Vertical Integration of Engineering Courses for Effective Learning of Continuous Quality Improvement Concepts

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Abstract

Industrial engineering juniors at Louisiana Tech University who enroll in INEN 401 Engineering Statistics II learn how to apply statistical quality control methods to monitor product quality in a traditional classroom setting while engineering freshmen enrolled in ENGR 120 Engineering Program Solving I work in teams to fabricate a small centrifugal pump in a factory-like laboratory setting. Presently, integration of INEN 401 and ENGR 120 class is nonexistent. This paper summarizes the development of an innovative way of teaching INEN 401, by vertically integrating it with ENGR 120, in a factory-like environment to enhance the overall efficiency of the pumps manufactured in ENGR 120 class. Tasks performed include identifying root causes, publishing new fabrication and assembly instructions, fabricating pumps based on new instructions, testing the efficiency of new pumps, and comparing pump efficiency. The preliminary result shows that new pump fabrication instructions developed by INEN 401 students resulted in better pump efficiency.

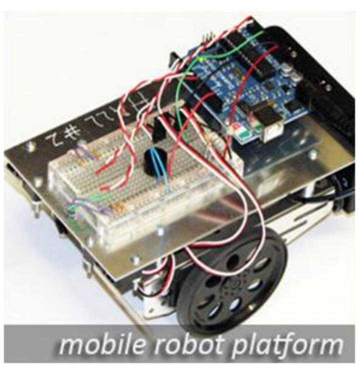
Keywords

Vertical integration of engineering courses, integrated industrial engineering curriculum, quality control education, root causes identification, centrifugal pump efficiency improvement

Introduction and Research Objectives

The vision of the College of Engineering and Science at Louisiana Tech University is to be one of the best colleges in the world at integrating engineering and science in education and research. During the past 15 years, significant improvement has been made in redesigning the freshmen engineering curriculum - in particular the freshmen ENGR 120 series - to achieve this goal. However, integration of upper level engineering courses with these lower level counterparts is still yet to be realized. At present, most upper level industrial engineering courses are still delivered in traditional classroom settings. Traditional education always faces the problem of bridging the gap between what is taught in the classroom and what is needed in real life. Nevertheless, certain critical engineering skills cannot be fully comprehended in school without vertically integrating lower level and upper level engineering courses. For instance, in INEN 401 Engineering Statistics II, industrial engineering juniors learn how to apply statistical quality control methods to monitor product quality in a manufacturing facility. While the quality control concepts are learned through lectures, homework exercises and a class project, students never go through the complete process of root causes identification and elimination that includes the steps of: (1) disassembling defective products, (2) inspecting individual components, (3) categorizing defects, (4) applying basic quality control tools to quantify the defects, (5) conducting statistical studies to find sources of variations, (6) eliminating root causes leading to process variations, (7) replacing defective parts with good ones, (8) reassembling and retesting the product, (9) writing up standard operation procedures including methods and tools to prevent the same mistakes from reoccurring, (10) repeatedly producing the product using the new operation procedures, and (11) observing the product quality being improved progressively. In practice, this cycle repeats itself continually and if done correctly should ultimately guide a process to Six Sigma quality - 3.4 defects per million parts produced. However, the current lecture-based instruction mode only allows Louisiana Tech industrial engineering students to at best practice steps 3 through 5 using the examples and exercises provided by the textbook selected by the course instructor. As a consequence, the critical hands-on experience composed of the rest of the steps is completely missing in the current curriculum.

In light of this weakness in our curriculum, this study aimed at providing an innovative way for industrial engineering juniors to apply the process improvement skills learned in INEN 401 to help improve the quality of centrifuge pumps they fabricated in ENGR 120 Engineering Problem Solving I. ENGR 120 is one of the three fundamental freshman engineering courses in Louisiana Tech's Integrated Engineering Freshmen Curriculum "Living with the Lab". All freshmen engineering students are required to take these three fundamental engineering courses in their first year of study. These include students majoring in biomedical engineering, chemical engineering, civil engineering, cyber engineering, electrical engineering, industrial engineering and mechanical engineering. Funded in 2008 by a NSF grant (Award No. 0618288), this curriculum has been the core of Integrated Engineering Curriculum at Louisiana Tech University. The curriculum is designed to put ownership and maintenance of the "lab" into the hands of the students. Each student purchases a robotics kit along with a programmable controller, sensors, servos, and software to provide the basis for a mobile lab, which allows them to work in the dorm rooms any time of day or night. Figure 1 shows the robotics kit and the Arduino microcontroller used in ENGR 120 series.

