microcontroller platform chosen for the freshman sequence. A temperature detector is immersed in the fluid in the flow loop and sends information about temperature to the BASIC Stamp. The BASIC Stamp is programmed by the students to make decisions about when to open or close solenoid valves to change the water composition and when to activate a heater to control water temperature. The program also provides a user information panel regarding various states of the system.

Conductivity Sensor

To provide salinity feedback to the control system, each student designs and fabricates a conductivity sensor. This sensor, consisting of two electrodes immersed in the salt water solution, acts as a variable resistor dependent on the salinity level of the solution. The use of this sensor allows us to spend a portion of several lecture periods on the topic of salt water chemistry, covering topics such as hydration, oxidation, reduction and concentration gradients. To specifically address concentration gradients and how to prevent them, the students are introduced to the 555 timer integrated circuit and capacitors. After discussing the fundamental concepts of capacitance and showing them graphs for the charge and discharge cycle of a capacitor, the students learn how to configure a 555 timer circuit to generate a square wave output whose frequency varies with resistance. With the conductivity sensor acting as the resistor in the timer circuit, the output frequency of this square wave therefore varies with the salinity of the solution. The application of this square wave across the capacitor causes the voltage across the conductivity sensor to alternate between positive and negative voltages with every cycle, thus helping to prevent the buildup of sodium and chloride ions at each electrode. Figure 2 shows the output of the 555 timer, as well as the alternating voltage across the resistance in the circuit. The students are able to use a photoresistor in place of the conductivity sensor which allows them to test their 555 timer circuits and the associated Basic Stamp programming required without the fluid component of the system.

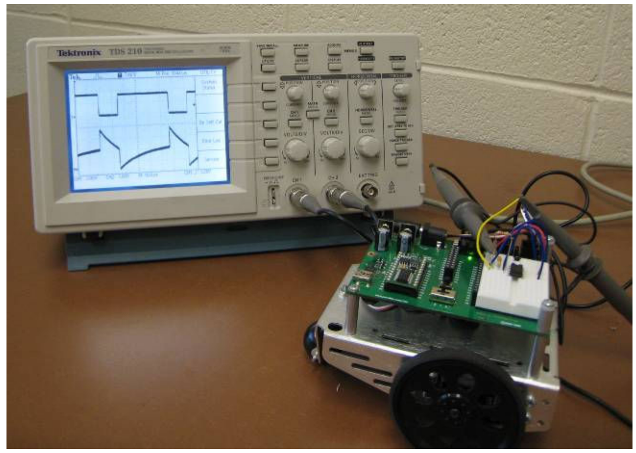


Figure 2 – Timer Circuit to Alternate Voltage

The conductivity sensor (shown in Figure 3) is fabricated from a short piece of Ultra High Molecular Weight Polyethylene (UHMWPE). Each team of students learns how to operate a digital lathe to face and bevel each end of the material and then drill a hole down the center of the piece for the fluid flow path. Holes are drilled through one side of the material and two short pieces of 1/16th-inch diameter 316 stainless steel are pressed into the material protruding approximately ½-inch outside the material and extending into the material across the flow path. 20-inch lengths of 22 AWG wire are crimped onto the exposed ends of the electrodes and each end of the assembly is tapped to allow 3/16th-inch barbed nylon fittings to be

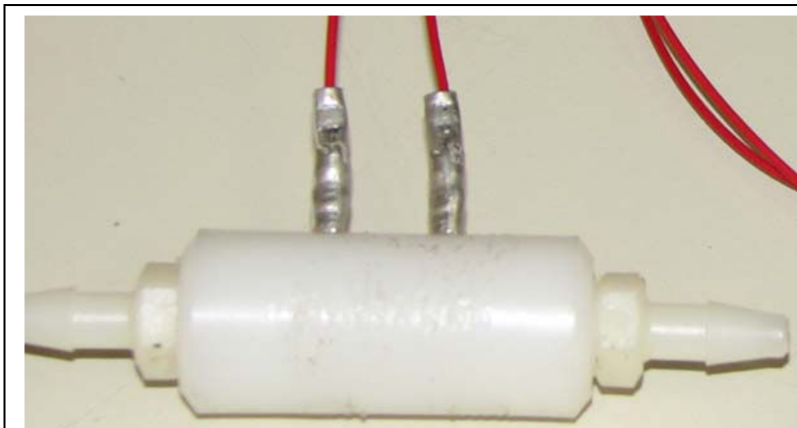
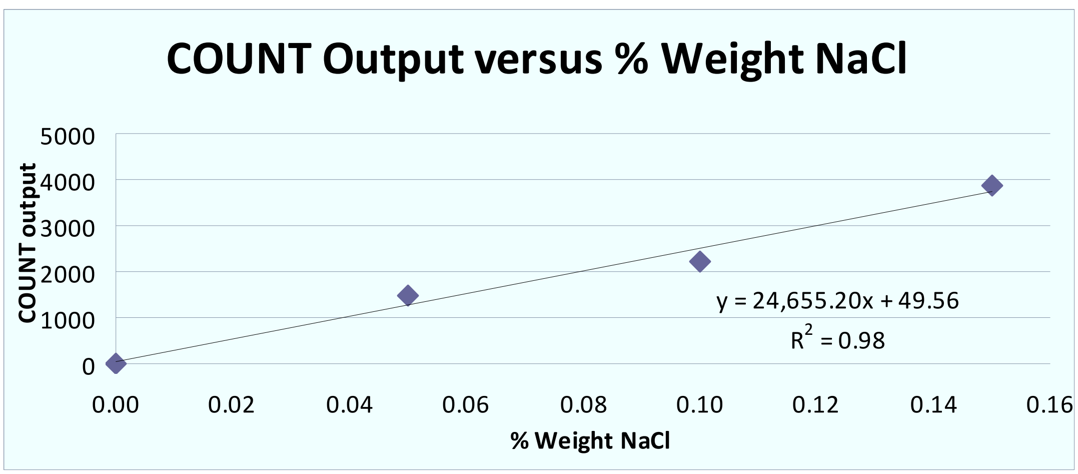


Figure 3 – Conductivity Sensor

attached. Once completed the sensor assembly is connected between the control volume containing the salt water solution and a small DC-motor driven pump that provides continuous circulation. The pumps used here are actually designed and fabricated by the students during a previous quarter.

