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Examining skill retention from a redesigned laboratory course to capstone design sequence

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Abstract

At Northeastern University, Measurements and Analysis is a laboratory course typically taken during the junior year. This course is the only place in the curriculum where topics such as design of experiments, measurement of engineering quantities, data analysis and selection of sensors are covered. Beginning in Fall 2011 this course underwent an extensive redesign to move from demonstration lab experiments to hands on, open ended laboratory experiences which emphasized the students' ability to design experiments, identify the variables to be measured, and select the best instrumentation for a given task. Previous research by one of the authors demonstrated measureable gains in retention of course concepts and the application of those concepts during a 'design your own measurement experiment' term project. The purpose of the current study is to determine whether these skills have been carried over into the two semester capstone design course. If the earlier course is effective in teaching experimental design and laboratory techniques, this should translate to more sophisticated experimental design and execution in the capstone design course. To determine whether these concepts have been retained in the capstone design course, design reports were examined to note the instances of specific Measurements and Analysis topics in the design projects. Reports were examined for student populations that had taken the revised course and were compared to reports for students who had taken the original course with two different instructors. Both the number of topics addressed and the number of instances of each topic was noted. Preliminary results indicate that the groups that took the revised lab course were considering more topics from that course at a much earlier point in their capstone design project. Prior to the change in the Measurements course, the design teams did not consider design of experiments topics until relatively late in their design process, if at all, and the experiments were primarily functionality prototype testing. After the change in the laboratory course, a larger number of groups were using more topics even at the end of the first of the two capstone design semesters. Twenty-two distinct concepts were observed in this investigation. The two cohorts of students who took the original course with instructor A used (11/22) and (12/22) distinct measurements and analysis concepts in their projects, respectively. In contrast, the first cohort to experience the new course and instructor B prior to capstone used (20/22) distinct measurements and analysis concepts in their projects. In addition, 47% of the teams taking the new course had prototypes that had been experimentally tested by the end of Capstone 2, versus 6-14% in the previous terms. This investigation provides evidence that hands-on, open ended experiments provide a teaching methodology which improves student retention of proper experimental design techniques.

Background

Engineering design requires a complex series of skills on the part of the students including skills in mathematical modeling, idea generation, experimental design, and written and oral presentation. The capstone design process requires the students to generate design concepts and specifications in response to real-world, open ended problems that may be ambiguous and involve a number of systems and a large degree of uncertainty.[1] Given the difficulty in teaching these design thinking skills, Dym et. al. discussed a number of methods for approaching design education with the idea of providing continuous improvement in the pedagogy. One of their suggestions was to attempt to bring design thinking into all parts of the engineering curriculum, starting with cornerstone design courses in the freshman year and proceeding through the capstone design sequence.[2] Although there are many opportunities throughout the curriculum where these skills can be addressed, the current work specifically concerns experimental design skills in the context of capstone design. Analytical design is introduced repeatedly in the Northeastern University curriculum, beginning in the freshman year Introduction to Engineering Design course, continuing with a Mechanical Engineering Design course in the summer before their senior year and culminating in the Capstone Design experience. However, it was recognized that experimental design was an area of relative weakness that needed to be addressed prior to capstone design.