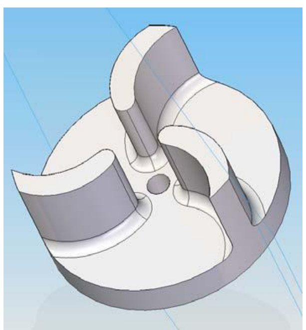


(a)

(b)

Figure 1. (a) Robotics kit used in ENGR 120 Series (b) Arduino Uno (ATMega328) microcontroller

Prototype development is supported by classrooms and laboratories equipped with hand tools, machine tools, test equipment, and a stock of sensors compatible with their microcontroller. Engineering fundamentals are introduced on a just-in-time basis to provide the knowledge required to complete the projects. The Integrated Engineering Curriculum is composed of three courses in series: Engineering Problem Solving I, II and III (numbered as ENGR 120, 121, and 122). Each course carries two semester hour credits. ENGR 120 and ENGR 121 require teams of two to four students to fabricate a small centrifugal pump driven by a DC motor and to test the pump performance through a Fishtank project. The project involves (1) Design: draw the pump impeller, body, face place and an assembled model of the pump using SolidWorks (as an ENGR 120 assignment); (2) Manufacturing: fabricate the pump parts and assemble the pump (as an ENGR 120 assignment) and (3) Testing: characterize the performance of the pump by completing a series of flow experiments (as an ENGR 121 assignment). Figure 2 illustrates a 3-D drawing of the impeller and a finished pump.



(a)

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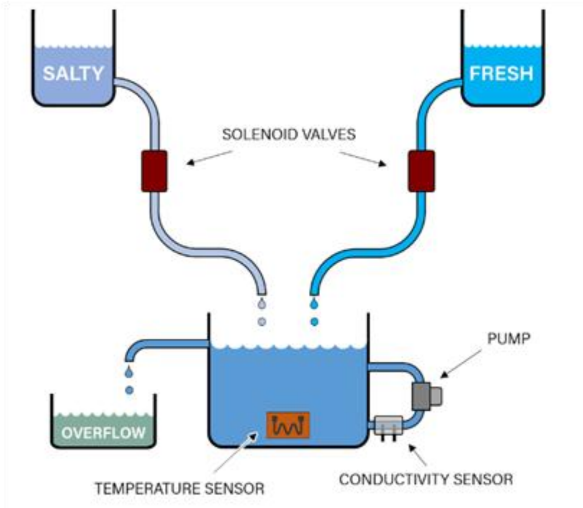
Figure 2. (a) CAD drawing of impeller (b) Completed centrifugal pump

The focus of ENGR 121 is the development of a fishtank where an Arduino microcontroller is used to measure and control the temperature and salinity of a small volume of water. The project involves fabricating the following system components: (1) a wooden platform onto which individual components are attached, (2) a small reservoir containing salt water with target salinity fresh water, (3) fresh water and salty water reservoirs, (4) a waterproofed thermistor for sensing temperature, and (5) a conductivity sensor. In addition, several other components are brought together to complete the system: (1) an Arduino microcontroller, (2) two solenoid valves, (3) a resistive heating element, (4) transistor/relay circuits to power the solenoid valves and heater, (5) a centrifugal pump (fabricated in ENGR 120) and (6) an external power supply to power the system. To control temperature and salinity in the fishtank, the conductivity and temperature sensors must both be calibrated. The calibration equations as well as control setpoints for salinity and temperature are incorporated into an Arduino sketch which determines when salty or fresh water needs to be added and when the heater needs to be activated. The end result of the fabrication, assembly, calibration and programming activities is an autonomous system that senses and controls salinity and temperature. The status of the system (current temperature and salinity, status of each solenoid valve, and status of heater) is displayed on an

LCD screen attached to the fishtank system. Figure 3 shows the design sketch of the fishtank and the flow experiment setup.



