

BUILDING CONFIDENCE THROUGH HANDS-ON ACTIVITIES

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Abstract

Living WITH the Lab is a first-year engineering curriculum that serves over 400 students each year at Louisiana Tech University. This year-long, three-course sequence uses student-owned software, tools, a robot kit, and an Arduino microcontroller to provide a mobile laboratory and design platform. At the end of each term, students are asked to report the number of times they have completed each of 26 hands-on activities (using hand tools, measurement instruments, etc.). They are also asked to rank their confidence in broadening activities, non-technical skills, technical skills, and course-specific areas. This paper examines the relationships between number of times a student engages in hand-on activities and their confidence. The assessment data show that the number of hands-on activities has increased fifteen-fold from the previous curriculum and student confidence is high, particularly on items related to the highest frequency activities.

Background and Introduction

In the last twenty years there has been a movement within the engineering education community to incorporate project-based hands-on learning into the classroom. The goal is an “emphasis on inquiry-based learning...with much less dependence on lectures,” because leaders in engineering education have recognized that a strictly lecture-based learning environment does not adequately prepare students to succeed as engineers in today’s workplace. Rather, “active, integrative project-based learning needs to replace much of the passive lecture-based instruction” [1].

This redirected focus is based in part on the constructivist school of thought, which says that students learn best through interactive, hands-on problem solving [2]. According to John Dewey,

“Methods which are permanently successful in formal education...go back to the type of the situation which causes reflection out of school in ordinary life. They give pupils something to do, not something to learn; and doing is of such a nature as to demand thinking, or the intentional noting of connections; learning natural[ly] results.” [2]

Measuring the quality of learning through hands-on activities can be accomplished by evaluating student confidence. As discussed by Hall et al. in their work on facilitating lifelong learning through freshman engineering curricula, several studies have confirmed that students with lower confidence were more self-critical and avoided certain tasks, whereas more confident students “were able to adapt to new situations more quickly, [and] enjoy learning more” [3]. In engineering, Besterfield-Sacre and colleagues found that students with lower confidence in basic engineering skills have an increased likelihood of leaving engineering despite being in good standing [4].

When applying the concept of hands-on learning to engineering education, the ideal way to maximize student learning would be through a highly interactive, hands-on curriculum. In particular, boosting student confidence at the beginning of their engineering studies can be done by designing an integrated, project-based freshman engineering curriculum. Louisiana Tech University has implemented this type of curriculum with great success. The College of Engineering and Science (COES) employs an integrated curriculum which is designed to maximize student learning and develop the qualities of the Engineer of 2020 through a series of project-based courses taken in the freshman year [5].

At Louisiana Tech, all engineering students must enroll in an integrated curriculum which incorporates many of the educational practices of the National Science Foundation Educational Coalitions [6]. Students complete a series of three engineering courses (Engineering Problem Solving I, II, and III) which are structured as combined lecture / laboratory classes. With two meetings per week, each class period is arranged so that the first 60 minutes are designed to be in a lecture format; the remaining 50 minutes are used as a lab, giving the students the opportunity to immediately test and implement their new knowledge.

To complement the material covered in the Engineering Problem Solving courses, the integrated freshman curriculum includes differential and integral calculus courses, basic chemistry lecture and laboratory courses, and a calculus-based physics course; students also typically enroll in several nontechnical courses during the first year (see Table 1). First year integrated courses are scheduled to be taken in “blocks” so that classes of 40 students take the same sections of each mathematics, science and engineering course during each quarter. Topics presented in the mathematics and science courses are coordinated to some degree with the topics presented in the engineering courses as a way to facilitate student learning [3]. Although Louisiana Tech uses a quarter calendar, credits are awarded on a semester credit hour basis, meaning that each course meets the same total number of hours as on a semester system, but on a condensed schedule.