As the sensor is part of a 555 timer circuit where the frequency of the square wave output varies with salinity, the students use the COUNT command in the Basic Stamp programming language, PBasic, to measure this value. The COUNT command allows the controller to count the number of high-low-high (or low-high-low) transitions that occur on an input pin during a fixed period of time (we have the students use 1 second). The students calibrate their sensors by circulating salt water solutions at four different concentrations (de-ionized water at 0%, 0.05%, 0.10% and 0.15%) and recording the number of transitions returned by the COUNT command. The students then use Microsoft Excel to plot a linear graph for these data points and to determine a best-fit equation using least squares regression analysis, as shown in Figure 4 below. An equation relating the COUNT output to the actual salt water concentration value is determined first, then this equation is inverted to provide the concentration value for a measured count value. In order to work inside the Basic Stamp controller using only integer values, the final calibration equation must be multiplied by a scalar factor to eliminate the decimal point. The students are able to reinsert the decimal point at the appropriate location when the values are displayed on the Basic Stamp debug terminal.



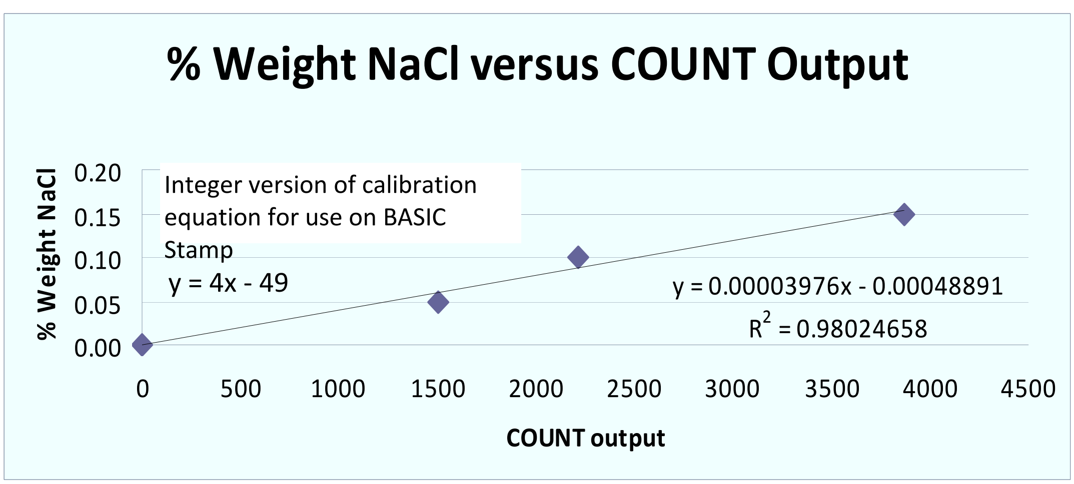


Figure 4 – Relationship Between Salt Percent and COUNT Values

Resistance Temperature Detector (RTD)

To provide temperature feedback to the control system, each student designs and fabricates a resistance temperature detector (RTD). After a discussion on the evolution of temperature measurement devices, the resistivity of a variety of materials, the effects of temperature on resistance and a brief over of the optical lithography fabrication process, the students are asked to design an RTD to meet a number of design parameters. These design parameters include:

- that the RTD have a nominal resistance value of 100 Ω at 20°C
- that it be fabricated using nickel film that is approximately 200 nm in thickness with a resistivity of 1.2x10-7 Ω-m
- that it include two lead wire attachment pads that measure 5 mm x 5 mm
- that the minimum line width of each section of the RTD be 200 µm
- and that the entire footprint of the RTD element fit inside a 2.5 cm square

Once fabricated, the RTD will function as a variable resistor in a simple resistive-capacitive (RC) circuit connected to an input/output pin on the Basic Stamp controller. Until the RTD is fabricated, students are able to simulate the operation of this device using a photoresistor as an alternate variable resistor.

Throughout the curriculum, computer aided design is required of the students, most often in the form of 3D solid modeling and assemblies. The students are required to model and assemble all of the components of the project in SolidWorks® or another package if they have it. There are also times in engineering design when it is more useful to create 2D drawings. To help teach the students how to use the 2D drafting capabilities of our chosen CAD package, tutorials were created that allow the students to learn some general 2D drawing techniques. The tutorials also demonstrate how to control line width in SolidWorks® which is a critical component to assuring that the RTDs have an acceptable resistance value when fabricated. Figure 5 shows some of the more creative designs that the students submitted.

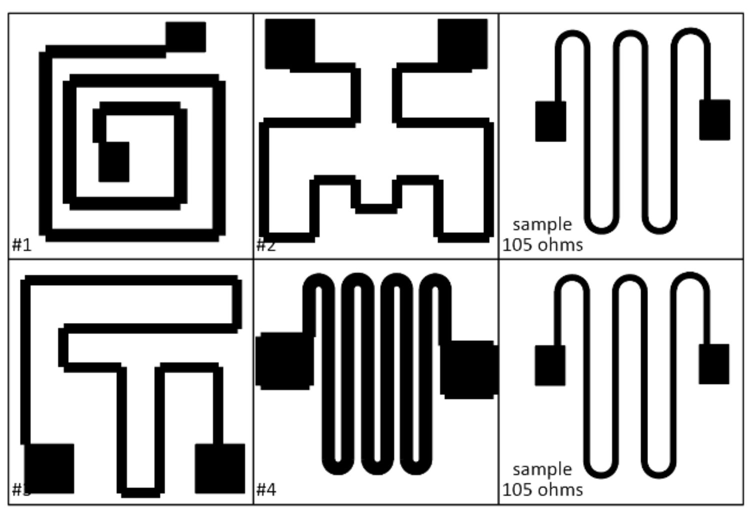


Figure 5 – Student RTD Designs

The mask designs are collected and printed using a high resolution imagesetter. This device produces masks patterns on a plastic film similar to a transparency and is a low cost method for mask fabrication requiring resolutions on the order of tens of micrometers and larger. This task is performed by a lab assistant between class periods so students are provided their mask patterns on the day photolithography is performed. The overall photolithography fabrication steps are:

