A Practice Oriented Final Design Project for an Instrumentation Course in Civil Engineering.

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Abstract: As technology advances, field instrumentation and real-time data analyses are quickly becoming a part of many civil engineering (CE) projects. However, many CE graduates are not equipped with the necessary skills to select and deploy the plethora of field instruments available to them. This is likely due to unfamiliarity with tools that are more often designed and used by electrical and mechanical engineering students. Likewise, the analyses of the data can be confusing and difficult to perform. Regardless of students' apprehension, instrumentation use grows because these tools can be used to validate important design assumptions and monitor performance as the design is built. This is especially true in situations when unknown design parameters must be verified and workers safety may be compromised, such as a large earthwork and shoring projects. The experience CE students gain in instrumentation is non-existent or scant in many undergraduate and graduate programs throughout the U.S. An instrumentation course was designed to help students learn; instrumentation selection, data collection, data analyses, data interpretation and finally decision making. This course aims to develop the students higher-order level of thinking and decision making skills, and culminates with a comprehensive final project. The final project for the course was developed with the help of a practicing engineer and used real-world data collected at a site in Colorado. This paper will present how the instrumentation course was designed along with challenges realized. In particular, details concerning the final project, how it was developed and assessed, and what objectives where or where not met will are presented.

INTRODUCTION

An instrumentation course was designed for undergraduates and graduate students in Civil Engineering (CE). This paper presents the design, implementation and evaluation of the final project used in the course. The interested reader is referred to Griffiths and Seeley (2018), which includes more details concerning the course content and the course objectives.

As smart cities are developed and advances are made in sensing and wireless technologies, it a worthwhile endeavor to train future engineers to use sensing technology. Consequently, a course teaching CE students about instrumentation has been developed and offered at the undergraduate and graduate level at the University of Wyoming.

At least two other instrumentation courses that have been developed specifically for civil engineers over the last 10 years. The first was developed for graduate students at Polytechnic University and included 14 modules that focused mainly on structural and geotechnical applications (Iskander et al. 2008). The second, developed at the American University of Beirut was an undergraduate course that included both civil engineering and electrical engineering students (Elhajj et al. 2016).

This undergraduate course covered a large breadth of instrumentation in multiple civil engineering disciplines (i.e. geotechnical, structural, and environmental). Key differences between other courses and the one developed at University of Wyoming (UW) include; attempts to include sensors used in the transportation and water disciplines, and the focus on providing the students with familiarity with all aspects of an instrumentation program. This holistic approach to instrumentation includes; instrumentation selection, data collection, data analyses, data interpretation and finally decision making.

COURSE STRUCTURE

CE 4650/5650, was offered for the first time at the University of Wyoming during the fall semester of 2017. The course was designed to familiarize students with the various types of instrumentation and sensors available to them in Civil and Architectural Engineering (CAE) applications. Specifically, the five course objectives, and skills that the students can expect to acquire after successful completion of the course include; 1) identify different instrumentation and choose instrumentation for specific applications, 2) deploy/Install sensors for data acquisition, 3) collect data using good scientific and bookkeeping procedures, 4) analyze data using available software, and 5) interpret data to aid in decision making and understanding of measured quantities. These objectives helped guide the design of the course lectures, homework assignments, labs and final project. This paper will focus on how the final project was developed and used to determine if course objectives 4 and 5 where met.

The course was divided into three sections. The first section was approximately two weeks long and included lectures covering; a review of mechanics of materials, electrical circuits, statistics, signals and sampling and overall planning of an instrumentation program. The second portion of the course used traditional lectures to present various types of instruments, how they work, and how to install them. The first and second sections of the course followed a standard lecture format and met twice a week for 75 minutes. The remaining portion of the class, section three, was scheduled around the laboratory exercises. This section accounted for approximately 7 of the 15 weeks of the course. Each lab focused on a single data collection device and was accompanied by a laboratory homework, which reinforced data analyses and decision making skills.

No examinations where given during this course. Instead quizzes during the first two sections of the semester where expected to provide important feedback for the student and instructor as well as evidence of meeting (or not meeting) course goals. Due to scheduling difficulties only a few quizzes where given (3 of 6) and the instructor learned that the students did not take the quizzes as serious as hoped. This resulted in poor quiz scores and lack of data. Future courses will implement an exam after the 1st and 2nd section of the course. In contrast to the quizzes, the lab projects and open ended nature of project based work proved to provide adequate opportunities for students to demonstrate data analyses and interpretation competency.