Table 1: Integrated Freshman Curriculum

Fall Quarter		Winter Quarter		Spring Quarter	
Course	Credits	Course	Credits	Course	Credits
Engineering Problem Solving I	2	Engineering Problem Solving II	2	Engineering Problem Solving III	2
Math for Engr & Sci	3	Calculus I	3	Calculus II	3
General Chemistry*	2	General Chemistry + Lab*	2+1	Physics for Engr & Sci**	3

*Students in cyber engineering fill these slots with a general education class and a cyber engineering class

**Students in chemical engineering postpone physics and take an additional chemistry in this slot

The first year engineering experience is designed to boost experiential learning through student ownership of a “laboratory” platform in a curriculum called “Living WITH the Lab” (LWTL) [7]. The program serves over 400 students each year at Louisiana Tech. This year-long, three-course sequence uses student-owned software (\$100), tools (\$70), a robot kit (\$60), and an Arduino microcontroller (\$30) to provide a mobile laboratory and design platform. Components of the student-owned “lab” are used throughout the first-year program in a variety of ways, providing students with a rich and varied learning experience.

Most of first-year classes, including Engineering Problem Solving courses, are taught by faculty who have earned a Ph.D. in an engineering discipline; occasionally, advanced graduate students with good communication skills and an interest in academic careers are selected to teach these classes. Class sizes vary from about 15 to 44 students. Classes with larger enrollments (larger than 28) are provided with an undergraduate classroom mentor to assist with hands-on activities during class and with the grading of homework assignments. The first-year program also operates a HelpDesk that is open five nights per week from 6 p.m. to 8 p.m. to support projects. This program allows students to finish up work not completed in the regular class period or to get assistance on assignments. The HelpDesk is able to take care of most of the situations where students need assistance, but students are also free to get help from their instructor during regular office hours.

At the end of each term, students are surveyed about the number of times they have completed each of 26 hands-on activities (using hand tools, measurement instruments, etc.), how many COES society meetings they attended, and the total number of service hours they completed during the term. They are also asked to rank their confidence in broadening activities, non-technical skills, technical skills, and course-specific areas. An abbreviated form of the survey is included in Appendix A.

This paper specifically explores and analyzes data collected from Spring Quarter 2012 through Fall Quarter 2013 to examine the relationship between hands-on experience and confidence for students taking the three first-year engineering courses in LWTL. It includes sections describing each course, the assessment methods, and key results. More details on the implementation and assessment of the curriculum can be found at www.livingwiththelab.com.

Engineering Problem Solving I

The first course in the LWTL sequence is Engineering Problem Solving I. In this course students begin by building the robot kit. As their lectures cover basic concepts relating to electricity and circuits, students are working during the lab time to breadboard circuits. This allows students to test concepts like Kirchoff's Voltage and Current Laws to gain a greater understanding of these naturally abstract concepts.

Later in the quarter, students have the opportunity to fabricate and test a centrifugal pump (see Figure 1 below). Using concepts learned in class and working in teams, students design an impeller using 3D modelling software. The impellers are then printed with a rapid prototyping machine and incorporated into the pump assembly. To build the body of the pump, students use the milling/drilling machines which are in the freshman engineering laboratories. Classroom knowledge and practical application must be combined when students test their pumps at different heads. By calculating the energy delivered to the pump's electric motor and the energy imparted to the fluid, students determine the efficiency of their pump. Through the pump project, working with the robot, and other activities completed during the quarter, Engineering Problem Solving I provides a strong hands-on learning experience for beginning freshman.