1. Prepare the substrate for spinning
2. Spincoat the substrate with photoresist
3. Soft bake (hardens photoresist slightly)
4. Apply a photomask of each student group's RTD pattern design and expose to UV light
5. Develop the photoresist
6. Rinse and dry
7. Hard bake (hardens photoresist more fully)
8. Etch exposed nickel
9. Remove photoresist
10. Dice substrate into individual RTDs
11. Solder leads to the RTD and dip in hot glue to seal

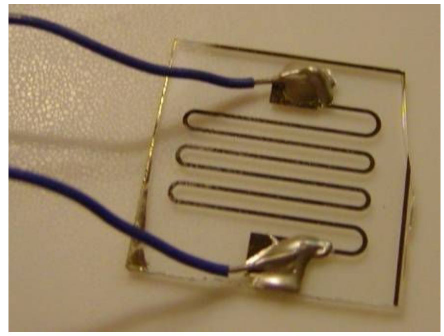


Figure 6 – A Completed RTD

A sample RTD produced by this process is shown in Figure 6. Figure 7 shows the steps in the RTD fabrication process as listed above. Students also perform an inspection of the line pattern produced on their RTDs using shop microscopes.

As a variable resistor in an RC circuit, the RTD will affect the charge and discharge time of the voltage across the capacitor. The Basic Stamp programming language, PBasic, includes an instruction named RCTIME that allows the controller to measure either the charge or discharge time of an RC circuit. This instruction allows a single I/O pin to be configured first as an output so that the capacitor can be completely charged or discharged. Then the RCTIME instruction is executed at which time the I/O pin is reconfigured internally as an input where the voltage level is monitored. The time required until the voltage on this pin rises above or falls below 1.4 volts is measured and returned as a number of 2 μs intervals. Since the resistance of the RTD increases as the temperature increases, the number of 2 μs intervals returned by this instruction will also increase as temperature increases.

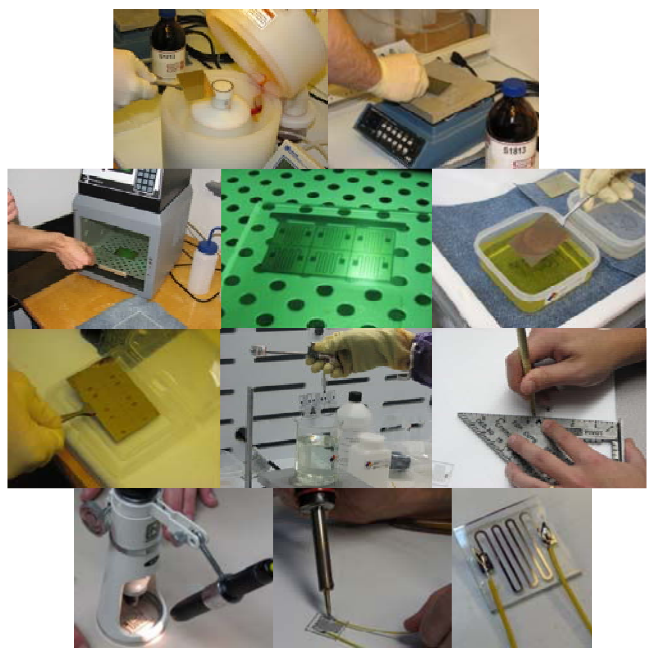
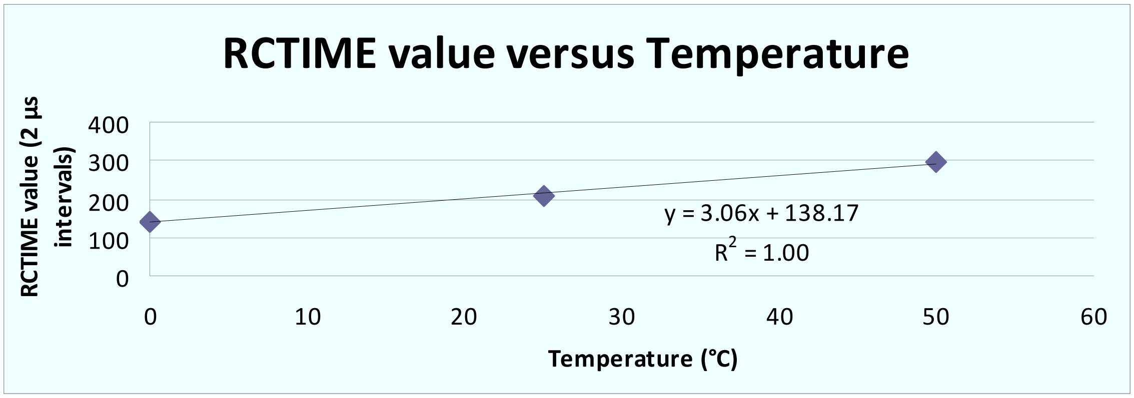


Figure 7 – RTD Fabrication Process Steps

To calibrate each RTD sensor, the students immerse them in three temperature baths at 0^{o}C, 25^{o}C and 50^{o}C. Using their Basic Stamp controllers they run a program segment that includes the RCTIME command which allows them to record a time value at each of these three temperatures. The students then use Microsoft Excel to plot a linear graph for these data points and to determine a best-fit equation using least-squares regression analysis as shown in Figure 8. As with the calibration equation for the conductivity sensor, this equation is first used to establish convenient set-point time values for various temperature values, then the equation is inverted to provide temperature values based on sampled time values. In addition, as with the conductivity sensor equation, this inverted calibration equation must be adjusted to work with the integer values provided by the Basic Stamp controller.