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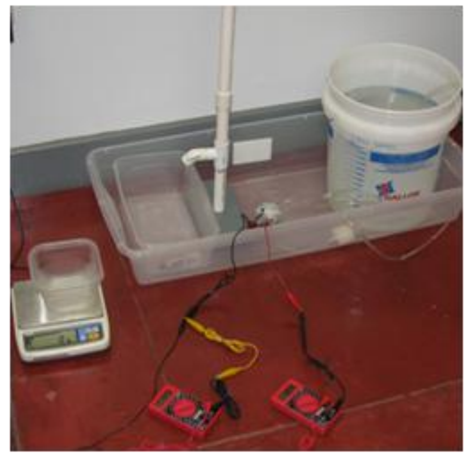

(b)

Figure3. (a) Fishtank design sketch (b) Fishtank flow experiment setup

The final stage of this project involves an in-class presentation that includes the following components: pump design, pump fabrication, overall system operation performance, and discussion of what worked well and what could be improved. However, due to lack of adequate inspection tools and procedures as well as insufficient test samples – only one pump per team was tested - the suggestions for future improvement provided by each team, in most cases, are merely "**guesses**" of what might have gone wrong without going through a rigorous quality inspection procedure to identify the root causes. In addition, these suggestions have never been implemented in any of the subsequent engineering courses to confirm their correctness. As such, students miss the opportunity to learn the quality control tools used by world class manufacturers to achieve "continuous quality improvement." A detailed description of the Integrated Engineering Curriculum can be found at the following link: http://www2.latech.edu/~dehall/LWTL/home/main.html

Literature Review

Recent research has shown that industrial engineering students tend to learn better when exposed to a real-world setting. For example, Jaeger et al.[1] suggests that Learning factory for industrial engineering education may be an excellent pedagogy that incorporate the approaches of interdisciplinary, experience-based learning and applied learning to enable students to apply theoretical knowledge to solve real-world problems and gain professional skills such as critical thinking and decision making. In addition, several research works have demonstrated that vertical integrating of curriculum could attain better learning outcomes. McCowan[2] reported that several Australian schools, particularly in the University of Melbourne, have introduced new learning methods and innovative approaches that create a team-based learning program with each team led by a senior undergraduate. He contended that a significant aspect of this development is the use of senior students as mentors and managers, which provides learning opportunities for the senior students while providing guidance and feedback to the junior students. Similarly, Coyle et al.[3] provided a case study of engineering projects in community service to demonstrate the impact of including freshmen, sophomores, juniors, and seniors in an engineering project. Additionally, Borgford-Parnell et al.[4] have found that compared to freshman engineering students, senior engineering students engage more frequently in back-talk with design problems by noting gaps in their knowledge and identifying new design requirement as the problem and solutions evolved.

Research Methodology and Experimental Results

a. Root Causes Identification

During the Spring 2014 Quarter, ten industrial engineering students who completed INEN 401 in the Winter 2014 Quarter were recruited to participate in this study. They first reviewed a power point presentation that contains pump fabrication and assembly instructions provided to ENGR 120 students. This power point presentation named centrifugal pump assignment (Class 13) can be found at the following link: http://www2.latech.edu/~dehall/LWTL/ENGR120/schedule.html

Afterwards, the group brainstormed to identify the root causes leading to low pump efficiency based on the pump manufacturing experiences they gained when they took ENGR 120 class a few years back. These root causes were grouped into five different categories and displayed in the form of a fish-bone diagram as shown in Figure 4.

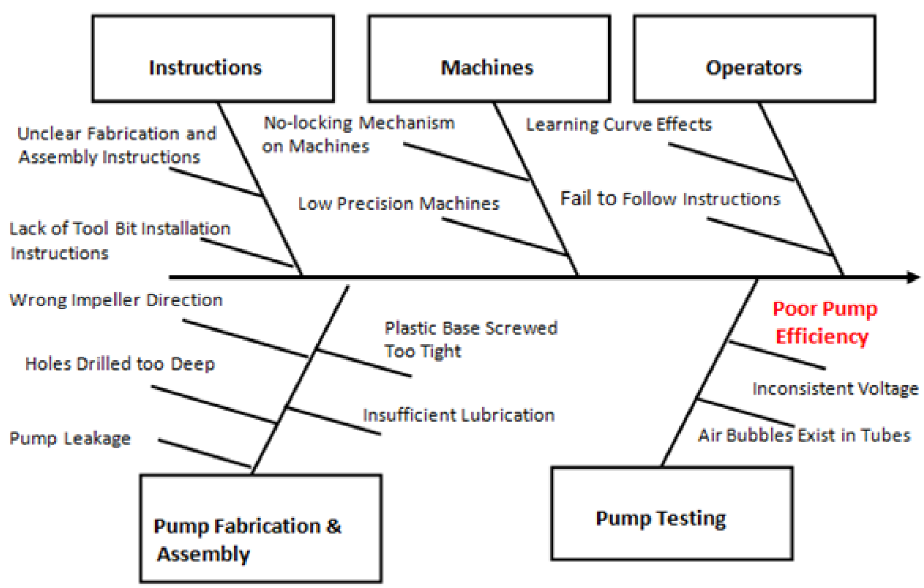

Figure 4. Fish-bone Diagram Showing Root Causes for Poor Pump Efficiency

For example, in the "Instructions" section, students felt the existing instructions were "unclear" since they did not provide the proper drilling speed needed to drill each hole on the block. Other critical technical data such as the depth of each hole to be drilled was also missing.

