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Implementation of "We Learn by Teaching"

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Implementation of "We Learn by Teaching" Within Capstone Design

Abstract

There are many quotes from great historians and current educators about the process of teaching and the benefits of learning. One effective method comes from the simple Latin Proverb *"We learn by teaching"*. This process of learning from teaching is also associated with Kolb's experiential learning cycle.[1] Kolb's methods of learning were implemented in a senior capstone design class where student learning is assessed. The capstone students are required to identify an educational need within the mechanical engineering technology program. This need is discussed with the faculty for the development of a hands-on laboratory instrument that will facilitate learning in the program. The results from these discussions determine the design requirements for the capstone project. These capstone students must also learn the design process that has milestones with deliverables associated with a Gantt chart and work breakdown structure. They must also develop an instructional lab with a series of questions that helps reinforce the theory taught in the classroom. And finally, they are required to teach this lab to their peers. The design premise/requirement for the capstone students is that they must incorporate at least three core areas of the curriculum into their team project. This will provide future implementation of the lab to different areas of study with the engineering technology programs. The areas of study for this lab apparatus in this paper include measurements and instrumentations with LabView, strength of materials, heat transfer and material behavior. The assessment included in the final paper is twofold. The capstone students are assessed in the area of retention of fundamental core knowledge upon graduation. The assessment tool was a comprehensive exam similar to the Fundamentals of Engineering exam. Undergraduate student learning utilizing student labs was also assessed through a performance-based assessment method. This consisted of a survey that evaluates student learning for the undergraduate students. Both assessments indicated positive results for retention of core knowledge in the senior capstone class and student learning through hands-on laboratories taught to freshmen and sophomore students.

Introduction to the Kolb's Method

Research on different learning styles has evolved from the early work from Carl Jung's theory of psychological types.[2] His foundational work suggested that people function and interact with different learning/communication types. This psychological research led to the development of how people can be evaluated for their preference of learning. Work done by Kolb,[1] Felder[3] and Myers-Briggs[4] each contributed extensive research in assessing how individuals learn and their preference of learning style. Each developed similar test questions to categorize and define the learning preference of a student. These learning styles in the Klob's research are diverging, accommodating, converging and assimilating. In a classroom setting research done by Mills[5] indicated that learning is optimized by the application of the above learning styles to the students. However, within an engineering learning environment, Holt and Solomon[6] noted that learning relies mostly science and engineering problem solving. This would be a student that has convergent and assimilative learning styles.

Senior capstone design should pull together the core engineering classes for analysis of the design project. However, ongoing observations indicate that some students do not retain fundamental engineering knowledge to correctly model and solve analytical problems in their project class. This data led to the development of this paper where the Kolb's experiential learning cycle and styles is integrated into the capstone design class.[1] This capstone class takes the approach that engineering students will learn and retain knowledge from the experience of teaching. The Kolb method works at two levels: a four state cycle of learning figure 1 and four separate learning styles table1. This method is concerned with the student's internal cognitive processes. It is a learning circle that can begin at any one of the four points. It often begins with an individual moving forward with a particular action and then observing the effect of his or her involvement with the action. Reflecting on observations is a precondition for problem-based learning. Kolmos and Holgaard[7] suggested that this reflection sets up a methodological framework for being innovative on the meta-cognitive level for being able to systematically improve individual and organisational learning processes. Following this, the second step is to understand these effects in the particular instance, so that if the same action was taken in the same circumstances, it would be possible to anticipate what would follow from the action. In this pattern, the third step would be understanding the general principle under which the particular instance falls.