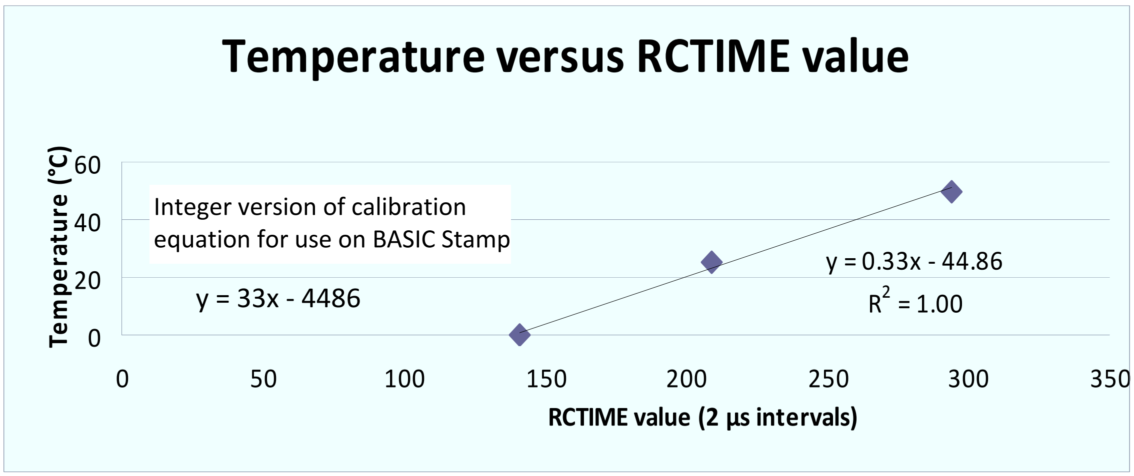


Figure 8 - Relationship Between Temperature and RCTIME Values

Control Outputs From the BASIC Stamp

The electrical loads that are needed to control the salinity and temperature in the control volume include two solenoid valves (one to release fresh water into the control volume, and the other to release salty water) and a heating element. All loads require a voltage input of 12V; the solenoid valves demanding 0.5A of current, and the heating element demanding 0.67A. The BASIC Stamp pins have an output voltage of 5V, and can only source 20mA. The pins themselves are inadequate for driving significant electrical loads like the valves and heater, therefore a switching circuit is needed. While a more expensive power transistor could have been used exclusively to drive these devices, we preferred to take the opportunity to teach the students about cascaded switching circuits using low-cost NPN transistors and mechanical relays. Figure 9 shows a connection diagram for switching the electrical loads required in the system. As students are forced to deal with real sources and loads, they begin to see that the circuit

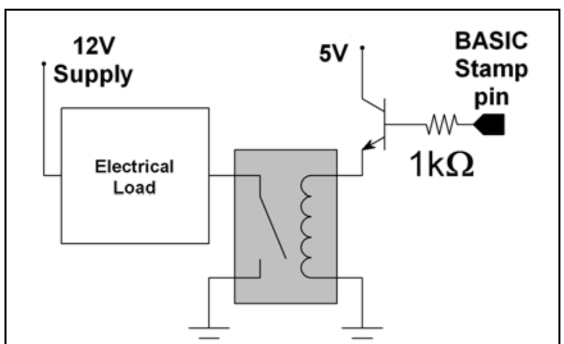


Figure 9 – Switching Circuit

theory that is taught in the classroom is very applicable. The idea of electrical power becomes very real to them as they even have to adjust certain things about the programming of their controller so as not to exceed their power budget. A project context makes circuit theory that would otherwise have seemed boring to many students become more meaningful.

The use of transistors to accomplish electrical switching gives us a good reason to go over the basics of how semiconductor-based circuit components work. The concept of a perfectly satisfied lattice structure is shown (i.e. pure silicon), then how introducing impurities into this structure can increase the number of electrons or empty valence shells (holes) to make that material conductive. It is shown how circuit components such as diodes and transistors may be assembled by forming junctions of the doped materials. Covering this material provides an excellent link back to the chemistry and physics that the students have already seen.

Nearly all engineering fundamentals are based on conservation principles. The problem of developing a strategy for controlling the temperature and salinity of a volume of water provides an excellent motivator for introducing the laws of the conservation of mass and the conservation of energy. In a salt water system, there are two substances (water and salt) and the accumulation of the mass of either substance may be accounted for by tracking the entry or exit of the masses of the substances from the system. The students can see a very practical application of mass conservation laws by computing the amount of salt water of a certain concentration that it would take to dilute or concentrate an existing salt water mixture. Ultimately this translates into a control strategy that they must implement in their BASIC Stamp to maintain a salt water concentration at a particular level. The concept of the conservation of energy is very similar, if the entry of energy into a system and the exit of energy away from a system can be tracked, then the accumulation of energy within the system can be known. The idea of internal thermal energy within a material is related to the temperature of that material, thus it is possible to show the students how electrical power can be converted into a change in temperature of a substance. The students are able to compute the amount of time required for their heater element to cause a temperature change of some magnitude in the fluid in the control volume. This allows them to see that the concepts of energy and power are applicable to both electrical and thermal systems, and are interchangeable between different disciplines.