There have been several attempts by previous authors to create experiences to specifically prepare students for capstone design. Palmer and Hegab developed a junior level laboratory experience designed to prepare students for the capstone design experience. The goal of this course was to provide transition between highly defined problems seen in typical courses and the open ended capstone design projects. The course focused on a single process and was designed for students in a specific nanosystems engineering program. Initial results did seem to indicate a measurable improvement, however this program seems to have a particularly well defined set of required skills.[3] The Mechanical Engineering program at Northeastern University encompasses skills from automotive research to biomedical/rehabilitation research, to nanomaterials, requiring a broad range of laboratory skills to successfully test projects or to perform the necessary experimental analysis to support the design process. Bluman and Klosky required students to complete a series of laboratory exercises during the capstone design class in order to promote awareness of technical issues in their small scale wind turbine projects. This approach provided benefits to groups that were having trouble getting started, and provided the opportunity to practice specific skills such as interpreting manufacturers' data.[4] Bluman and Klosky reported that this technique required additional work on the part of the advisors, and that the advisors had to be cautious not to provide too much direction which would stifle the team. Additionally, it seems as if this would be a difficult task for a capstone design course in which all the students worked on completely different problems, instead of the teams working on the same basic tasks. Another pre-capstone course for electrical engineers was designed to promote specific skills in engineering design and fabrication. This course did show some transfer of skills to the capstone design course and allowed students to be more confident in hands on fabrication skills.[5] At Northeastern University the desire was not to create a new course, or to alter the existing capstone sequence, but to determine if improving and redesigning an existing junior level lab course could provide an improved transfer of needed lab skills to capstone design.

Certain learning objectives have been commonly agreed upon for engineering laboratory classes. Engineers often need experimental data to answer fundamental questions in order to be able to get the necessary information to complete a design. A new design must be tested to determine if it performs as intended and to be able to make comparisons to existing designs. However, many laboratory classes involve problems that are presumed to have a single, known answer that the students are required to discover.[6] These 'cookbook' labs may teach specific skills, such as how to acquire thermocouple data using LabView™, but do not necessarily teach students how to decide when to use a thermocouple, as opposed to another temperature measurement device, or how to properly install a measurement device to avoid experimental errors.

The idea of redesigning laboratory courses to benefit capstone design has been attempted previously by Folz et. al. In their case, a junior-level materials engineering laboratory course was altered to include more engineering design concepts as well as problem solving, collaboration, and communication skills. The teams in this course were assessed during the course and showed gains in applying theory to practice. Folz et. al. had planned, but not finished, assessment of the students after capstone design to determine if the skills learned in the lab course had transferred to the capstone design experience.[7] Folz et. al. demonstrated this type of assessment using data from several terms of a continually improving lab course. This study and others emphasize the need for active techniques to improve both understanding and long term retention of concepts.

Evolution of ME4505 – Measurements and Analysis with Thermal Science Application

Measurements and Analysis classes are common features in Mechanical Engineering departments.[8-10] In the Mechanical Engineering department at Northeastern University the course has traditionally been taught by an instructor who also acted as the laboratory director for the department. This is a required junior level lab course intended to teach experimental design and analysis skills and to familiarize students with available technology for measuring engineering variables. It has the largest number of experiments of any lab course in the department, with 7 or 8 experiments over the course of the 14 week term. The format consists of three 65 minute lectures per week along with one 100 minute lab session. The lectures have typically consisted of theory related to the way various measuring devices work, topics such as calibration and statistical data analysis and various topics required to understand the theory behind the various experiments such as lumped capacitance calculations in heat transfer, Bernoulli's equation, etc. This course is the only lab experience in thermal fluids that is offered in the department.

Historically the course consisted of 8 lab experiments, weekly homework taken from the textbook, 2 exams, and a term project. The term project required groups to research an existing measurement application and present a written and oral report. The course content was delivered in a traditional lecture style. The lab experiments were: Rotational Frequency, Data Analysis, Pressure Measurement, Strain Measurement, Temperature Measurement, Hydrodynamic Power, Heat Transfer, and Drag Coefficients. In addition, a lab session on LabView programming was inserted after the Pressure Measurement lab. The lab experiments were in most cases at least 15 years old, with some dating back as far as 1986 in essentially the same form. In Fall 2010 the course was taken over by instructor B, but otherwise retained the same format, lab experiments, and project.