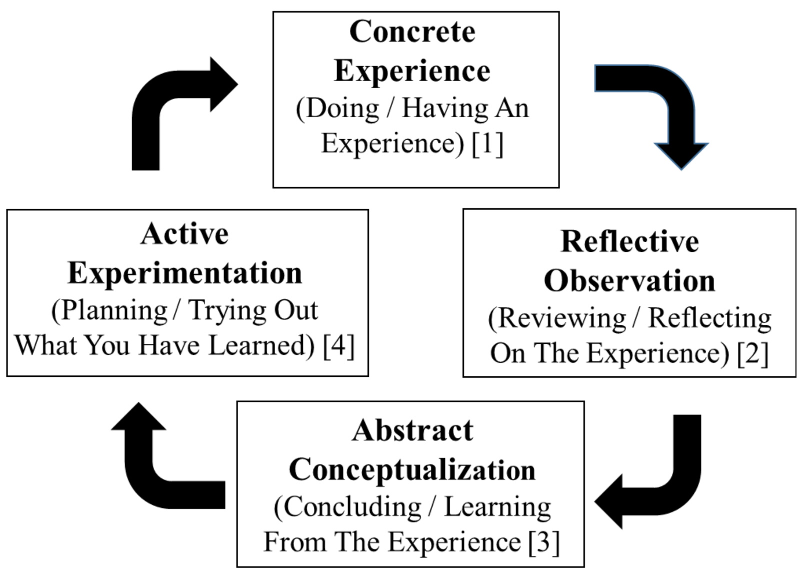

Figure 1. Kolb's Experiential Learning Cycle

Kolb states "effective learning only occurs when a learner is able to execute all four stages of the model. Therefore, no one stage of the cycle is as effective as a learning procedure on its own." The learning cycle also has four distinct learning styles: Accommodating, Diverging, Converging and Assimilating.

	Doing Active Experimentation (AE)	**Watching Reflective Observation (RO)**
Feeling **Concrete Experience (CE)**	Accommodating (CE / AE)	Diverging (CE / RO)
Thinking **Abstract Conceptualization (AC)**	Converging (AC / AE)	Assimilating (AC / RO)

Table 1. Kolb's Learning Styles.

Brief descriptions of the four Kolb learning styles are listed below along with a comprehensive description found in reference 1.

- Accommodating – Individuals in business, sales, and social sciences are often found in this area.
- Diverging – Philosophers, artists, and service oriented individuals often exhibit a stronger preference for this learning style area.
- Converging – Engineers and technologists tend to exhibit converger preferences.
- Assimilating - Mathematicians and scientists tend to exhibit strong assimilator preferences.

In a capstone project learning environment, the education students experience is typically hands-on, kinesthetically based. Designing and building experiments are an important element in developing creativity. Learning from practical experiences is recognized as an important process in the learning cycle. Research from Makoto[8] also indicates that seeking challenging tasks, critical reflection, enjoyment of work, learning goal orientation, and developmental network directly and indirectly facilitate performance of the four steps of Kolb's experiential learning cycle.

Background

There are about forty-five students each year enrolled in the capstone design course. The course is separated into two three-credit classes over two semesters. Typically there are around seven projects supporting five to eight students depending on the complexity of the project. At the beginning of the year, the engineering students took the Kolb learning style quick assessment. Retrieved from https://www.google.com/?gws_rd=ssl#q=kolb+quick+assessment. This quick assessment consists of twenty questions that determine the learning style or preference of a student as described in table 1. Engineering students with project teams consisted mostly of student learning styles that are converging and assimilating. However, each team also had one or two students with learning styles of diverging and accommodating. Therefore, each team consisted of individual learning preferences that tend to complement one another. Also, in order to have successful capstone projects, faculty rearranges and balances out the makeup of the teams in terms of academic strength along with hands-on machining and manufacturing skills.

Capstone students meet with faculty to discuss ideas for a hands-on instructional lab. These projects should satisfy an instructional need within the mechanical, manufacturing, electrical, welding or design engineering technology programs. Some labs discussed were an air flow chamber to measure pressure and air flow relating to characteristics of air filters, fans and blowers. Impact crash tester to study the kinematics and kinetics of dynamic systems. Heat transfer lab of electronic components. Mini roller coaster to study Newton's laws and conservation of energy. Material test machine to study material behavior under different loading conditions including thermal environments. A rotational cantilever bend fatigue machine and a thermal lab to measure thermal expansion and thermal stress of materials. All these potential labs would be designed as table top portable units with a budget up to six thousand dollars.

Within the capstone team, there are student positions of a project manager, scribe and purchasing/budget manager. Design requirements and functionality requirements are established along with a schedule consisting of milestones shown in table 2. Students meet with an advisor once a week for checks and balance relating to any concerns and progress of the project. Students are required to follow the design process outlined in figure 2.

In this paper there were a total of six projects studied. Four out of the six projects did not require the students to develop and teach an instructional lab. The remaining students who were selected to create two capstone projects with instructional labs to teach were also exposed to the Kolb learning cycle in figure 1. From Kolb's theory, students learning is the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping experience and transforming it.[1] Having capstone students experience teaching their hands-on lab to other student's aids in the learning cycle process.