Hardware and Cost Summary

To accomplish a project of this scope for all incoming freshmen, it takes a significant amount of hardware and supplies. Many of these components are supplied to the students; some are given to them outright and others are loaned. To assure that all of the required materials for the project were recognized, we compiled a list with all the pieces and the prices associated with those items as of the time the project was undertaken. Table 1 provides this list. Many of the items are very low cost, but are not the kind of things that can be obtained locally. While the cost of items supplied to the students is somewhat high (~$17.24), most of this cost is due to the solenoid valves, which are durable items and are reused from term to term. The actual cost of non-recoverable items per student is only estimated at $3.78, which is a cost that can be absorbed by the college. The project is thus sustainable from a cost standpoint.

Table 1: Materials and Costs

Parts for Control Volume - 1 kit for every 2 students - CLASS 1

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	McMaster	5116K82	nylon barbed fitting - 3/16" tube ID, 1/8 NPT male	10 pack	2.66	2	$ 0.53
2	Lowes	23830	1 1/2 inch SCH 40 PVC pipe	10' length	4.29	3 in	$ 0.11
3	Lowes	23899	1 1/2 inch Cap SCH 40	each	0.64	1	$ 0.64
4	Mcmaster	18815K61	PVC clear cement (1/4" to 6" pipes) 8-oz dauber-top can	each	2.95	1% of can	$ 0.03
5	McMaster	18815K72	PVC purple primer (8-oz dauber-top can)	each	3.27	1% of can	$ 0.03
					Total:		$ 1.34

Parts for Conductivity Sensor - 1 kit for every 2 students - CLASS 1

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	McMaster	5116K82	nylon barbed fitting - 3/16" tube ID, 1/8 NPT male	10 pack	2.66	2	$ 0.53
2	McMaster	8701K43	UHMEPE rod - 3/4" diameter	ft	1.4	1.7 5 in	$ 0.20
3	McMaster	71285K13	crimp-on snap-plug terminal, non-insulated male, 22-18 AWG, .156" plug d	100 pack	9.04	2	$ 0.18
4	Omnitronelectronics	KSM2201-3	22g wire, 1000 ft, orange	1000'	23	3	$ 0.07
5	Small Parts	ZRXX-01-72	s/s round type 316 1/16" dia rod 72" long	6' long	8.95	2	$ 0.25
6	omnitronelectronics	CP8009	555 Timer chips, NE555/LM555 Timer IC	25 pack	15	1	$ 0.60
					Total:		$ 1.83

Pump Flowloop for Conductivity Sensor Calibration - 1 kit for every 2 students - CLASS 5

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	mcmaster	5233K532	PVC clear tubing - 3/16" ID x 5/16" OD (cut to 12 inches in this kit)	100' length	0.12	1 ft	$ 0.12
2	Omnitronelectronics	KSM2201-3	22g wire, 1000 ft, orange	1000'	23	2	$ 0.05
3	mcmaster	69525k95	female noninsulated terminal 26-20 AWG, .110" wide x 0.020" thick	100 pack	2.01	2	$ 0.04
					Total:		$ 0.21

Wood for Fishtank Platforms - 1 kit for every 4 students - CLASS 6

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	lowes	940	1x4x8 (0.75" x 3.5" x 8') - top choice (two 10", one 6", & one 3 3/4" piece	each	3.1	0.309896	$ 0.96
2	lowes	6003	2x4x92 (1.5" x 3.5" x 8') 5/8 SPF Select (one 18" piece)	each	2.05	0.1875	$ 0.38
3	lowes	234729	1 5/8" drywall screws - large box (assume 1 box will serve 100 projects)	box	20.48	0.01	$ 0.20
					Total:		$ 1.55

Transistors, Relays and Solenoid Valves - 1 kit for every 2 students - CLASS 7

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	digikey	2N3904D26ZTR-ND	Transistor, NPN, 40V, 200mA max, tape&reel, package TO-92	tape&reel	48.5	1	$ 0.02
2	digikey	pb370-nd	SPST-NO Relay, 3A contact, coil=5V, coil=40mA	each (250)	1.01252	1	$ 1.01
3	mcmaster	7877K3	polypropylene solenoid valve, 1/4" quick disconnect, 1/8"NPT, 12VDC, .5A	each	24.8	1	$ 24.80
4	McMaster	69525K13	female noninsulated terminal 22-18 AWG, .25" wide x 0.032" thick	100 pack	5.32	2	0.1064
5	Omnitronelectronics	KSM2201-3	22g wire, 1000 ft, orange	1000'	23	3	$ 0.07
					Total:		$ 26.01

Additional Parts for Project - 1 kit for every 4 students - CLASS 7

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	Lowes	22686	3" Sewer and Drain Thin Walled PVC Cap	each	1.08	2	$ 2.16
2	Lowes	24132	4" Sewer and Drain Thin Walled PVC Cap	each	1.37	1	$ 1.37
3	McMaster	5116K82	nylon barbed fitting - 3/16" tube ID, 1/8 NPT male	10 pack	2.66	8	$ 2.13
4	mcmaster	5233K532	PVC clear tubing - 3/16" ID x 5/16" OD	100' length	0.12	5 ft	$ 0.60
5	McMaster	5116K83	nylon barbed fitting - 1/4" tube ID, 1/8 NPT male	10 pack	2.68	2	$ 0.54
6	McMaster	5233K562	PVC clear tubing - 1/4" ID x 3/8" OD (cut to 14 inches in this kit)	100' length	0.14	14 inches	$ 0.16
7	Omnitronelectronics	KSM2201-3	22g wire, 1000 ft, 8 feet (2 feet each of four colors)	1000'	23	8	$ 0.18
8	Walmart	51213	8" cable ties (~0.095" wide)	pack of 20	0.97	2	0.097
9	Walmart		4" zip ties	big bundle	0.02	5	$ 0.10
10	McMaster-Carr	90190A153	#6 sheet metal screws - 1" long	pack of 10	5.91	4	$ 0.12
					Total:		$ 7.46