b. Proposed New Fabrication and Assembly Instructions

The student group then developed new instructions aiming to improve the fabrication process and the assembly process of the pump. These step-by-step instructions including all the needed technical data such as cutting speed and depth of the drill for each hole are summarized in Table 1 below. Note that the photo accompanied in each step is omitted in the table due to space constraints.

Component Name	Fabrication Steps
Block Base	1. Draw an X on the top of the block base (side A) to find the center. 2. Install an N-bit into the chuck and drill through the center of the block. Speed=40. 3. Install a $1\frac{1}{4}$ " Forstner bit into chuck. Lower it down until it touches the surface. Then zero out the surface. Drill to depth of 0.08". Speed=30. 4. Install a 1" Forstner bit into chuck. Drill 0.42" deeper. Speed=30. 5. Flip the pump body (side B). Install a ½" Forstner bit. Drill 0.11" deep. Speed=40. 6. Turn the block base on its side and mark 5/16" from the bottom (big hole side) and 11/16" from the left side. Install a Q bit into chuck and drill 1" depth. Speed=40. 7. On side B of the block base mark two points 3/8" from the bottom and the top, and 1" from the side. Drill 0.25" deep with a 5/32" bit. Speed=50. 8. Turn the block base on its side. Below the holes drilled in Step 7, mark 3/16" from the top. Drill .4375" deep with a 5/32" bit. Speed=50. 9. Place the block base in the vice for tapping. Tap the hole drilled in Step 6. Make sure the tool is perpendicular to the part. 10. Press the bronze bushing into the pump body until the bushing is flush with the bottom of the hole.
Plastic Base	1. Draw an X on face of the plastic base. Drill through the center with the Q bit. Speed = 40. 2. Mark 4 points on the face of the plastic base 0.25" from the corner of two adjacent sides. Drill with a #42 bit all the way through. Speed=50. 3. Tap the center hole drilled in Step 1. 4. Clamp the block base and the plastic base together, then place it in vice and align. 5. Drill the holes in Step 2 with a 5/32" bit using the hand drill.

Table 1. Step-by-step pump fabrication instructions

Table 2 below shows step-by-step assembly instructions and additional fabrication and assembly tips.

Assembly Operations	Steps
	1. Lubricate the area around the bushing and the O Ring. 2. Insert a zip tie through the four small holes on the body. 3. Insert the DC motor into the pump body and secure it with the zip tie. 4. Flip the pump body over and install the impeller made onto the shaft of the DC motor. 5. Place the O Ring around the top edge of the base surrounding the impeller. 6. Place the plastic base on the top of the block base and secure it with four screws. 7. Apply Teflon tape to the threads on the barb fittings and screw into appropriate holes.
Additional Fabrication and Assembly Tips	1. Do not drill through the four corners of the base where screws will be inserted. 2. Zip tie DC Motor firmly before flip it over to install the impeller. 3. When drilling do not remove your hand from the z axis drill press handle to know what direction the drill bit is moving. 4. Note that the drill bit goes down when turned clockwise and comes up when turned counter clockwise. 5. When tapping, keep 27 NPT Tap perpendicular to *the base and apply light pressure.* 6. *Make sure* the bit touches the drilling su*rface before zeroing out.* 7. *To zero out the z-axis press "z", "0", and "enter"*. 8. Do not push the drill bit all the way in. Push enough to keep it tightly held. 9. Standardize impeller design for efficiency purposes. 10. Be careful not to hit the y-axis wheel while drilling. 11. When tightening the four screws on the pump, the distance between block base and the plastic base should be equal.

Table 2. Assembly steps and additional tips

<u>c. Fabricated and Assembled Pumps Using New Instructions</u>

The ten students were then divided into five groups to fabricate and assemble pumps based on the newly developed instructions. One pump was produced by each group resulting in a total of five pumps being produced.