No.	Milestone	Week Due 1st Semester
1	Design Proposal w/Gantt Chart & Work Breakdown Structure (WBS)	4
2	Conceptual Design Oral Report (CoDR)	5
3	Preliminary Design Review (PDR)	7
4	Midterm Peer Evaluations	8
5	Critical Design Review (CDR)	15
6	Design Report	16
7	Design Drawing Package	16
8	Peer Evaluations	16
		Week Due 2nd Semester
9	Updated Drawing Package from First Semester	2
10	New Gantt Chart w/WBS and Milestones	2
11	Functional Prototype	8
12	Mid-Term Peer Evaluation	8
13	Prototype Test Plan	9
14	Prototype Test Results oral report	12
15	Prototype Test Results & Evaluation Report	14
16	As Built Drawing Package	15
17	Final Design Report, Presentation & Demonstration	16
18	Teaching the Lab	16
19	Summary Poster Presentation of Design Project	16
20	Bill of Materials & Labor Distribution by tasks and team members	16
21	Peer Evaluations	16

Table 2. Senior Project schedule with Milestones.

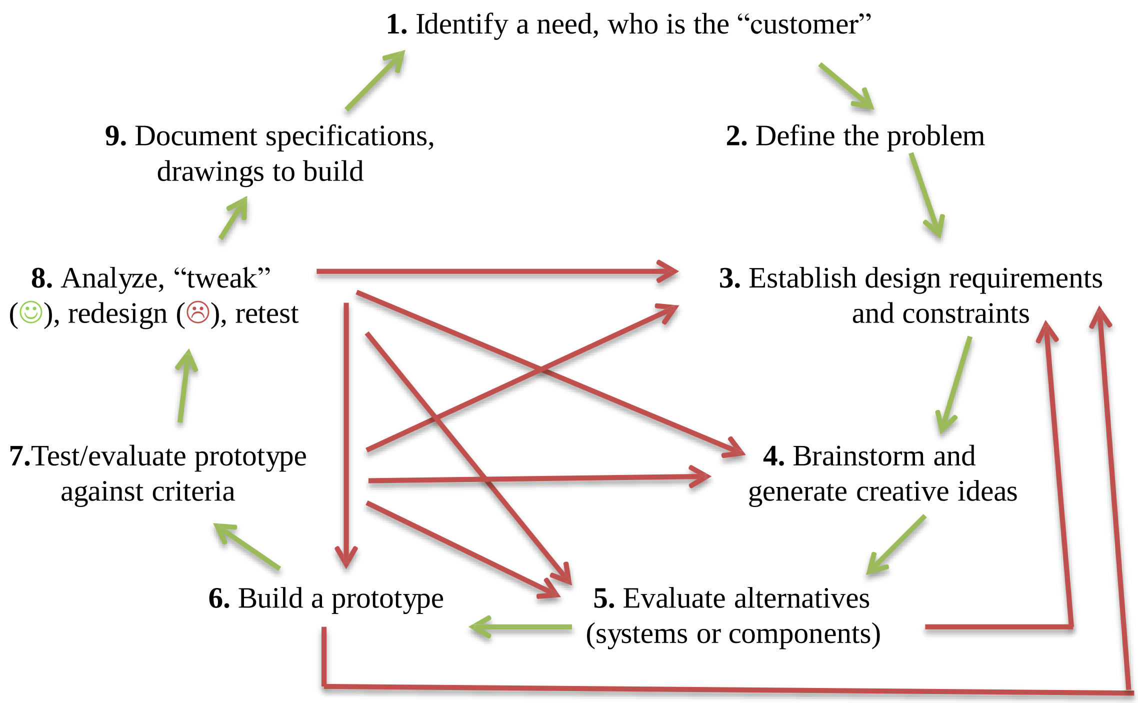

Figure 2. The Capstone Design Process.

Objectives

In this research project the Kolb's methods of learning were implemented in a senior capstone project class where student learning is assessed. This goal was met by the following objectives.

- Apply the Kolb learning style quick assessment to create design teams consisting of student learning preferences that complement one another.
- Apply the Kolb learning cycle to two of the six capstone teams within the engineering design process to improve learning.
- Create an instructional hands-on lab where the capstone students are required to teach to improve learning by experience.
- Assessment of capstone results from the design experience itself.
- Assessment of undergraduate learning via hands-on lab
- Evaluate the retention of lower division engineering core knowledge by a comprehensive engineering assessment exam.

Project Discussion

Included in this paper is an example of one of the hands on prototype lab. The students designed and manufactured this prototype in the capstone design course and was called the *Thermec Lab* in figure 3. The capstone students also developed the experimental procedure on the instructional part and taught it to students. The purpose of this project is to design a desktop lab instrument that will measure and record the thermal expansion of different metallic materials. This instrument will also measure the strain and calculate the stress that occurs during expansion. The instrument will be portable and can be demonstrated events and as a recruitment tool for students exploring interest with the engineering programs.