FINAL PROJECT

The final project included three parts and was used to assess all of the course objectives as discussed in Griffiths and Seeley (2018). The 3rd portion of the final project consisted of the data analyses and interpretation of a full-scale instrumentation project. Data for the project came from an excavation support company (Cary Lange, personal communication) working on a 10 story hotel in downtown Colorado Springs, CO. The project involved excavation support for a new underground parking structure adjacent to two existing structures. Instrumentation was installed on the ground surface near the excavation, along two micopile foundation elements, and on two existing structures near the excavation. The owners of the property agreed to instrument the site to ensure the adjacent buildings did not move more than tolerable limits during the excavation. A schematic of the site as well as a few snippets from the instrumentation blue-prints are presented as Figure 1.

Using actual data from a real site, as opposed to contrived data, gives students an idea of what real-world data looks like and improves their engineering judgement. The latter, improved engineering judgement, is an art-skill that requires time and experience. Combining real-world data with open ended overview questions helps the students begin to develop engineering judgement. An example of an overview question may be, "What are the pros and cons of using a specific ground anchor?", or "What are the consequences of failure for this retaining wall?". While these questions are more difficult to grade, than standard calculation type questions. They force the student to think about the bigger picture, and place there analyses inside a decision making context.

As part of the final project the students were given all pertinent information for the site (locations, offsets, ect…), instrumentation plans as well as the data collected over about a six month period of time. Students were required to analyze all the data obtained from the excavation and asked to answer specific questions about each instrument type. For assessment of course objectives 4 and 5 (analyze and interpret data, respectively) the instructor picked just two of the assigned problems for evaluation. The course objectives and evaluation criteria for meeting expectation is presented as Table 1. These two course objectives incorporated cognitive