It was clear at the end of Fall 2010 that the lab handouts were extremely dated and confusing to the students. For example, the handouts instructed students to bring a floppy disk to lab, despite the fact that this technology is clearly out of date and no longer used. Because of this and in response to student feedback, instructor B kept the same lab experiments for Spring 2011, but completely rewrote and updated the lab handouts in order to clarify objectives and analysis questions. Instructor B also increased the number of active lecture techniques used during the classroom portion of the class, including in class demonstrations and problems worked individually or in groups. The number of exams and the term project remained unchanged for Spring 2011. The Spring 2011 term can be considered a transition term where systematic changes were beginning to be applied to the course.

After Spring 2011 the course, including the lab experiments, was completely redesigned.[11] Beginning in Fall 2011, the lab experiments were: Pressure Measurement, Temperature Measurement, Strain Measurement, Mechanical Power, 1st Order System Response (Heat Transfer), Drag Coefficients, and Flow Measurement. The LabView instruction session preceded the first lab experiment. Data analysis was taught using hands on in class demonstrations rather than a specific lab devoted to data analysis. A large number of in class demonstrations, group problems and individual quizzes were added to the lecture and class participation became 20% of the grade. Homework was altered so that rather than doing textbook problems the students engaged in pre-lab activities such as predictive calculations, choosing sensors, planning what data they would gather, and writing procedures. The exams were completely eliminated. Finally, the term project was changed to one in which each lab group had to plan and execute an independent experiment of their choosing and report the results orally and in a written report. Details of the term projects and lab changes are discussed in previous work by one of the authors.[11]

It should be emphasized that the majority of the course topics remained the same before and after the change in lab experiment. Some additional topics were added; however the fundamental topics remained the same, and are in line with similar courses at other universities. The importance of measuring fundamental engineering quantities such as temperature, pressure, strain, and flow rate did not change. In both the old and new version of the course it was expected that students would be exposed to statistical data analysis, including calculation of design stage and higher order uncertainty, as well as design of experiments concepts. Topics such as accuracy, precision, repeatability, variable identification, and the importance of calibration were also common to both versions of the course under both instructors.

Goals of the Capstone Design Course

The Capstone Design course is required for senior students in the MIE department. This course satisfies the ABET requirement for senior level design experience.[12] The students work in self-selected teams of 3-5 students. The first term is spent primarily on research and problem definition tasks. The second term is spent on developing, building, and testing their design. Students are expected to engage in both analytical and experimental design as necessary. Each team receives a unique project, with new projects introduced every term. Although the projects vary widely, they all must show clear design methodology, both analytical and experimental, and all are expected to deliver a working prototype at the end of the second term. The final oral presentation and executive summary are evaluated by a jury consisting of alumni and individuals from related industry. Projects are evaluated based on their technical aspects as well as the ability of the group to communicate their findings. In addition to prototype verification testing, groups must often design and perform experiments during the design process as part of their information gathering. Students may need to select and order sensors and other testing equipment, and are required to justify the need for any purchases to the Capstone coordinator. Finally, all experimental work requires that a safe operating procedure be written and approved of by the course coordinator and the departmental safety officer. A list of specific skills taught in Measurements and Analysis which are required by all capstone groups is given in Table 1 below.

Table 1: Specific Measurement and Analysis skills required by all capstone design teams.

Understanding the characteristics of measurement systems and reading manufacturer's specs
Calibration techniques and standards
Calculation of measurement uncertainty
Design of experiments
Rationale for choosing sensors
Predicting outcomes using theoretical calculations prior to experimentation
Statistical data analysis

Methodology

The methodology consisted of three distinct steps. First, a list of topics that were identifiably emphasized in Measurements and Analysis was generated and mapped to particular laboratory experiments. Next, the capstone design reports were carefully examined for discussions of these topics. The data was organized based on the Capstone 2 term for each cohort. The number of times each topic was mentioned was tallied, as was the number of discrete topics used in each cohort. Finally, the executive summaries for each team were examined to score the prototypes based on their completeness and the presence or absence of prototype testing.