Listed below are the design requirements for the project. The capstone students are required to follow the design process in figure 2 along with the project schedule in table 2 above. The *Thermec* test equipment was manufactured by the capstone team utilizing machining and manufacturing equipment on site. The complete text for the lab procedure can be found in Appendix A. This testing instrument shown in figure 3 will aid in obtaining data from various test samples. Test samples will include aluminum, copper, steel, and stainless steel as a benchmark for test validation and calibration. The samples will be heated by a thermo-electric element within the range of 232 - 832 degrees F. The temperature will be recorded with three thermocouples per specimen placed in different locations on the test sample. The expansion of the metal will be recorded with the LabVIEW software in conjunction with linear displacement transducer. Material strain will also be recorded with strain gauges to determine how much stress the sample places on the fixture during expansion. All data collected will be compared with theoretical data to ensure accuracy of the testing instrument. An error analysis will be performed and adjustments to the testing instrument will be completed if necessary. Upon completion of the project, the hands-on lab will be taught to the engineering students in Manufacturing Engineering Technology (MFET) strength of materials class and Mechanical Engineering Technology (MET) material selection and heat treatment class.

Design Requirements

- Materials to be measured: aluminum, copper, steel, stainless steel
- 120v connection for some type of heat source
- Minimum temperature change of the materials to be 180^{o}F
- Use of LabView to record all outputs
- Outputs to be measured, temperature, elongation, strain
- Graphs to be created, elongation vs. temperature, stress vs. temperature
- Calculate coefficient of thermal expansion and error analysis
- A mechanical output to visual see the elongation along with electrical sensors/transduces to measure and record temperature, elongation and strain
- Nice aesthetics, light weight, under 25 lbs
- Budget under six thousand dollars
- Develop operational manual and experimental procedure to teach this lab

Example Project: Hands-on Thermec Lab

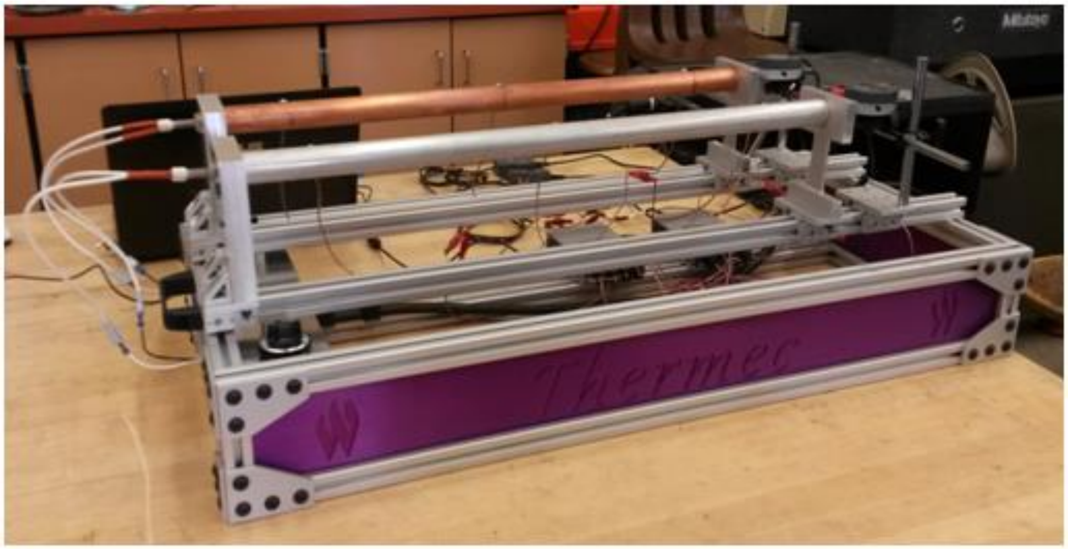

Figure 3. Thermec Lab Instrument.

Capstone Project Assessment

Capstone projects are assessed by the following two grading rubrics. The rubric tables 4 and 5 were developed from ABET's program criteria for mechanical engineering technology and its student outcomes (a through k). Typically, there are three faculty members involved in the assessment process. Each member will submit a score according to the scale below. The advisor to the project will average the totals and include the scores into the final grade.