Parts for Heater - 1 kit for every 4 students - CLASS 15

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	Digikey	CWE-18CT-ND	18 OHM 5% 13W silicone WW resistor	each	0.866	1	$ 0.87
2	Omnitronelectronics	KSM2201-3	22g wire, 1000 ft, 3 feet	1000'	23	3	$ 0.07
3	Digikey	Q2F332B-ND	heat shrink poly 3/32" black 4' length	4"	0.298	1 inch	$ 0.07
					Total:		$ 1.01

Parts for RTD Assembly and Calibration - 1 kit for every 4 students - CLASS 15

	Vendor	part number	Description	Packaging	Price	Amount Required	per kit cost
1	Omnitronelectronics	KSM2201-3	22g wire, 1000 ft, 3 feet	1000'	23	3	$ 0.07
2	Walmart		hot glue (multitemp for coating RTDs by heating on hotplate)	10 sticks	5	.2 stick	0.1
3	Digikey	P10425TB-ND	10 uF electrolytic capacitor	tape&box,	$ 54.00	2	$ 0.05
4	Digikey	100QBK-ND	100 ohm carbon film resistor	1000	8.55	1	0.00855
					Total:		$ 0.16
				(Per Student)	Grand Total:		$ 17.24
					Non-Recovered:		$ 3.78

BASIC Stamp Programming

The students are given the task to write a program that allows the BASIC Stamp to accept all the sensor inputs and display the information gathered on a debug terminal. The raw data arrive from execution of the COUNT command and the RCTIME command as described earlier. In the integer-only environment of PBASIC, dealing with decimal quantities requires multiplying all the values by the power of ten necessary to eliminate the decimal point, performing the arithmetic operations, then displaying the results so that they appear to be a decimal value. A sample debug terminal window is shown in Figure 10. Other information the students are required to show on the debug terminal are the states of the solenoid valves and the heater, and the setpoints for the control of the salinity and temperature. Displaying information correctly in the debug terminal requires the students to deal with moving a cursor around the terminal properly, and making sure that each character on the screen is appropriately set or cleared in their program. This in itself is a good exercise for them to begin thinking programmatically.

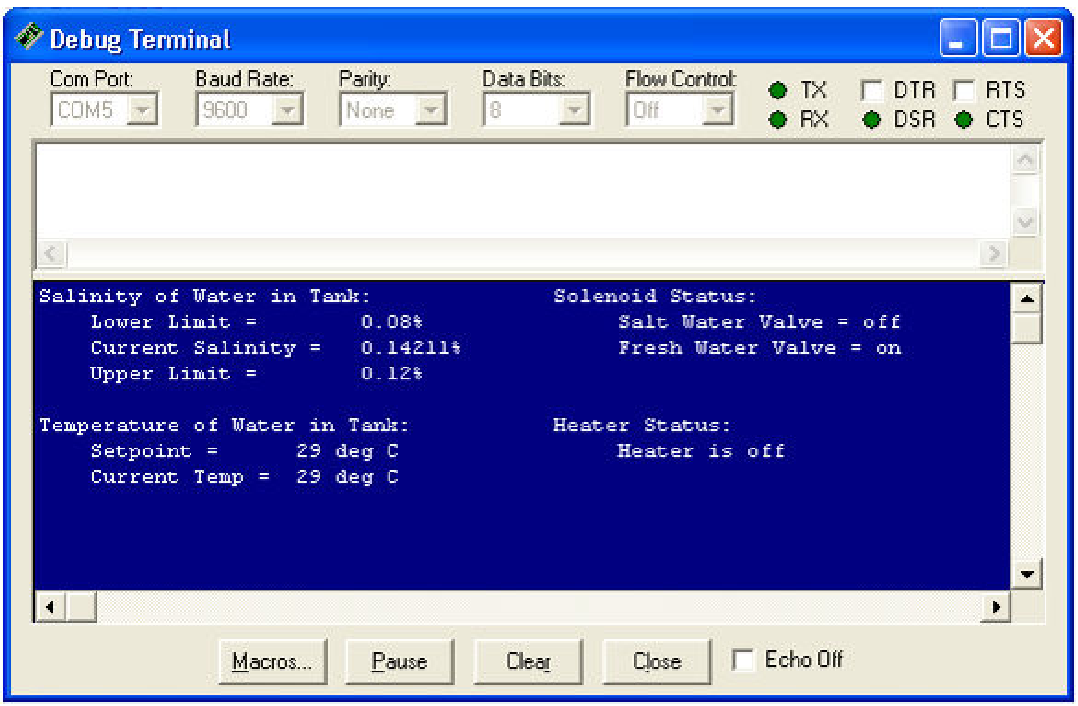


Figure 10 – The Debug Screen Interface

The control algorithm for the system that most students use is a relatively simple on-off type of control. The program is an infinite loop that alternately checks temperature and salinity against fixed setpoints and activates the heater or the valves as necessary. Due to the power demand of the valves and the heater and the size of the power supply used by the students, only one of these components may be operated at a time. For this reason, it is necessary for the students to include an instruction to stop delivering power to the heater when they are about to activate a valve. The flowchart shown in Figure 11 represents a typical algorithm a student may implement to deliver the desired user feedback and control of the system.