A list of topics covered in the Measurements and Analysis course was generated, as shown below in Table 2. The table also indicates which particular experiment emphasized a given topic. Note that some topics were addressed via assignments in lecture rather than specifically in a laboratory experiment. Although some topics on this list may also have been covered in other courses, the laboratory experiments and assignments were designed to specifically emphasize these topics and skills

Table 2: Measurement and Analysis Topics

Topic	Labs Emphasizing this Topic
Fundamentals of Measurement Systems	Lab 1
Characteristics of Instruments	Lab 2, Lab 4, Lab 6
Calibration and Standards	Lab 1, Lab 2, Lab 3
LabView	Lab 1, Lab 2, Lab 5, Lab 7
Signal Processing in LabView	
Pressure	Lab 1, Lab 6, Lab 7
Temperature	Lab 2, Lab 5
Strain	Lab 3
Uncertainty	Lab 6, Lab 7
Rotational Measurement	Lab 4
Mass, Force, and Torque	Lab 3, Lab 4, Lab 7
Power and Electrical Measurements	Lab 4, Lab 7
1^{st} and 2^{nd} order system response	Lab 5
Wind speed measurement	Lab 6
Fluid flow measurement	Lab 7
Design of Experiments	Lab 2, Lab 4, Lab 6, Lab 7
Length and distance	
Measurement Signal Transmission	
Acceleration, Load and Vibration	
Choosing sensors	Lab 1, Lab 2, Lab 4, Lab 6
Predicting outcomes using theoretical calculations	Lab 3, Lab 5, Lab 7
Data Analysis	Lab 5

Capstone Design final reports were examined to determine which topics from this list were addressed in each project. If a given topic was addressed in the report in a manner that showed understanding of the topic, it was noted. Theoretical calculations were only noted if used to predict the outcome of a physical experiment. Design of experiments topics were rather more subjective, as the range of experimental plans encompassed everything from simple experiments to full formal factorial experiment design. However, if the experiment was clearly planned with a procedure, a hypothesis of the expected result, and a discussion of the results in relationship to the design problem, the group was considered to have achieved the ‘Design of

Experiments' topic. Certain topics such as 1st and 2nd order system response are covered more extensively in the Systems and Controls class. In this case, that topic was only noted if it related to measuring engineering quantities, rather than for PID control or other control systems topics. It should also be noted that although not every capstone design team will need to measure all engineering quantities, the instances of students measuring these quantities (strain, temperature, pressure, etc.) was noted when the measurement demonstrated experimental skills or techniques specifically taught in the laboratory course.

Table 3 below lists the various cohorts of students whose reports were examined for this research. Note that the Capstone 2 term is listed as the identifier for each cohort. The capstone design course coordinator was the same for all cases. Cohorts were examined with the old laboratory experiments before and after the instructor changed in order to examine whether improvements were due solely to the change in instructor. The students who took Capstone Design 2 in Fall 2010 and Spring 2011 had for the most part taken Measurements and Analysis with Instructor A. There were isolated cases of individual students taking Measurements concurrently with Capstone 2 or taking Measurements after Capstone 2. The Capstone 2 students in Fall 2011 and Spring 2012 had Instructor B, but performed the old experiments. The redesigned open ended laboratory experiments were introduced in Fall 2011 and Spring 2012, and these students were enrolled in Capstone design during the Fall 2012 and Spring 2013 semesters. Although students are required to submit several reports over the course of the two semester capstone sequence, only the final reports from the end of Capstone 2 were examined for Measurements topics. The one exception is the Spring 2013 class, who have only completed 1 semester of capstone thus far. For this class, the report at the end of Capstone 1 was examined.

