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More skills, more retention? Reexamining the effectiveness of a pre-Capstone lab course

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A 2013 paper by the author showed that an improved junior level lab course provided new skills that were adopted by capstone design students. Since that time additional material has been added to the lab course to emphasize experimentation as an integral part of the design process. The current work examines whether the new skills were equally absorbed by the capstone design students. Use of skills such as design of experiments, statistical data analysis, Arduino programming, and instrumental uncertainty increased significantly since the initial study.

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Introduction

Many universities have developed courses taken prior to capstone design to teach design process, teamwork skills, and additional skills that will prepare students to be successful in capstone.[1] Other pre-capstone courses teach students how to evaluate designs and develop functional requirements[2] and others teach additional skills in communication, ethics, and other professional skills[3]. Although these skills are all part of the capstone design curriculum at Northeastern University, other gaps in experimentation and measurement skills were identified as needing additional reinforcement. In an earlier study by the author[4] a newly redesigned lab course was shown to have a positive effect on these hands-on capstone design skills. Since the publication of that paper, the laboratory course has been further refined, with new topics and new lab experiments. The purpose of this study is to examine whether these new skills were also being used by the capstone design students.

The lab course in question is entitled Measurements and Analysis with Thermal Science Application and is typically taken in the junior year before the capstone design sequence. In the previous study, which took place in 2013, the course focused on using the LabView program for data acquisition and concentrated on details of how to measure specific engineering concepts. Table 1 below shows the course topics in 2013 compared to those in the current course. Some of the course topics that had been in the previous version of the course had been either removed or reorganized in the current course. As the author was teaching both courses, it was natural to continually redesign the lab course in response to needs in the capstone course[5]. To this end, additional practice in designing experiments, reading and using manufacturer's specification sheets, and graphical data analysis. New experiments in heat transfer and renewable energy also necessitated new or additional material.

Table 1: Comparison of course topics for Measurements and Analysis course

Course Topics 2013	*Course Topics 2021*
Fundamentals of Measurement Systems	Introduction to Measurement Systems
Characteristics of Instruments	Accuracy and Precision
Choosing sensors	Deciphering spec sheets
Calibration and Standards	Calibration and Standards
Design of Experiments	Problem Definition
1st and 2nd order system response	Variables and Data Analysis Design
Measurement Signal Transmission	Experiment Design
Signal Processing in LabView	1st and 2nd order system response

Data Analysis	Electrical Signals
Uncertainty	Data Acquisition
Temperature	Data Analysis
Pressure	Uncertainty
Wind speed measurement	Curve Fitting and Regression Analysis
Fluid flow measurement	Temperature Measurements
Strain	Thermodynamics Measurements
Power and Electrical Measurements	Heat Transfer Measurements
Acceleration, Load and Vibration	Pressure Measurements
Predicting outcomes using theoretical calculations	Air flow Measurements
LabView	Wind Tunnels and Wind Power
Length and distance	Pipe/ Fluid Flow Measurements
Rotational Measurement	Strain/ Load Measurement
Mass, Force, and Torque	Mechanical Power Measurement
Communicating Results	Displacement, Velocity, and Acceleration
	Smartphone Sensors
	Communicating Results
	Arduino

Methods

Reports from three recent capstone terms were examined to look for evidence of use of information taught or emphasized in Measurements and Analysis. For topics specific to certain types of measurements, such as measuring temperature or pressure, a topic was noted if it was used in a significant way during experimentation or as an integral sensor in their prototype. For topics such as data analysis, statistical calculations, and graphical data analysis were considered demonstration of this skill, but a simple pie chart showing the demographics of a survey population was not counted. Skills in experimental design were counted if they demonstrated a distinct experimental testing plan, rather than simple 'quick and dirty' experiments that showed no evidence of planning. Multiple instances of the same skill were only counted once for a particular group. Both the number of skills used per group and the number of groups who used a particular skill were totaled.

Results and Discussion

Table 2 shows the percentage of teams in each term that demonstrated each skill. Skills that were not common to both versions of the course were removed from the list, and skills were aligned to compare common topics more easily. The skills in 'Communicating Results' and 'Problem Definition' were removed from the table as all capstone teams are required to perform these tasks as part of the course. The Fall 2019 lab course had all but 2 labs in common with the Spring 2013 version of the course, although the lab details have been updated and refined over the years. In Fall 2020 and Spring 2021 the lab class was operated in a hybrid mode due to the COVID pandemic. On campus students were grouped with remote students who experimented at home with kits provided by the college. To convert the labs to experiments that could be done at home, the course and the experiments were substantially redesigned. This allowed for additional practice in experimental design, statistical data analysis, and heat transfer related measurements.