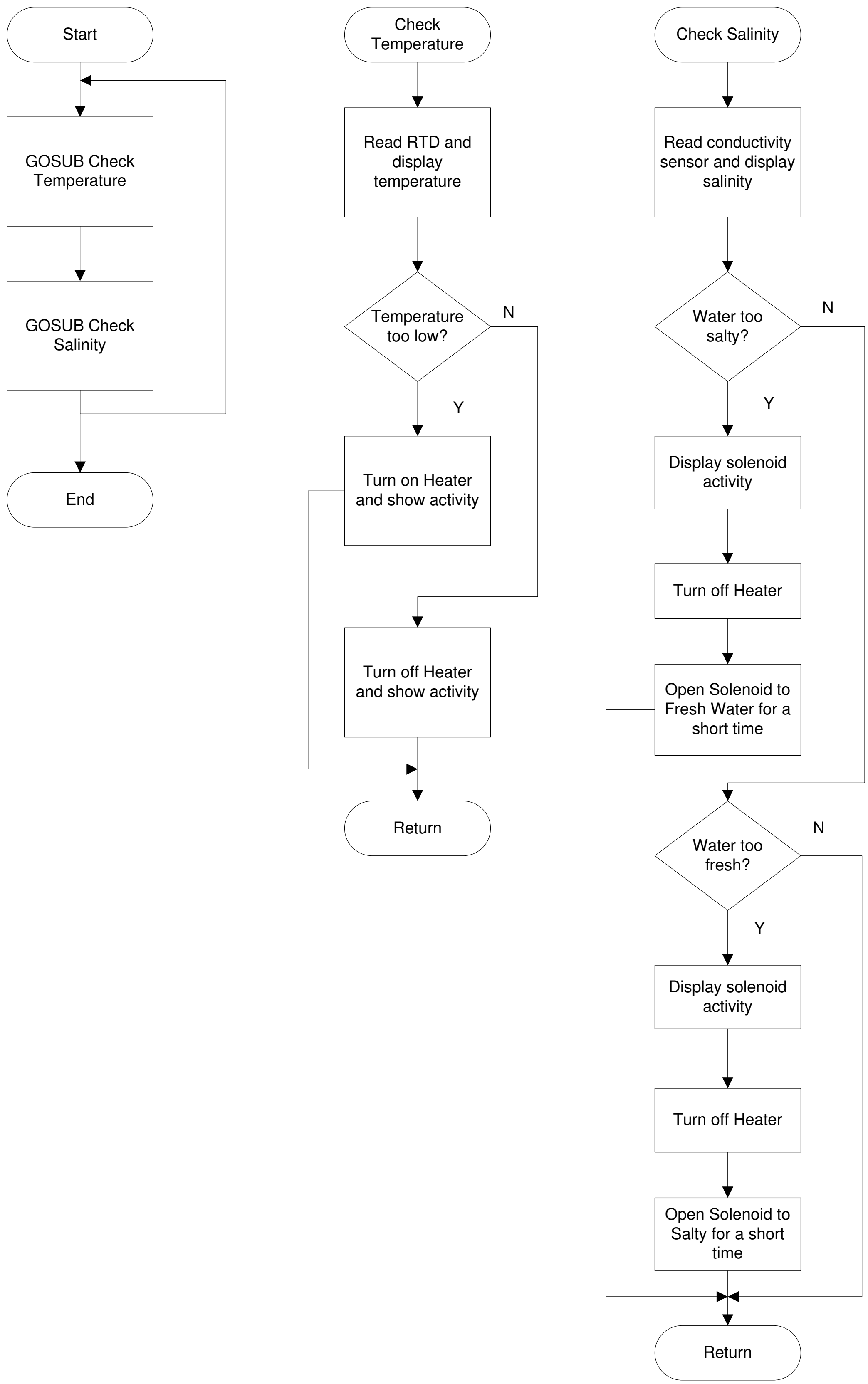


Figure 11 – Control Algorithm Flowchart

Assessment

At the end of each term, the students are surveyed to try to measure whether the course objectives and outcomes are achieved. The surveys were developed with input from an external evaluator, who also took responsibility for compiling and analyzing the data gathered from the survey. The surveys are administered online via the course management suite Blackboard®, so as to minimize the amount of data entry and to give instructors a way to assure that all of their students take the survey. The survey contains questions that attempt to capture the level of confidence the students feel in certain skills areas, as well as their perceived frequency of practicing in those skills areas.

There are a series of three freshman level courses in engineering at Louisiana Tech University that students in all declared disciplines must take. The project described here is part of the second of this series, and there are several common questions between the surveys for these classes. By comparing the student responses on the later surveys with the earlier surveys, some idea of effectiveness of the project to accomplishing certain goals may be attained. In addition to the questions that are common between the two surveys, there are several questions on the second-term survey that are more specific to just the content of the second-term engineering course that give some idea of student confidence, but lack a baseline for comparison. For each question, the students are asked to respond according to a 6 point scale with respect to confidence, and a 7 point scale with respect to frequency of performance. The response anchors are shown in Table 2. There was a population of 65 for the first term engineering course and a population of 104 for the second course. The results are reported as mean scores, and an ANOVA was run to identify statistically significant differences between the first and second term classes. The data compiled for the common questions is shown in Table 3, along with an indication of any statistical significance.

Table 2: Confidence and Frequency Anchors

Rating	Confidence Anchor	Frequency Anchor
1	Completely Unconfident	Never
2	Mostly Unconfident	Very Infrequently
3	Slightly Unconfident	Rarely
4	Slightly Confident	Occasionally
5	Mostly Confident	Frequently
6	Completely Confident	Very Frequently
7		Always

Table 3: Before and After Confidence and Perceived Frequency of Performance

Item	Confidence ENGR 120	Confidence ENGR 121	Significant?	Performance ENGR 120	Performance ENGR 121	Significant?
Utilize the prescribed solution format when solving problems.	***5.10***	4.98		***5.59***	5.41	
Work collaboratively with one or more other students.	***5.26***	5.18		5.02	***5.59***	✓
Present the results of assignments and projects using written communication.	***4.94***	4.89		5.16	***5.32***	
Present the results of assignments and projects using oral communication.	4.54	***4.57***		4.12	***4.27***	
Generate 3D models of engineering components and assemblies using Solid Edge.	4.38	***4.78***	✓	***4.77***	4.64	
Present technical data in tables and on graphs in a professional manner.	***5.15***	4.99		***5.28***	4.95	
Locate specifications and prices for the supplies, parts and systems used in course projects from manufacturers and on-line retailers.	4.88	4.88		4.05	***4.60***	✓
Use linear regression analysis as appropriate in class projects.	***4.87***	4.85		***4.93***	4.72	✓
Utilize MathCAD to assist in solving engineering problems.	***4.85***	4.49	✓	***5.17***	4.53	
Utilize Excel to assist in solving engineering problems.	***5.15***	4.70	✓	***5.45***	5.07	✓
Use creative techniques to overcome at least one project difficulty.	4.91	***5.18***		***4.77***	4.74	