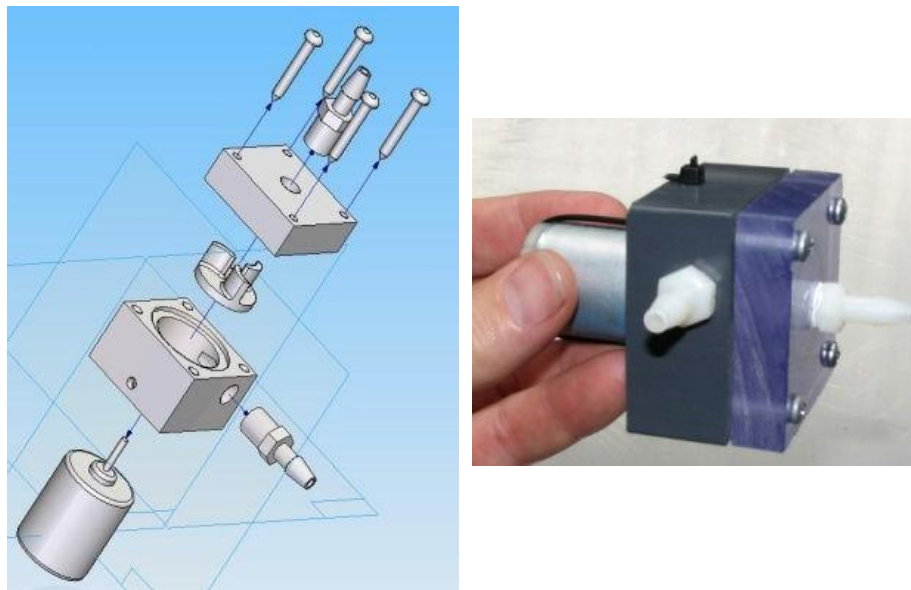


Figure 1: Engineering Problem Solving I– Centrifugal pump project

Engineering Problem Solving II

Next in the series is Engineering Problem Solving II. The focus of this course is the “fish tank project,” which involves multiple design and fabrication steps in order to produce a controlled system for maintaining the temperature and salinity of a small volume of water at a set point. Students work in groups to complete this project. In addition to building the platform on which

the system is mounted, students use a lathe and milling machine to fabricate a conductivity sensor. The centrifugal pump from Engineering Problem Solving I is used to circulate the water through the system. Students design and assist in the photolithography process to create a resistance temperature detector (RTD) for measuring the temperature of the system. Students are also responsible for wiring the system and programming an Arduino microcontroller to coordinate the functions of each component in order to stabilize and maintain the salinity and temperature of the water. Below, Figure 2 shows a student working with their fish tank project.



Figure 2: Engineering Problem Solving II– Fish tank project

In Engineering Problem Solving II students learn fundamental saltwater chemistry. Through the fish tank project students have the unique and powerful opportunity of immediately synthesizing these concepts with linear regression, which they learned in Engineering Problem Solving I, to calibrate the conductivity sensor. Number of hands on here? Conservation of mass and energy are also taught in the lectures and implemented in the project. Troubleshooting and creative problem-solving skills are taught on a just-in-time basis to help students assess and improve the function of their fish tank.

Engineering Problem Solving III

The third and final course in the LWTL series is Engineering Problem Solving III. Teams of students work to conceive of, design, and fabricate a functional prototype of a “smart product” for the Freshman Design Expo which is held at the end of the term. In the first stages of the project, students employ mind maps the principles behind Tom Kelley’s book, The Ten Faces of Innovation, to brainstorm. Using the Pugh method, students evaluate their ideas and determine which concept to pursue for the project. A strong emphasis is placed on self-teaching as students are encouraged to employ a wide variety of sensors and output devices in their projects. As a homework assignment, students create a short video (which they post on YouTube) describing

the function of their “smart product.” Two examples of student design projects are shown below in Figure 3.



Figure 3: Engineering Problem Solving III– Design project; finger activated TV remote; smart fan (turns on when it gets hot)

The culmination of the project is the Freshman Design Expo, where teams present their projects to judging teams comprised of faculty, engineering upperclassmen, and local professionals. Awards are given to projects demonstrating exceptional design and technical quality.

Assessment Methods

At the end of each quarter, students are surveyed about their experience in the Engineering Problem Solving course in which they are currently enrolled. A condensed form of the survey can be found in Appendix A. An assessment of LWTL is then performed by examining the results of the quarterly student surveys. The survey is distributed to students via email using SurveyMonkey online survey software. Each student receives a unique link tied to their email address; this allows the software to track whether a student has responded or not, making it possible to send reminder emails to students who have not yet completed the survey.