<u>d. Tested the Efficiency of New Pumps</u>

Each pump produced by the student group was then tested six times to generate pump efficiency data. Thirty sets of data were generated during the test period.

e. Pump Efficiency Comparison

The pump efficiency data generated by the industrial engineering student group were compared with the data generated by students enrolled in ENGR 120 in the 2013-2014 year. A total of one hundred and fifteen pump efficiency data points generated by ENGR 120 students were available for such comparison. Table 3 shows the results of this comparison.

Student Group	Number of Data Points	Mean Pump Efficiency	Standard Deviation	Max. Value	Min. Value
ENGR 120	115	1.254%	1.109%	3.6	0.0
INEN 401	30	1.628%	0.708%	3.6	0.8

Table 3. Pump Efficiency Comparison

Table 4 and Table 5 show the dot plots of pump efficiency data generated by ENGR 120 and INEN 401 students, respectively.

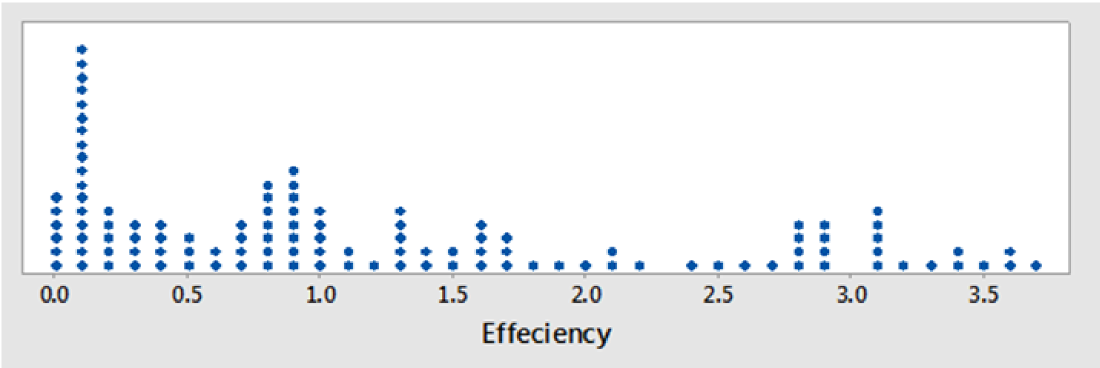

Table 4. Dot Plots of Pump Efficiency – ENGR 120 Students

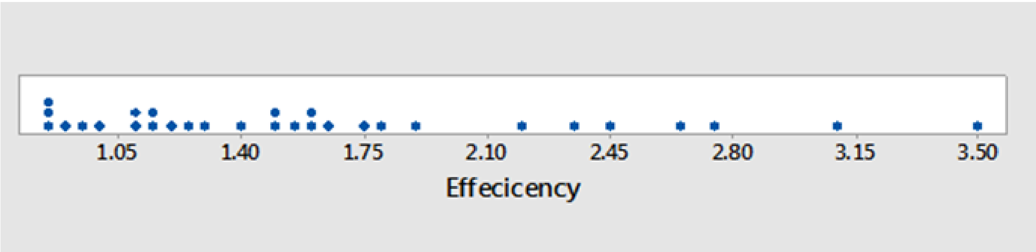

Table 5. Dot Plots of Pump Efficiency – INEN 401 Students

Based on the test results, the performance of the pumps made by INEN 401 students appeared to be superior to those made by ENGR 120 students. Not only is the mean efficiency higher – increased by nearly 30% - but the standard deviation is also smaller – decreased by nearly 57%. The result seemed to indicate that the newly developed pump fabrication and assembly procedure had helped improve the quality of pumps due to their higher efficiency and smaller variability. As a note, Montgomery[5] defined quality in a modern way as

"Quality is inversely proportional to variability."

f. Filming of Newly Developed Pump Fabrication and Assembly Procedure

The newly developed pump fabrication and assembly procedure were explained step-by-step and filmed by three industrial engineering students who participated in this project. This new instructional film was posted on Youtube in early December 2014 and can be viewed at the following the link: https://www.youtube.com/watch?v=xsAnj81AfxM&feature=youtu.be

Discussions

Although the experimental results seemed to suggest that the new fabrication instructions likely to contribute to pump efficiency improvement to some extent, such a claim should be further investigated. Juniors who participated in this study might have gained better pump fabrication skills due to their participation in the brainstorming session held to identify root causes. They also had experiences in making the same pumps a few years back when they were freshmen. Thus, they were deemed as more "experienced" workers compared to their ENGR 120 freshmen counterparts. It is not clear to what extent the effect of learning - if it in fact existed - affected the results of this study. One way to improve this study in the future is to assign one ENGR 120 class as the control group and ask students to follow the original pump fabrication instructions to manufacture pumps. The efficiency of pumps generated by this group can then be compared to that generated by the experimental group that follows the new pump fabrication instructions. This way the effect of learning will be eliminated.