Table 3: Capstone classes examined

Capstone 2 Term	Measurements Instructor	Measurements Lab Sequence	Number of Capstone Design Teams
Fall 2010	Instructor A	Old labs	14
Spring 2011	Instructor A	Old labs	16
Fall 2011	Instructor B	Old labs	15
Spring 2012	Instructor B	Old labs (Transition)	14
Fall 2012	Instructor B	New labs	19
Spring 2013*	Instructor B	New labs	19

*Data available for first semester report only

In addition to the final reports, the executive summaries were examined using the method described by an earlier work by the authors.[13] The executive summaries for each of the teams were rated for prototype and testing information. Prototypes were scored on a 5 point scale where 5 = functional prototype, 4 = partially functional prototype, 3 = expected functionality by end of course, 2 = prototype in progress, but not expected to be functional, and 1 = no prototype, prototype unlikely by end of course. The testing was rated on a similar scale where

5 = testing completed, 4 = testing substantially completed, 3 = testing in progress, 2 = testing planned, and 1 = no testing planned/testing not discussed.

Results

Table 4 below presents the data on the number of times the topics listed in Table 2 were mentioned in the design reports for the various terms. Certain topics such as Calibration, Uncertainty, Design of Experiments, Choosing sensors, and Data Analysis are particularly worth noting since these topics are only emphasized in the Measurement and Analysis course and are required by all Capstone groups regardless of their particular project. Calibration was not discussed in any capstone reports for teams who took Measurements with instructor B. The largest number of groups using calibration appeared in Fall 2012, which was the group that had been exposed to the new measurements and analysis laboratory experiments. It is also interesting to note that the Spring 2013 cohort already has the second largest number of teams discussing calibration after the end of Capstone 1. Uncertainty, while not used by a large number of teams, was only mentioned in teams in the transition term (Spring 2011) and after the course redesign. The number of teams using Design of Experiments concepts did not show any particular patterns, although again, the largest number of teams using these concepts was in the Fall 2012 cohort. One encouraging trend is that the number of teams who were systematically comparing sensors based on their specifications was much higher after the transition term, and increased further in the teams exposed to the new laboratory experiments. Use of Statistical Data Analysis was much more variable, showing no clear pattern.

Table 4: Number of groups using given Measurements topics per term

Topic	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012	Spring 2013
Measurements Lab Sequence	Old	Old	Old	Transition	New	New
Fundamentals of Measurement Systems	0	0	0	1	0	0
Characteristics of Instruments	0	0	3	5	3	0
Calibration and Standards	0	0	3	3	7	4
LabView	1	4	5	4	4	0
Signal Processing in LabView	0	0	0	2	2	0
Pressure	5	2	3	2	5	0
Temperature	6	5	4	4	3	2
Strain	0	0	1	1	3	0
Uncertainty	0	0	0	1	1	0
Rotational Measurement	0	1	2	1	3	2
Power and Electrical Measurements	0	1	1	1	3	1
Mass, Force, and Torque	4	4	5	5	8	4
1^{st} and 2^{nd} order system response	0	0	2	1	1	0
Wind speed measurement	2	1	1	2	1	1
Fluid flow measurement	3	0	3	0	3	0
Design of Experiments	6	7	4	5	9	2
Length and distance	0	0	1	5	2	2
Measurement Signal Transmission	0	0	0	0	0	0
Acceleration, Load and Vibration	2	2	3	3	7	2
Choosing sensors	1	1	5	5	8	5
Predicting outcomes using theoretical calculations	10	11	13	12	12	7
Data Analysis	5	1	0	6	2	0
Total Topics Used	**11**	**12**	**17**	**20**	**20**	**11**

In addition to tallying individual topics, Table 4 also sums the number of discrete topics discussed in the reports for each term. It is interesting to note that the two highest numbers of topics discussed were in Spring 2012 and Fall 2012, during the transition term and after the new experiments were introduced. It is also notable that the number of topics discussed at the end of the first Capstone semester for the Spring 2013 cohort is the same as the Fall 2010 cohort, who had been exposed to the old experiments. This is encouraging since most teams are still in the problem identification and early analytical stages of the design process at this time and have not completely formulated a design methodology approach appropriate to their project.