In the survey, students are asked to report the number of times they completed 26 hands-on activities, as well as how many meetings of societies within the COES they attended, and the total number of service hours they completed during the current term. Students are also asked to rank their confidence in broadening activities, non-technical skills, technical skills, and course-specific areas. The ranking scale is from 1 to 6, with 1 indicating “completely unconfident” and 6 meaning “completely confident” [8]. This wording is reasonably consistent with Bandura’s work on constructing self-efficacy scales, however, he recommends a scale with 10 or more intervals for greater sensitivity. The first portion of the survey is the same for all students; the last portion, which asks students to rank their confidence in a variety of areas, covers both “fundamental” areas taught throughout the program as well as topics which are covered in the student’s particular course.

Once the deadline for completing the survey has passed, the results of the survey are downloaded for analysis. Data sets that are incomplete or obviously include random/false data (e.g. a student

claiming to have attended 5 meetings of each of the 25 student organizations in the COES during one term) are not considered in the analysis. In this way, a large body of data has been collected relating to students' hands-on activities, involvement in the COES, and confidence in both fundamental and course-specific areas. The following discussion utilizes this data to examine the relationship between hands-on activities and students' confidence in related areas.

Results and Discussion

As discussed in the introduction, there is an expected relationship between the confidence expressed by students and their completion of related activities. The data collected from the LWTL student surveys also provides some support of this concept.

Frequency of Hands-on Activities

Table 2 below gives a summary of the number of hand-on activities reported in the Fall 2013 survey; for comparison, these results are given with the results of another survey given to freshman engineering students under the curriculum used prior to LWTL [9]. The Fall Quarter 2013 survey was deployed to 8 sections of Engineering Problem Solving I, 5 Honors sections of Engineering Problem Solving I, 2 sections of Engineering Problem Solving II, and 2 sections of Engineering Problem Solving III. In the older survey, data for honors students was not collected separately.

Table 2: Fall 2013 Hands-On Averages in Engineering Problem Solving Courses

average hands-on activities per student	Engineering Problem Solving I	Engineering Problem Solving I-Honors	Engineering Problem Solving II	Engineering Problem Solving III
Old Curriculum	13.52	--	4.10	26.29
LWTL	202.03	215.28	217.42	196.30

The old curriculum was a traditional, lecture-style class. In it, students had far fewer opportunities for guided, hands-on exploration of topics discussed in class. As Table 2 shows, LWTL takes a very different approach to learning by coupling lectures with related hands-on work for students. What the LWTL curriculum offers students is the opportunity to test what they are taught as a way of solidifying their understanding. This thorough comprehension, and the confidence which accompanies understanding, is one of the main goals of the first year engineering program at Louisiana Tech.

Student Confidence

Using the data collected from the student surveys, a bubble plot can be used to visualize the relationship between students' confidence in a given area and the number of times they completed a related activity. The size of the bubbles then reflects how many students gave a

particular set of (x, y)/(#hands-on, confidence) responses. Plotting the data in this way makes it possible to identify both any patterns in student responses (e.g. a linear relationship) as well as the number of students who respond in a given way (e.g. many students with high hands-on numbers reporting high confidence).

Students in Engineering Problem Solving I are asked how many times they use the Arduino programming environment; they also report their confidence in interfacing the Arduino microcontroller with a variety of sensors and output devices. The bubble plot in Figure 4 below shows their responses when asked about using photoresistors with the Arduino microcontroller.