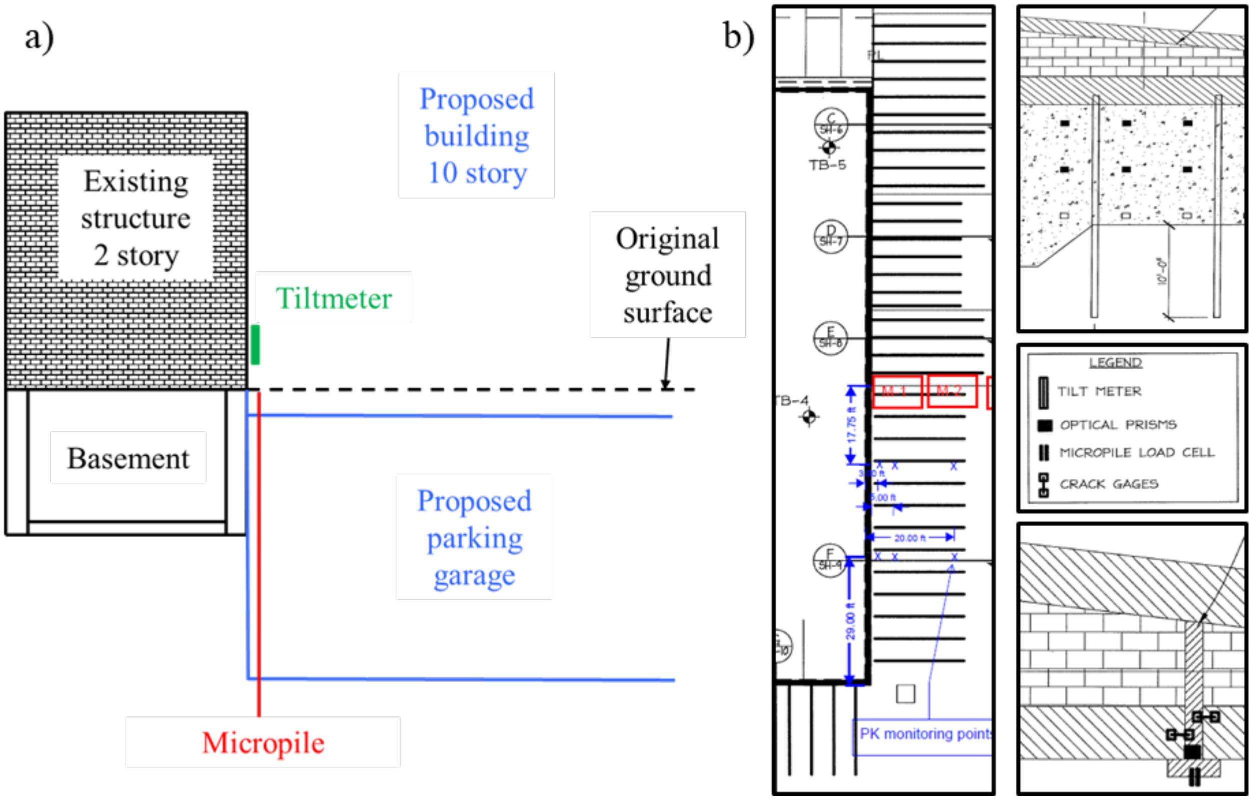

Figure 1: Final data analyses and interpretation project for determination of course outcomes 4 and 5, a) schematic of final design project, and b) snippets of plans provides from industry partner (Cary Lange, personal communication).

Table 1: Rubric used to evaluate course objectives 4 and 5.

Course Objectives	**Below Expectations**	**Meets Expectations**	**Exceeds Expectations**
4. Analyze data	Unable to process data correctly	Proper analyses of data including; removal of unreliable data and application of necessary corrections	Meets expectations and demonstrates higher level applications
5. Interpret data	Interpretation is inconsistent with analyses or lacks detail	Interpretation is consistent with analyses and has sufficient detail	Meets expectations and includes outside influences that may affect results

learning within the higher levels of Bloom's taxonomy (Bloom et al. 1956) including; analyze and evaluate.

ANALYZE AND INTERPRET

Prior to grading any material, a goal of 70% was set as a minimum acceptable criteria. Meaning that outcomes with less than 70% of students meeting or exceeding expectations will require a change in course design or curriculum. It is noted that the pilot offering of this course only had an enrollment of 11 students and this sample size is not adequate for a robust evaluation. However, the rubric and evaluation still provided some data and can be used to improve the course for future offerings.

In ordered to determine if objective 4 was met, students where required to analyze data from a strain gage attached to a micropile. The gage was attached to the micropile prior to pre-loading. Proper analyses required students to convert the data to engineering units, delete unusable data, and correct for a zero reading. This problem was chosen for evaluation because demonstration of the data analyses at this level was a clear indication of fundamental knowledge. If the data was analyzed correctly the student could easily determine the date the micropile was pre-loaded, as a spike in the strain gage readings. In terms of analyzing data, Eight of the 11 students (73%) were able to properly determine the date and magnitude of the pre-load applied to the micropile (Table 2).

Table 2: Evaluation of course outcomes.

Course Objectives	Below Expectations	Meets Expectations	Exceeds Expectations	% of Meet or Exceeds
4. Analyze data	3	8	0	73%
5. Interpret data	8	3	0	27%

Objective 5, interpret data, was evaluated based upon the students ability to interpret the data from a series of 3 tiltmeters. This data was used because all of the students, except 1, who did not attempt any of final design questions, were able to properly analyze this data. This allowed for a proper assessment of data interpretation separate from data analyses. The proper interpretation of the data required the students to relate the analyzed data to the physical situation. In this case I asked the students to tell me why there were cyclic fluctuations in the tiltmeter data, which required the students to realize the fluctuations where minute daily occurrences and could be related to the temperature changes occurring over a 24 hour period. This data is presented in Figure 2. Unfortunately only 3 of the 11 (27%) students were able to meet this expectation (Table 2). This result is in spite of the numerous notes and lectures that included the importance of temperature changes on sensor readings. Clearly interpretation of results is an area for future improvement within the course.

While this provided only a single example of students struggling to interpret and relate data to the physical situation. I should have suspected students would struggle with this step based on my previous experience as an instructor. I have witnessed that student are often able to calculate a solution but unable to explain its significance in terms of the real-world applications. The instructor believes that the step of interpreting data is fundamental to being a good engineer, and will devote more time to data interpretation in future offerings of this course. In future course offerings, this will be accomplished by taking class time after every assignment to talk about the physical meaning of the calculated sensor readings. By reinforcing this interpretation step for every lab assignment (7 total lab assignments) it is expected that this skill will be sufficiently reinforced and more students will meet this expectation in the future.