The number of teams with 0 topics discussed, less than 5 topics discussed, and more than 5 topics discussed is presented in Table 5. Among the teams who had completed Capstone 2, the largest number of teams that discussed 0 topics occurred in the Fall 2010 and Spring 2011 semesters. Initially it seems as if the Spring 2013 cohort is particularly poor in recalling these concepts, however it must be emphasized that this cohort has only completed the first half of their capstone design sequence and have not yet reached the point of designing experiments in many cases. The percentage of teams with less than 5 topics was lower in Fall 2011, Spring 2012, and Fall 2012. The number of teams with more than 5 topics discussed was lowest in the Fall 2010 and Spring 2011 terms.

Table 5: Number of design teams using given numbers of Measurements topics

Term	Number of Teams	# with 0 topics	% with 0 topics	# with < 5 topics	% with <5 topics	# > 5 topics	% with >5 topics
Fall 2010	14	2	14	10	71	4	29
Spring 2011	16	5	31	14	88	2	13
Fall 2011	15	0	0	7	47	8	53
Spring 2012	14	1	7	6	43	8	57
Fall 2012	19	1	5	12	63	7	37
Spring 2013	19	7	37	18	95	1	5

Because the Capstone 1 reports are not archived, it was difficult to compare the Spring 2013 cohort with the other cohorts. However, data was available for the Fall 2012 cohort for Capstone 1, which is shown in Table 6 below. Both of these cohorts had the current configuration of Measurements and Analysis. The results at the end of Capstone 1 were similar for both cohorts, with fewer than 40% of the teams discussing zero Measurements topics. It is also interesting to note that the percentage of teams with 0 Measurements and Analysis concepts dropped to 5% by the end of the 2 semester sequence. This indicates that the cohorts exposed to the new experiments are retaining the concepts from the Measurements and Analysis course and are applying these concepts early in the design process.

Table 6: Comparison of Capstone 1 and Capstone 2 Results

Capstone Term	% Teams with no Measurement and Analysis Topics	# Measurements and Analysis Topics Used
Spring 2013 (Capstone1)	37	11
Fall 2012 (Capstone 1)	32	16
Fall 2012 (Final)	5	20

Table 7 presents the prototype scores for the completed executive summaries. The Spring 2013 term is not discussed in this table as their executive summaries have not yet been submitted. There is a notable increase in the number of teams with a prototype score ≥ 9 in the most recent two groups. The largest number of groups with scores less than 5 was in Spring 2011, a group who had had Instructor A with the old experiments.

Table 7: Prototype scores by term

Term	# Teams	% scores <5	% scores >5	% scores ≥9	Measurements Instructor	Experiments
Fall 2010	14	14	86	14	Instructor A	Old
Spring 2011	16	31	69	6	Instructor A	Old
Fall 2011	15	27	73	7	Instructor B	Old
Spring 2012	14	0	100	50	Instructor B	Transition
Fall 2012	19	11	89	47	Instructor B	New

Discussion

The capstone design sequence at Northeastern University has long had an expectation that students will provide a working prototype at the end of the second term. Analytical design and modeling, while important to the design process, was expected to be accompanied by verification testing. As projects have gotten more sophisticated and complex, teams have found the need to gather experimental data before the final design could be developed. It was the experience of the authors that both exploratory and verification testing were done as an afterthought in many previous terms. Students would try out an idea, tinker with it, and try something else, without systematically controlling variables. Part of the motivation for improving the measurements and design class was to address the deficiencies in experimental design and data analysis seen in capstone design.

The 21 week capstone design sequence does not provide enough time for students to develop the level of expertise needed to perform complex numerical modeling. Despite this fact, students historically spent a great deal of time trying to numerically model their designs instead of incorporating physical experiments into the design process. After the changes in the measurements and analysis class experiments it seems that students are getting the message that experimentation needs as much consideration as modeling or prototype building. Calibration is a key example of this type of thinking. Prior to changing the experiments, capstone teams typically did not think about the need to verify that their sensors were working. They would borrow a pressure transducer, a thermocouple, or a load cell and assume that it worked. The number of teams actually providing calibration data for their sensors increased from 0 groups to 7 groups before and after the laboratory change. Another topic that showed a dramatic improvement in understanding was the ability to systematically choose sensors. Prior to the new experiments, students would use whatever sensor was available and accept the answer that sensor gave. After the new experiments, two of which required students to choose sensors and justify their choice, the students were much more likely to compare multiple sensors, carefully consider the manufacturer specifications, and calculate design stage uncertainty in order to determine if the sensor they wanted to use would do the job. There was also much more evidence of systematically designing experiments and test fixtures, rather than doing ‘quick and dirty’ verification.