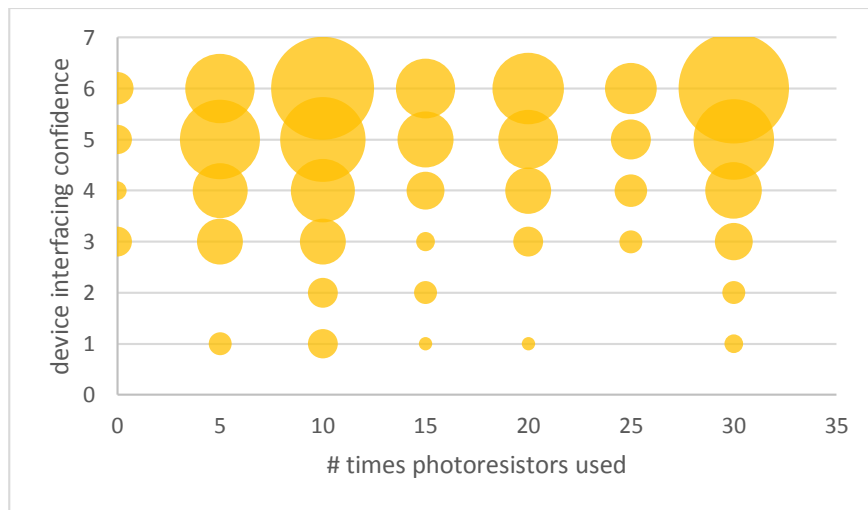


Figure 4: Engineering Problem Solving I Arduino Use and Device Interfacing Confidence

While there is a spread among the responses, the largest bubble in Figure 4 represents students who said they used the Arduino programming environment “30+” times during the term and reported that they were “completely confident” interfacing the Arduino with photoresistors. The next largest group is students who report using the Arduino programming environment around 10 times and say they are “completely” or “mostly confident” in it. It is interesting to note that fewer students report high confidence who say they have used photoresistors with the Arduino 0 times or 5 times. And in keeping with what was expected, most students who report a high number of hands-on activities say they are very confident in using photoresistors with the Arduino.

In Engineering Problem Solving II, students are asked a similar question, but this time relating to implementing sensors on their fish tank project.

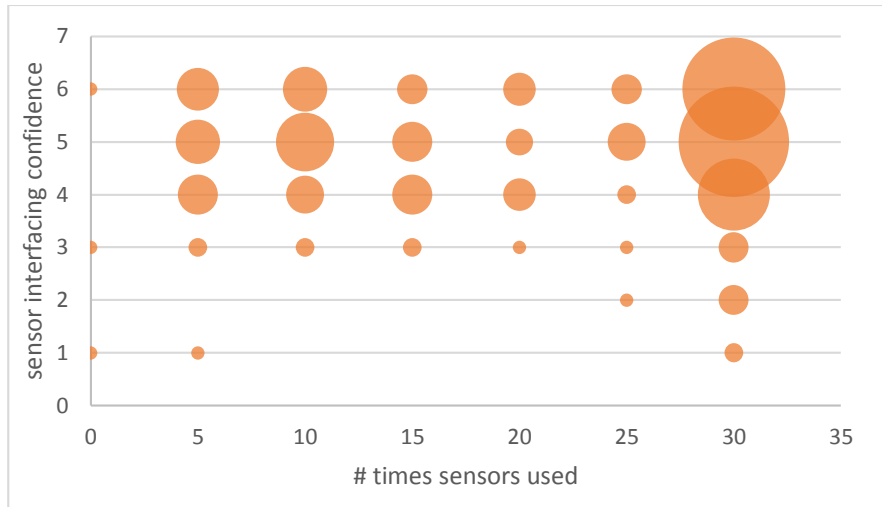


Figure 5: Engineering Problem Solving II Arduino Use and Sensor Interfacing Confidence

As Figure 5 shows, students appear to be fairly confident overall “implementing circuits and sketches to interface the Arduino microcontroller with sensors (such as temperature and conductivity),” as asked by the survey. Similar to the students in Engineering Problem Solving I, the majority of students report a high confidence and a large number of hands-on activities. This is exactly the sort of results which would be expected in a curriculum such as LWTL with a heavy emphasis on hands-on learning.

In Engineering Problem Solving III students are also asked to report their confidence in interfacing the Arduino microcontroller with sensors. The results, shown below in Figure 6, are similar to those of the previous two courses.