Capstone Design Project Written Report Assessment			
	Reviewer 1	Reviewer 2	Reviewer 3
Adequate problem definition & project technical description (f)			
Appropriate use of experiments, testing, measurements & prototyping (c)			
Appropriate design assumptions, techniques & engineering analysis (b, d, f)			
Appropriate utilization of engineering tools (ie cad software, analysis software, etc.) (a, b ,c, d, f)			
Appropriate use of graphs, tables & figures (g)			
Appropriate format, technical writing technique & logical flow of information (g)			
Complete, accurate references & bibliography (g)			
Demonstrated application of engineering principles to formulate a solution to a technical problem (a)			
Totals			

Evaluation Scale	
4.0	Excellent
3.0	Good
2.0	Average
1.0	Poor
0.0	Unacceptable

Table 4. Assessment Rubric for Written Report.

Capstone Design Project Presentation Assessment			
	Reviewer 1	Reviewer 2	Reviewer 3
Introduction of project & design problem description (f)			
Appropriate presentation materials (slides, visual aids, video clips, photographs & models (g)			
Technical content of presentation (b, c, d, f)			
Team member appearance & professionalism (e)			
Flow of presentation (including transitions between presenters) (e, g)			
Closing summary with follow-up questions handled correctly (b, g)			
Prototype demonstration, does it satisfy functionality requirements, design requirements, level of completeness of design & aesthetics (c, d, g, k)			
Demonstrated application of engineering principles to formulate a solution to a technical problem (a)			
Totals			

Evaluation Scale	
4.0	Excellent
3.0	Good
2.0	Average
1.0	Poor
0.0	Unacceptable

Table 5. Assessment Rubric for Presentation.

Assessment and Evaluation of Student Learning

Performance-based assessment method was implemented to evaluate this lab as a teaching tool for student learning. This method consists of an anonymous student survey, grading of lab reports, and oral communication within the lab. The anonymous student survey was administered to the undergraduate students in the MFET strength of materials class and MET material selection and heat treatment class. The survey consists of the following questions that the students fill out after the lab assignment was submitted.

Anonymous Student Survey

Key (SA) strongly agree, (A) moderately agree, (D) disagree, (SD) strongly disagree, (U) unsure

1. I would have preferred another method of teaching.	(SA)	(A)	(D)	(SD)	(U)
2. It was easy to remain attentive in the lab.	(SA)	(A)	(D)	(SD)	(U)
3. I would take another course that has hands on labs.	(SA)	(A)	(D)	(SD)	(U)
4. I learn more when other teaching methods are used.	(SA)	(A)	(D)	(SD)	(U)
5. Not much learning was gained by this lab.	(SA)	(A)	(D)	(SD)	(U)
6. Oral discussions in the lab facilitated your learning.	(SA)	(A)	(D)	(SD)	(U)
7. Overall this lab was a good additional to the course.	(SA)	(A)	(D)	(SD)	(U)

The sample size for this assessment survey was 45 students. Each statement one through seven is weighted as 100%. The following assessment data shows the evaluation of the anonymous student survey. This assessment data indicates a positive effect on student learning.

1.	(SA) 3%	(A) 8%	(D) 27%	(SD) 52%	(U) 10%
2.	(SA) 70%	(A) 19%	(D) 3%	(SD) 7%	(U) 1%
3.	(SA) 41%	(A) 29%	(D) 13%	(SD) 8%	(U) 9%
4.	(SA) 10%	(A) 16%	(D) 42%	(SD) 30%	(U) 2%
5.	(SA) 6%	(A) 4%	(D) 31%	(SD) 59%	(U) 0%
6.	(SA) 40%	(A) 41%	(D) 7%	(SD) 7%	(U) 5%
7.	(SA) 45%	(A) 33%	(D) 7%	(SD) 9%	(U) 6%

Assessment of Capstone Students (Retention of fundamental core knowledge)

The capstone students are assessed in the area of retention of fundamental core knowledge upon graduation. An open-ended exit exam was created by selecting engineering problems from the mechanical discipline of the Fundamentals of Engineering (FE/EIT) exam review manual. The topics included: statics, solid mechanics, machine design, materials, electronics and thermal fluid science. This was a good representation of the mechanical engineering technology undergraduate course curriculum. All six projects included students with individual learning preferences that tend to complement one another. Projects five and six required these capstone students to use the Kolb' learning cycle. A key part of the learning cycle was to develop a lab along with teaching the lab to undergraduate students. Therefore, the data were analyzed in relation to four capstone teams that were not required to use the Kolb learning cycle or teach a lab. An average score was recorded per team to determine if the Kolb learning cycle had an effect on student learning and the retention of fundamental engineering courses. The data presented in figure 10 indicates, for this sample size the Kolb method has an effect on the retention of lower division engineering core knowledge.