Conclusions

This study provided students who completed INEN 401 with hands-on experience in applying what they learned in class to improve the fabrication and assembly of a product that they are very familiar with – the pump that they made in their freshman year. The experimental results show that students were able to identify the root causes leading to low pump efficiency. In addition, they were able to develop a better fabrication and assembly procedure. The effectiveness of the newly developed procedure was proven, as shown in Table 3. To broaden the impact of this study, the newly developed procedure was documented and filmed so it can be followed by current ENGR 120 students. This newly developed pump fabrication and assembly procedure may be reviewed by students enrolled in INEN 401 periodically with an aim to continue to improve the pump production process. This vertical integration of INEN 401 and ENGR 120 to enhance the quality of pumps, in fact, is recursive and will likely never end as shown in Figure 5.

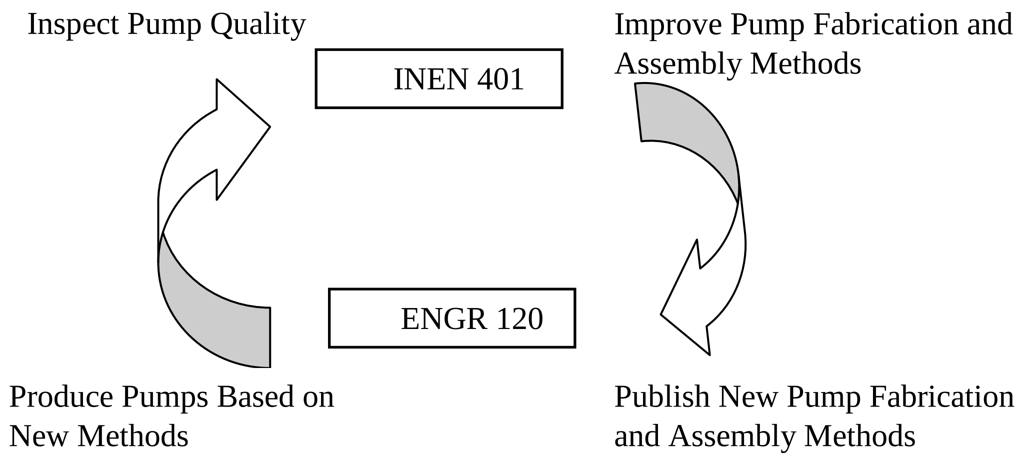

Figure 5. Continuous Improvement of Pump Quality through Vertical Integration

References

1 Jaeger, Andreas, Walter Mayrhofer, Peter Kuhlang, Kurt Matyas, and Wilfried Sihn, "Total Immersion: Hands and Heads-On Training in a Learning Factory for Comprehensive Industrial Engineering Education," International Journal of Engineering Education, Dublin Institute of Technology Tempus Publications, Ireland, Vol. 29, No. 1, 2013, pp. 23–32.

2. McCowan, James D., "An Integrated and Comprehensive Approach to Engineering Curricula, Part Two: Techniques," International Journal of Engineering Education, Dublin Institute of Technology Tempus Publications, Ireland, 2010, Vol. 18, No. 6, pp. 638-643.

3. Coyle, Edward J., Leah H. Jamieson, and William C. Oakes, "EPICS: Engineering Projects in Community Service," International Journal of Engineering Education, Dublin Institute of Technology Tempus Publications, Ireland, 2005, Vol. 21, No. 1, pp. 139-150.

4. Borgford-Parnell, Jim, Katherine Deibel, and Cynithia J. Atman, "From Engineering Design Research to Engineering Pedagogy: Bringing Research Results Directly to the Students," International Journal of Engineering Education, Dublin Institute of Technology Tempus Publications, Ireland, Vol. 26, No. 4, 2010, pp. 748–759.

5. Montgomery, Douglas C., Introduction to Quality Control, John Wiley & Son, Inc., New Jersey, U.S.A, 2013, page 6.

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