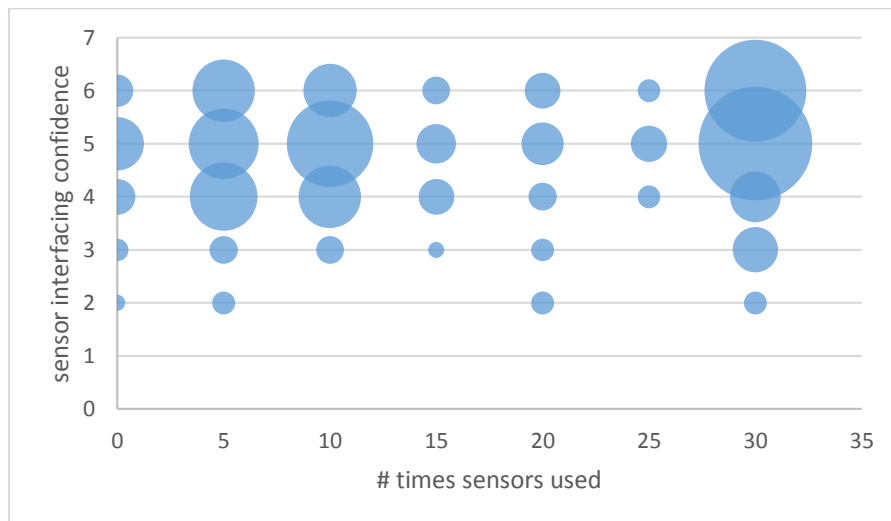


Figure 6: Engineering Problem Solving III Arduino Use and Sensor Interfacing Confidence

The overall confidence reported by students in Engineering Problem Solving III is slightly lower than in the two previous courses. This may be indicative of changing expectations which the students have for themselves; it may also be related to the fact that learning is much more student-driven in Engineering Problem Solving III. Students must take more initiative to successfully complete their project, and this added level of responsibility may have some influence on their confidence.

Conclusion

As this data illustrates, the correlation between hands-on activities and student confidence may not be a linear one. However, as shown by the fact that the majority of students in all cases reported a high number of hands-on activities and a correspondingly high confidence, there is undoubtedly some relationship between the two. To better understand this connection, it would be worthwhile to examine the student survey itself and perhaps make some modifications to ensure clarity and improve sensitivity in the survey items.

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Appendix A: Quarterly Student Survey

Fundamentals

During the current quarter, approximately how many times did you use the following...

1. HAND TOOL?
wire strippers
screwdriver
pliers (e.g. standard, needle nose)
hand drill
tap or die to cut threads
saw
rivet gun
metal hole punch?
2. piece of STATIONARY EQUIPMENT?
milling/drilling machine
lathe
sheet metal shear / brake
soldering iron
heat gun
vise
3. MEASUREMENT INSTRUMENT?
dial caliper
scale (ruler)
multimeter
4. ACTIVITY?
layout (e.g. marking a piece before cutting or drilling)
assembly
implement circuits on a breadboard
rapid prototyping
5. SOFTWARE?
Arduino programming environment
SolidWorks
Excel
PowerPoint
MathCad [only in Engineering Problem Solving III survey]
6. Please indicate how many meetings you attended this quarter for each of the organizations listed below (leave a row blank if you did not attend any meetings for that organization).
7. How many total hours did you spend participating in service projects this quarter?

How confident are you in...

8. your understanding of societal concerns (e.g. population growth, food and water supply, ethical dilemmas, globalization, etc.) and their implications in a broad engineering context?
9. using creative techniques to overcome at least one project difficulty?
10. Once you set a goal, how confident are you to continue going after it, no matter what the obstacles?
11. I enjoy developing technical tools that improve the quality of life for people.
12. I intend to develop new products/processes during my career as an engineer.
13. I prefer improving products/processes that already exist instead of developing something new.
14. utilizing the prescribed solution format (Given, Required, Solution, Discussion) when solving problems?
15. working collaboratively with one or more other students?
16. presenting the results of assignments and projects using written communication?
17. presenting the results of assignments and projects using oral communication?
18. presenting technical data in tables and on graphs in a professional manner?
19. locating specifications and prices for the supplies, parts, and systems used in course projects from manufacturers and on-line retailers?
20. using linear regression analysis as appropriate in class projects?
21. utilizing Excel to assist in solving engineering problems?
22. generating 3D models of engineering components and assemblies using SolidWorks?

Optional comments about Engineering Problem Solving (not the instructor)

Please comment on the content and structure of the Engineering Problem Solving course.