It is particularly exciting to see students already including experimental design topics at the end of Capstone I. Students are expected to do verification testing, but in the past have spent most of the first capstone term in problem definition and research. However, now it seems that more groups are using testing to get fundamental information to build from, rather than waiting until later in the process. In some recent cases, the testing schemes developed to get this fundamental information were patentable or otherwise highly original and beneficial for future research. Whereas before the laboratory redesign many groups never performed experiments, after the new laboratories were introduced observations as noted in the tables suggest that students are beginning to incorporate experimental investigation into their problem solving approach.

In addition to demonstrating retention of measurements and analysis concepts, the students also seem to be producing better prototypes. The prototype scores for the most recent two terms had ~50% of the teams having a complete prototype that was tested or on which testing was far along at a point two weeks prior to the end of term. This was a substantial improvement over previous terms. The incorporation of early testing and experiment design seems to have helped the teams to produce better designs in the end.

Another benefit seems to have come from the open ended term projects in measurements and analysis which specifically required students to design and conduct experiments. The students initiated the projects and came up with the question they expected their experiment to answer. There was no ‘known answer’ that the students needed to discover. Because of this, the students were forced to choose sensors and experimental methods that would provide the data that they determined was necessary to make their point. This is exactly the type of experimentation that is necessary in an open-ended capstone design project, and it seems that the specific practice in this skill was helpful in the subsequent capstone course. This fits in well with previous work demonstrating the benefits of practicing specific skills prior to capstone.[3-5]

There are some limitations to the study. It is difficult to determine how much effect the change in instructor had on the skill transfer. For example, in Spring 2012, even though the old experiments were still in place, effort had been made to clarify the laboratory handouts and to bring more active lecturing techniques into the classroom. It is possible that the active lecture techniques had some benefit in terms of skill retention apart from the laboratory experiments. In addition, the new instructor made a concerted effort to relate the Measurements and Analysis class skills to capstone by using past capstone design projects as examples of the need for experimental design techniques. Despite these potential objections the Fall 2012 capstone group, who had been exposed to the new version of measurements and analysis clearly retained a large number of class concepts, which seemed to have translated into better prototypes overall. It should also be noted that the instructor for Measurements and Analysis works closely with the Capstone design students, acting as the technical writing instructor. While this does raise the need to cautiously guard against research bias, it also allowed for the instructor to be able to witness firsthand the increasing sophistication of the experimental design. Introduction by the coauthors to the objective measures listed in Tables 4-7 was a means to minimize this potential bias. Students were seen to pull out notes and laboratory handouts from the Measurements and Analysis course to use as reference material during Capstone design, a clear indication that the concepts were remembered and seen as useful. Providing this continuity of message in the curriculum would appear to translate to more skill retention and as a result improved capstone performance.

Conclusions

Open ended problems and active techniques have been shown repeatedly to improve understanding and concept retention. The evidence from this study seems to indicate that improvements of this nature in the measurements and analysis laboratory course have allowed students to transfer the skills learned in that course to the capstone design experience. Students appear to have retained more class concepts, and applied them more widely to their design projects. The projects showed improved prototype scores, as well as evidence of topics that are only emphasized in measurements and analysis. Going forward, it is hoped that these open ended concepts can be introduced into additional laboratory courses in the curriculum, since the benefits seem to be measurable and substantial. Further study is planned to see if the gains continue in subsequent terms.

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