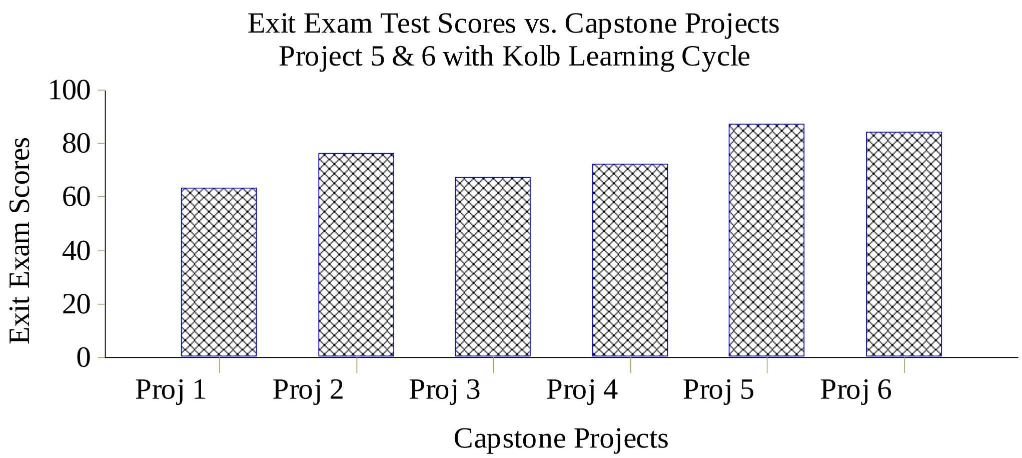

Figure 10. Bar chart of Exit Exam Scores Associated with Capstone Projects.

Conclusions and Discussion

The capstone design course was modified to validate if learning can be improved and engineering core knowledge retained upon graduation. All students were given the Kolb's quick assessment to determine their learning style. Compare to past projects, these teams seemed to function much better with individuals with learning preferences that tend to complement one another. This was observed early in the design cycle where students are brainstorming and developing conceptual ideas as possible solutions to the design problem. It was also determined through an assessment rubric containing ABET's (a through k) outcomes that in general the quality of the projects improved compared to past projects.

Two out of six projects in this paper require the students to follow the Kolb learning cycle. The basis of this cycle is experiential learning where students learn by teaching a hands-on lab to undergraduate engineering students. These capstone students had concrete experiences, reflective observations, abstract conceptualization and active experimentation throughout the design process. Assessment data from an exit exam indicated that these two teams compare to the remaining four projects showed the Kolb method had a positive effect on the retention of lower division engineering core knowledge.

This hands-on lab has been implemented into the Manufacturing Engineering Technology (MFET) strength of materials class and Mechanical Engineering Technology (MET) material selection and heat treatment class to facilitate the theory taught in the classroom. The tools for assessment of learning are the anonymous student surveys, grading of lab reports and direct opinion from students commenting on how they understand and learn through practical experiences. This assessment data recorded indicated a positive effect on student learning. Students seemed more relaxed as senior capstone students taught the lab.

Overall, this paper showed how learning can be improved in the lower division engineering classes through students participating in a hands-on lab exercise. It also demonstrated how graduating seniors can retain engineering core knowledge by introducing the Kolb's methods into the capstone design course. And how the quality of capstone can improve by balance teams with complimentary learning styles.

While there is more research to be completed, this paper advances the theory that engineering students can benefit from understanding the Kolb learning cycle. Follow up discussion with the capstone students identified that they were unaware of different methods of learning styles and learning cycle. Capstone students commented that this topic of how students learn should be introduced into their introductory engineering class. Another comparison between the two Kolb learning cycle projects and the other four was, these students realize that they must thoroughly understand the material in order to take on the responsibility to teach. This required them to review and explore experiential learning within the Kolb learning cycle.

Future Work and Improvements

While this paper explored how Kolb's learning styles can impact engineering learning through capstone design, additional research needs to be completed.

Potential Next Phase

- Create capstone projects that are multidisciplinary with a makeup of students from the mechanical, manufacturing, design, electrical and computer science programs.
- Broaden the scope of the projects to include modern system design that challenge the students in topics that include mechatronics, automation and computer control algorithms.
- Undergraduate students commented that subdividing the lab class into smaller lab sections would aid in the hands-on learning.

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Appendix A. Procedure for Lab

PART I Objective:

In this lab, the thermal mechanical analyzer (*Thermec)* will be used to measure and record change in temperature and length of aluminum, copper, stainless steel and steel. These values will then be used to calculate the various materials' coefficients of thermal expansion, the strain, and the force applied by the various specimens to the backstop. The strain value will then be used for comparison to actual measurements taken by the strain gage located on the *Thermec* backstop.