Some topics, such as the fundamentals of measurements systems, were not seen in any of the reports. It is also acknowledged that some topics were grouped together in some course offerings and dealt with separately in others. However, some skills which were previously weak in the capstone design course have shown some improvement between 2013 and 2021. Calibration and the use of published standards increased from a low of 21% of the teams to 55% of the teams in Fall 2021. Design of experiments showed up in less than half of the reports prior to the current study, while after the course improvements all terms had more than 50% of the teams demonstrate a clear and deliberate design of experiments methodology. This was particularly encouraging, as the capstone course had previously struggled with 'tinkering' and quick and unsystematic testing, rather than an organized approach to design validation.

Another interesting observation pertained to data acquisition and sensor control. From Spring 2013 to Fall 2019, the course used the LabView program and the Vernier SensorDAQ hardware to acquire data from various sensors. The students generally disliked this, as the lab course was the only place where LabView was taught, and there was not enough course time devoted to teaching students how to use the program. Attempts were made to provide additional information by using videos outside of class time, however students still struggled to master LabView. Subsequently, few capstone teams used LabView in their projects. When it was necessary to redesign the course to allow for at home experimentation, it was taken as an opportunity to replace LabView. Engineering students take a common First Year Engineering cornerstone course, during which they learn to use and program Arduino hardware. Since most students still had their Arduino kit from cornerstone, and many expressed interest in additional practice with this platform, it seemed natural to switch to Arduino for sensor control and data acquisition. The more recent course offerings had larger percentages of teams using Arduino. Although more teams used Arduino in Fall 2019, prior to the switch from LabView, many teams used Raspberry Pi hardware since Arduino was not able to handle their data acquisition and control needs. Prior to Fall 2019, students weren't using LabView, but were also not using many sophisticated sensors and electronics of any sort. Familiarity and additional practice with Arduino sensors and control appears to provide students with additional confidence in designing experimental setups and using a variety of sensors.

Conclusions

Capstone projects at Northeastern University have become increasingly sophisticated in the past several years. As projects become more complex and demanding, students need skills in selecting and designing with sensors. They also need to see experimentation as an integral part of the design process, rather than something to do in a rush during the last week of term. By specifically tailoring the required junior year lab course to the needs of capstone design, it is possible for students to learn and retain skills in experimental design. This allows for more organized and robust validation testing, leading to more successful physical prototypes.

References

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Table 2: Comparison of skill retention from Measurements course to Capstone Design across time

Data shows percentage of teams for the given term who demonstrated the listed skill						
Skill	Fall 2012	Spring 2013	Skill	Fall 2019	Spring 2021	Fall 2021
Fundamentals of Measurement Systems	0	0	Introduction to Measurement Systems	0	0	0
Characteristics of Instruments	16	0	Accuracy and Precision	10	12	10
Choosing sensors	42	26	Deciphering spec sheets	20	36	41
Calibration and Standards	37	21	Calibration and Standards	30	24	55
			Variables and Data Analysis Design	30	36	45
Design of Experiments	47	11	Experiment Design	50	60	66
1st and 2nd order system response	5	0	1st and 2nd order system response	7	0	10
Measurement Signal Transmission	0	0	Electrical Signals	17	20	28
Signal Processing in LabView	11	0	Data Acquisition	20	24	10
Data Analysis	11	0	Data Analysis	53	60	45
Uncertainty	5	0	Uncertainty	3	24	17
			Curve Fitting and Regression Analysis	20	20	10
Temperature	16	11	Temperature Measurements	17	36	10
			Thermodynamics Measurements	0	0	0
			Heat Transfer Measurements	7	4	10
Pressure	26	0	Pressure Measurements	20	12	17
			Air flow Measurements	17	32	7
Wind speed measurement	5	5	Wind Tunnels and Wind Power	7	12	3
Fluid flow measurement	16	0	Pipe/ Fluid Flow Measurements	23	20	17
Strain	16	0	Strain/ Load Measurement	43	28	52
Power and Electrical Measurements	16	5	Mechanical Power Measurement	3	0	14
Acceleration, Load and Vibration	37	11	Displacement, Velocity, and Acceleration	30	16	24
			Smartphone Sensors	0	0	0
Predicting outcomes using theoretical calculations	63	37	Predicting Results	83	68	79
LabView	21	0	Arduino	43	36	28