Please don't comment on your instructor here (use the University course evaluation for that purpose).

32. Do you have a suggestion for improving the course?
33. What did you like best about this course?
34. What did you like least about this course?

Engineering Problem Solving I Topics

How confident are you in...

23. converting between decimal numbers and binary numbers?
24. explaining the origin of electric charge and defining electric current, voltage, resistance, and power?
25. computing the current, resistance, voltage, and power in circuits composed of resistors and DC power sources using Ohm's law and Kirchoff's laws?
26. identifying and describing the purpose of each component of the robot, including the Arduino microcontroller board, servos, breadboard, and whiskers?
27. using circuit diagrams to implement the following types of circuits on a breadboard?
LEDs
piezospakers
servos
photoresistors
whiskers
28. using the Arduino programming environment to control or receive input from...
LEDs
piezospakers
servos
photoresistors
whiskers
29. fabricating a centrifugal pump driven by a DC motor with an impeller drawn in SolidWorks and printed on a rapid prototyping machine?
30. utilizing a multimeter to troubleshoot circuits and to measure the current, voltage, and power usage of an electric pump?
31. computing the efficiency and evaluating the performance of a centrifugal pump using DC circuit analysis, conservation of energy, and linear regression analysis?

Engineering Problem Solving II Topics

How confident are you in...

23. computing the molarity, concentration, and mass of the constituents in a salt water mixture?
24. computing quantities such as ion 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?
25. applying conservation of mass to batch and rate problems to compute the inputs, outputs, and changes of system constituents?
26. applying 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?
27. evaluating the compatibility of electrical components and devices (transistors, solenoid valves, heaters, pumps, sensors) with the Arduino microcontroller and with external power supplies?
28. implementing cascaded switching circuits consisting of transistors and relays to allow the Arduino microcontroller to turn external components (e.g. a heater or pump) on and off?
29. implementing circuits and sketches to interface the Arduino microcontroller with sensors (such as temperature and conductivity)?
30. explaining the microfabrication steps and processes used to fabricate a resistance temperature detector (RTD)?
31. designing a nickel-based RTD by computing the length and width of the resistance element and by drawing the chosen resistor layout using SolidWorks?
32. designing and fabricating a system where the temperature and salinity of a small fluid volume are measured and controlled?
33. troubleshooting, testing, and validating a system where the temperature and salinity of a small fluid volume are measured and controlled?

Engineering Problem Solving III Topics

How confident are you in...

34. purchasing supplies and parts for an innovative product?
35. applying statics principles to determine resultants of force systems?
36. applying statics principles to determine unknown forces and moments for concurrent and non-concurrent force systems?
37. applying the principles of electrical circuits, statics, and conservation of energy to evaluate the efficiency of a motor/gearbox system, computing quantities such as electrical power usage, mechanical power output, torque, and angular velocity?
38. computing present worth, future worth, and uniform payment schedules when performing engineering economic analyses?
39. utilizing Mathcad to assist in solving engineering problems?
40. implementing infrared LED/receiver circuits (IR pairs) to detect objects?
41. implementing the specifications and Arduino programming commands to interface selected sensors with the Arduino microcontroller?
42. explaining the physics behind how sensors function?
43. explaining the roles of the ten "Faces of Innovation" as discussed in "The Ten Faces of Innovation" by Tom Kelley?
44. creating a mind map to organize ideas around a central topic?
45. applying the Pugh method to evaluate concept ideas?
46. completing the following steps of creating a functional prototype of an innovative product that utilizes one or more sensors, actuators, or other output devices, and the Arduino microcontroller board?
 47. *conceiving of a product*
 48. *designing a prototype*
 49. *fabricating a functional prototype*
50. developing a work plan to manage your time and resources to successfully produce a prototype of an innovative product?
51. How many types of sensors did you use for your smart product? Examples include accelerometers, distance sensors, temperature sensors, radio frequency communication, or remote control devices.
52. How many output devices did you use for your smart product? Examples include LEDs, LCDs, gear motors, or sound output.
53. How many sensors AND output devices did you learn to use on your own (without significant help from your teacher)?