Introduction:

The coefficient of thermal expansion (α) is a measure of the change in length of a material subjected to a change in temperature. It is defined by the relation:

$$\frac{\Delta L}{L} = \alpha_L \Delta T \qquad \alpha_L = \frac{\text{Change in length}}{L\,(\Delta T)} = \frac{\text{strain}(\varepsilon)}{(\Delta T)}$$

Where L = original length
ΔT = change in temperature

Virtually all metals and plastics expand with increasing temperature, but different metals expand at different rates. For machines and structures containing parts of more than one material, the different rates can have a significant impact on the performance of the assembly and on the stresses produced.[9] The modulus of elasticity or Young's modulus can be used to display a materials linear elastic behavior. Defined by Hooke's Law, stress is proportional to strain which is called the modulus of elasticity.[9] The modulus of elasticity is the slope of the straight line in figure 4 below.

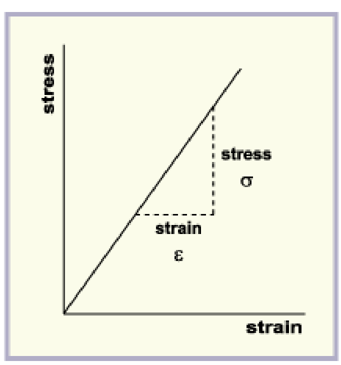


Figure 4. Stress-Strain Relationship

As long as this stress-strain relationship (Young's modulus) is linear, it can be used to determine the stiffness of a material or its resistance to deformation in the elastic region. Once the relationship is no longer linear, the proportional limit has been reached and this relationship can no longer be used to determine this behavior. Figure 5 below shows a rod subjected to a tensile stress. As a result, the rod experiences a change in length.

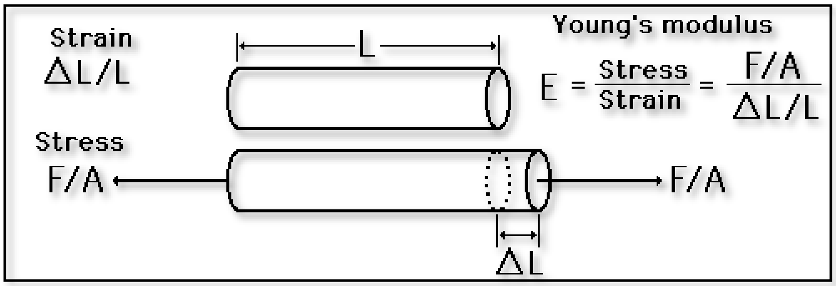


Figure 5. Mathematical Relationship between Stress and Strain.

Experimental Procedure:

1. Place an aluminum and copper Specimen on the *Thermec* lab device.
2. Refer to the *Thermec* operations manual to operate the lab device and obtain the requested data below. **(Note each lab will have different input values to eliminate copying results)**
3. Heat the specimens to _________ °F
4. Observe and record the following for each test specimen:
   a. Aluminum
      i. Initial Temperature Reading: _____________ °F
      ii. Final Temperature Reading: _____________ °F
      iii. Initial Length (L): __________inches
      iv. Change in Length (ΔL): _________ inches
      v. Strain applied to backstop: ___________
   b. Copper
      i. Initial Temperature Reading: _____________ °F
      ii. Final Temperature Reading: _____________ °F
      iii. Initial Length (L): __________inches
      iv. Change in Length (ΔL): _________ inches
      v. Strain applied to backstop: ___________

5. Using heat gloves, remove the copper and aluminum test specimens.
    a. Refer to the *Thermec* operations manual for how to remove the specimens
6. Place a steel and stainless steel specimen on the *Thermec*
7. Refer to the *Thermec* operations manual to operate the lab device and obtain the requested data below.
8. Heat the specimens to __________ °F
9. Observe and record the following for each test specimen:
    a. Stainless Steel
        i. Initial Temperature Reading: ______________ °F
        ii. Final Temperature Reading: ______________ °F
        iii. Initial Length (L): ___________inches
        iv. Change in Length (ΔL): __________ inches
        v. Strain applied to backstop: ____________
    b. Steel
        i. Initial Temperature Reading: ______________ °F
        ii. Final Temperature Reading: ______________ °F
        iii. Initial Length (L): ___________inches
        iv. Change in Length (ΔL): __________ inches
        v. Strain applied to backstop: ____________

Calculations:

1. Calculate the coefficient of thermal expansion (α) and strain (ε) for each specimen (show your work)
    a. Aluminum:
    b. Copper:
    c. Stainless Steel:
    d. Steel:
2. Compare the strain values above to the actual values obtained above.
    a. Are the values different? Explain:
    b. Calculate the % error

3. Calculate the area add image of specimen here
4. Using table 3 below and the area calculation from step 3, calculate the force (F) applied to the backstop by each specimen (show your work) NEED ACTUAL MATERIAL OF SPECIMENS.