Most of the confidence indicators did not show statistically significant differences after completing the second term course. Exceptions are for the generation of 3D models in which a change for the better is seen, and the use of MathCAD and Excel in which a decline in confidence is noted. The meaning of these statistically significant changes are not entirely clear. The project has a relatively large scope for a Freshman project, and it could be that being exposed to so many things leaves the students realizing that there is a large world of topics in engineering, and they have a lot left to learn. In any case, a look at the actual average response of a student is indicative of their assessment of their own confidence. The confidence score averages range between about 4.5 and 5.2, meaning that on average, the students felt between "Slightly Confident" and "Mostly Confident" about all of the categories indicated above. It is also interesting to interpret the perceived frequency of performance of each of the items. The "Work Collaboratively" category makes a lot of sense because the project forces them to work in a team much more than the previous term. Also, the students are required in several homework assignments to research the best source for procuring items needed for their project, thus it is not surprising that the "Locate Specifications" category has an increase in perceived frequency. The other items that came out with significant differences do not make as much sense, since the students use as much or more of these tools (linear regression and Excel) as in the first term. One possible explanation is that the more they use the tools, the more they see the other possible uses for them, and they feel less confident because they feel they have used such a small percentage of the capability of the tools.

The questions specifically addressing skills acquired in the second term course did not have any "before" data to which the results could be compared. It will have to suffice, therefore, to look at the student responses simply relative to the anchors they used to make their self-assessment. It could be speculated that many of the survey items would have scored very low in a "before" survey, had it been given, since the items address such specific skills (e.g. designing, fabricating, troubleshooting and testing a temperature and salinity controlled system) to which the students have had no exposure. Table 4 shows the average scores for student confidence in a range of specific skills. The scores for confidence again indicate an average level of confidence in the range of "Slightly Confident" to "Mostly Confident". While it is encouraging that the students seem to feel confident in the skills we are trying to impart, what is more encouraging is that the students are being exposed to topics that are quite advanced for Freshmen, and they are able to apply the analytical skills they are learning to designing a systems level project. Whether or not the student confidence or perceived frequencies seem high, direct observation of what the students are learning how to do validates the effectiveness of the project.

Table 4: Confidence and Perceived Frequency of Performance for Project-Specific Skills

Item	Average Confidence Score	Average Frequency Score
Compute quantities such as iron concentration, mass of reactants and products, and electrical current for a salt water mixture undergoing oxidation/reduction reactions due to the presence of a conductivity probe.	4.64	5.06
Compute quantities such as iron concentration, mass of reactants and products, and electrical current for a salt water mixture undergoing oxidation/reduction reactions due to the presence of a conductivity probe.	4.29	4.69
Apply conservation of mass to batch and rate problems to compute the inputs, outputs and changes of system constituents.	4.37	4.87
Apply conservation of energy to a small volume of water that is heated using an electrical resistance heater, computing quantities such as heater wattage, temperature change, and heating time.	4.49	4.48
Design an electrical resistance heater to heat a small volume of water in a specified period of time, where the design involves choosing the gage and length of a segment wire.	4.18	3.56
Evaluate the compatibility of electrical components and devices (transistors, solenoid valves, heaters, pumps, sensors) with the BASIC Stamp II microcontroller, the Board of Education and with external power supplies.	4.34	4.86
Implement cascaded switching circuits consisting of transistors and relays to allow the BASIC Stamp II microcontroller to turn external components on and off.	4.46	4.79
Implement RC circuits and PBASIC programs to interface the BASIC Stamp II microcontroller with sensors.	4.3	4.76
Explain the microfabrication steps and processes used to fabricate a resistance temperature detector – RTD.	4.64	4.53
Design a nickel-based RTD by computing the width and length of the resistor and by drawing the chosen resistor layout using Solid Edge.	4.59	4.01
Program a BASIC Stamp II microcontroller using the PBASIC language to control the speed and direction of servos.	4.65	4.41
Design and fabricate a system where the temperature and salinity of a small fluid volume are measured and controlled.	4.63	4.3
Troubleshoot, test, and validate a system where the temperature and salinity of a small fluid volume are measured and controlled.	4.42	4.53

Conclusion

A project which exposes all engineering freshman to a real application of circuits, electrochemistry, microcontrollers, semiconductors, and microfabrication techniques has been implemented at Louisiana Tech University in the second of a three-course sequence. The project reinforces fundamental concepts that are covered in the lecture portion of the course such as the conservation of mass and energy. Students fabricate and implement conductivity and temperature sensors along with the necessary circuitry to interface them with a microcontroller. Devices that demand more power than the microcontroller can deliver are actuated through the means of cascaded switching circuits that the students also implement. The students learn programming skills as they develop control strategies and implement them on their microcontrollers. The end result is a student-built system that is capable of closed-loop control of the temperature and salinity of a small volume of water. While the statistics gathered about the effectiveness of the project are mostly inconclusive, it is the strong opinion of the faculty involved in the project that it benefits the students greatly to literally build their own engineering problems, and through solving them to end up with a working system. The data collected does suggest that the students are confident in what they have learned how to do by the time they finish the course. The range of topics that can be motivated by this project is truly impressive; it would be difficult to imagine a better experiential learning centerpiece that was as easily implemented to an entire incoming class of freshmen.

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