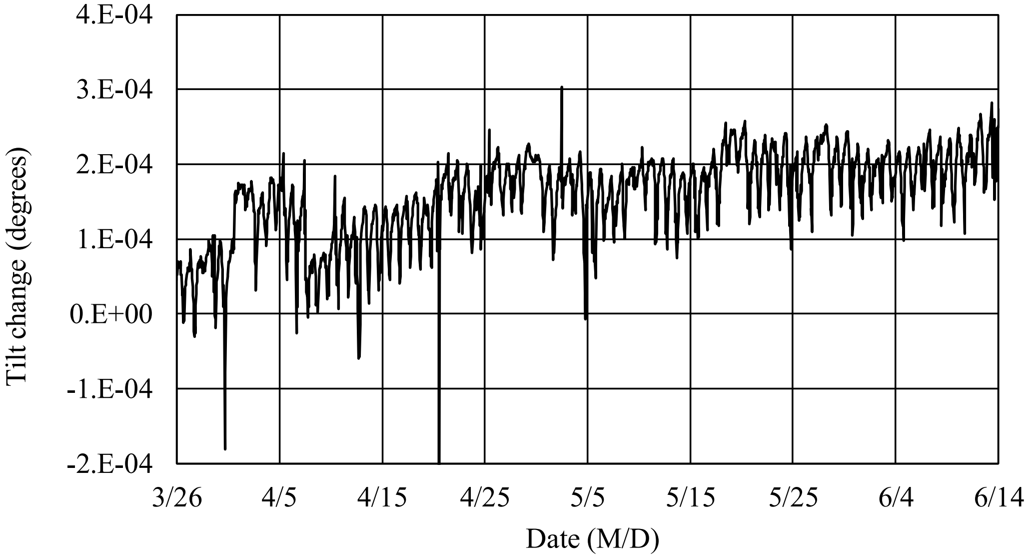

Figure 2: Tiltmeter data used to determine if course outcome 5, data interpretation was being met.

CONCLUSIONS

While formal evaluations for the course where not conducted (clerical error), informal evaluations, carried out twice during the semester, showed that student engagement/interest in the course content was high. Multiple students mentioned that the lab format of the course was good, however, because the lab time/duration changed each week depending on the lab needs they would have preferred a once a week 3 hour meeting time verses a continually changing lab schedule. About half of the students also mentioned that prior to each lab, they would have liked a brief review of the fundamentals regarding the instrumentation to be used during lab. The instructor believes that an exam after the 1st and 2nd sections of the course would have provided an opportunity and motivation for the students to learn and remember much of this fundamental knowledge, that would have been helpful for future lectures and labs.

The data provided for the final project included real-world project data from a support excavation company in Colorado Springs, CO. The instructor believes that the data obtained and used for the final project helped keep the students engaged and allowed them to see real world data, instead of clean “nice” data that is common in many engineering homework problems and examples. This data allowed the students to analyze and interpret actual data which helps them begin developing engineering judgment, and understand the difficulties associated with real-work data.

Although no rigorous analyses could be performed due to the low number of enrolled students, graduate students demonstrated a higher level of understanding in nearly every homework than the undergraduate students. This may be due to understanding or, redundant information from other classes. The goal of a minimum acceptable criteria of 70% shows that future progress concerning data interpretation is required. Future changes to this course will include more emphasis on data interpretation throughout the semester. The author hypothesizes that one reason students struggle with data interpretation may be related to the amount of new information that students are presented with during their upper division classes.

REFERENCES

Bloom, B.S. (Ed), Engelhart, M.D., Furst, E.J., Hill, W.H., Krathwohl, D.R., (1956). "*Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*." New York: David McKay Co Inc. 1956.

Elhajj I. H., Gurunian, M., and Rishani, N. “Applied Instrumentation for Civil Engineering at the American University of Beirut,” IEEE Instrumentation and Measurement Magazine, December 2016, pp 46-51.

Griffiths, S.C. and Seeley, J. (2018). “Development and evaluation of an Evidence-based Instrumentation Course in Civil Engineering”. 125 Years in the Heart of Engineering Education, American Society of Engineering Education, Paper ID #22700.

Iskander, M. (ed) Yu, E., and Yakubov, N. *A course in instrumentation & monitoring of civil infrastructure.* in *Innovative Techniques in Instruction Technology, E-learning, E-assessment, and Education.* Houten, Netherlands: Springer, pp. 292-297, 2008.