Material	Allowable stress (psi)	Yield stress (psi)	Modulas of Elasticity (psi)
Al 6060-T6	21,000	35,000	10,000,000
SAE 1010	20,000	28,000	30,000,000
304 SS	30,000	55,000	28,000,000
C23000	11,000	18,000	17,000,000

Table 3. Mechanical Properties of Typical Engineering Materials

a. Aluminum:
b. Copper:
c. Stainless Steel:
d. Steel:

PART II Objective:

In this portion of the lab, the force calculated in PART I, centroid of an area, moment of inertia of an area, and the parallel axis theorem will be used to determine the stress applied by the various specimens to the backstop. These values will then be used to create a graph of the stress vs. temperature for visual comparison.

Introduction:

The centroid of an area refers to the point that defines the geometric center for the area. Often an area can be divided into several parts having simpler shapes. In figure 6 the algebraic distances or x, y coordinates for the centroid of each composite part ∑ A represents the sum of the areas of the composite parts or simply the total area. Also, if the total area is symmetrical about an axis, the centroid of the area lies on the axis.[10]

$$\bar{x} = \frac{\sum x_i A_i}{\sum A_i} \qquad \bar{y} = \frac{\sum y_i A_i}{\sum A_i}$$

Figure 6. Algebraic Distances for the Centroid.

The moment of inertia of an area is a geometric property that is calculated about an axis. It is a geometric property that is calculated about an axis and for the x and y-axes shown in figure 7 it is defined as the integrals. These integrals have no physical meaning, but become very useful when combined with the parallel axis theorem for an area. Note: Although similar information, the moment of inertia of an area should not be confused with the moment of inertia of a mass, which is a dynamical property of matter.[10]

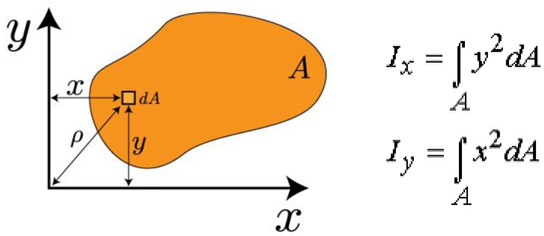
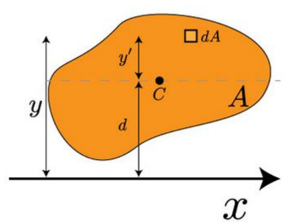


Figure 7. Area Moment of Inertia and Associated Integrals

If the moment of inertia for an area is known about a centroidal axis, the moment of inertia of an area about a corresponding parallel axis can be determined using the parallel-axis theorem. The equation shown in figure 8 below states that the moment of inertia of an area about an axis is equal to the area's moment of inertia about a parallel axis passing through the centroid (C) plus the product of the area (A) and the square of the perpendicular distance (d) between the axes.[10]



$$I_x = \overline{I}_{x'} + Ad^2$$

Figure 8. Parallel Axis Theorem

Calculations:

1. Measure and record the distance from the specimen to the strain gage.
    a. Distance:
2. Calculate the centroid of the back stop in figure 9 using the dimensions below (show your work) Hint: Think of the backstop as a T-beam
    a. Centroid

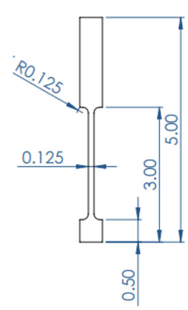


Figure 9. Backstop.

3. Using the parallel axis theorem, calculate the moment of inertia of the cross-sectional area of the backstop.
    a. Area moment of Inertia (I)
4. Using the Force results for each specimen from PART I of this lab and the results from steps 1-3 above, calculate the stress applied to the backstop by each specimen.
    a. Stress (σ)
        i. Aluminum
        ii. Copper
        iii. Stainless Steel
        iv. Steel:
5. Create a graph of the Stress vs. Temperature and attach to this lab report.
    a. Use the stress results for each specimen calculated in step 4 and the final temperature recorded from each specimen in PART I of this lab.
    b. Attach the graph to this lab report. Make sure to label your x and y axes.

Is there a correlation between the stress applied to the plate by each specimen and the temperature of the specimen? If so explain.