2018 ASEE Annual Conference & Exposition, June 24–27, 2018, Salt Palace Convention Center, Salt Lake City, UT

Paper ID #22700

# Development and Evaluation of an Evidence-based Instrumentation Course in Civil Engineering

**Prof. Shawn Griffiths, University of Wyoming**

Shawn Griffiths is an Assistant Professor of Civil Engineering at the University of Wyoming. Shawn holds a B.S. in Civil Engineering from Utah State University (2009), M.S. in Civil Engineering from the University of Arkansas (2011) and a Ph.D. in Geotechnical Engineering from the University of Texas at Austin. He believes attitude and hard work are the two most important ingredients in successful learning. As such, he strives to have a classroom that is filled with ideas, questions, and a positive environment. He also believe school is the place to make mistakes, and encourages students to be brave enough to ”try, try again,” until they succeed.

**Dr. Janel Seeley**

# Development and Evaluation of an Evidence-based Instrumentation Course in Civil Engineering

This is an evidence-based practice paper. 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. The holistic approach to this course includes; instrumentation selection, data collection, data analyses, data interpretation and finally decision making. The course is designed to give students hands-on instrumentation experience through the installation and collection of laboratory data. The labs are designed and run by graduate students enrolled in the course with instructor oversight. Because the department is a mix of many disciplines within CE including; Transportation, Structures, Geotechnical, Hydraulic, Architectural and Environmental Engineering, a breadth of instrumentation is covered. This course aims to develop the students higher-order level of thinking and decision making skills, and culminates with a comprehensive final project. This paper will present how the instrumentation course was designed and allow others to build from the successes and challenges realized from the pilot offering.

## Introduction

This evidence-based practice paper presents the development and evaluation of a new instrumentation course. The course was designed for undergraduates and graduate students in Civil Engineering (CE). As the world develops and resources to build infrastructure continue to increase in cost as well as diminish in availability, civil engineers are tasked with designing and building using less. Less energy, less materials, and often less time. As advances in sensors and data acquisition have occurred, so too has the ability of civil engineers to validate important design assumptions and to measure quantities previously only estimated. This allows for more efficient design and construction practices to be implemented, so long as proper measurement and monitoring are performed and safety is not compromised.

Advances in sensing technology are occurring at an ever increasing pace. As smart cities are developed and advances are made in sensing and wireless technologies, training engineers to use this technology will also likely be an important part of developing the future engineer. Consequently, a course teaching students about instrumentation has been developed and offered at the undergraduate and graduate level at the University of Wyoming. This paper presents an overview of the course content, an evaluation of the course objectives, and lessons learned.

The authors are aware of 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 [1]. The second, developed at the American University of Beirut was an undergraduate course that included both civil engineering and electrical engineering students [2]. This undergraduate course covered a large breadth of instrumentation in multiple civil engineering disciplines (i.e. geotechnical, structural, and environmental).

The course developed and described in this paper differs from the first two courses in that it includes both graduate and undergraduate students, attempts to include sensors used in the transportation and water disciplines, and is focused on providing the students with familiarity with all aspects of an instrumentation program including; instrumentation selection, data collection, data analyses, data interpretation and finally decision making. To the authors knowledge the holistic approach to an instrumentation course is one of the unique elements of this course.

## Course Structure

CE 4650/5650, Application in Field Instrumentation, was developed as a dual listed graduate/undergraduate three credit course 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
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.

The course was offered as a technical elective to undergraduate students. The pre-requisite for the course is mechanics of materials (ES 2140) which is a required course in the CAE department, and the minimum course necessary for a good understanding of stress and strain which the authors believe is fundamental to understanding instrumentation applications. Enrollment in the course included eight graduate and three undergraduate students. Eight graduate students is an optimal number for this course, however three undergraduates is well below what was expected. The low undergraduate enrollment could be due to the nature of a new course, scheduling conflicts with other courses, or apprehension from undergraduate students to take a course for such an unfamiliar subject.

The course schedule is presented in Table 1. The course was divided into three sections. The first section was approximately two weeks long and included lectures covering; a review of

Table 1. Schedule for class and laboratory.

| | Week | Class | Lecture/Lab |
|---|---|---|---|
| Section 1 | 1 | 1 | Syllabus, Review of Mechanics |
| | 2 | 2 | Circuits / Ohms law |
| | | 3 | Data acquisition / Signals and sampling |
| | 3 | 4 | Planning a Monitoring program / Uncertainty / Accuracy |
| Section 2 | | 5 | Strain Sensors / Vibrating wire gages |
| | 4 | 6 | Foil Gages, theory and installation |
| | | 7 | Foil Gages, selection and voltage |
| | 5 | 8 | Fiber optics / Load cells |
| | | 9 | Piezometers / Linear deformation / Tilt |
| | 6 | 10 | Temperature/ dynamic sensors |
| | | 11 | Review of all sensor types |
| Section 3 | 7 | 12 | Dust collection and traffic monitoring lab |
| | | 13 | Dust and traffic data reduction (optional) |
| | 8 | 14 | Streamflow data collection lab |
| | | 15 | Streamflow data reduction (optional) |
| | 9 | 16 | Bridge deflection using fiber optics |
| | | 17 | Fiber optic data reduction (optional) |
| | 10 | 18 | Concrete expansion measurement lab |
| | | 19 | Concrete expansion data reduction (optional) |
| | 11 | 20 | Load and deformation lab |
| | | 21 | Load deformation data reduction (optional) |
| | 12 | 22 | P-wave refraction demonstration |
| | | 23 | P-wave data analyses |
| | 13 | 24 | Speaker (cancelled) |
| | | | Thanksgiving break, no class |
| | 14 | 25 | Vibrating Wire lab |
| | | 26 | Foil strain gage lab |
| | 15 | 27 | Final project handout and description |
| | | 28 | Class cancelled, bring questions to instructor |

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. Although the laboratory exercises are shown in Table 1 as regular lecture times, they actually varied from the scheduled class times in duration and day offered depending on the needs of the lab. For example, class 16, “Bridge deflection using fiber optics” required a visit to the lab where the fiber optics sensors where spliced followed up with a field trip to the bridge site where the data acquisition was connected to the instruments for a class demonstration on data acquisition. The total time for this lab was 3.5 hours, and it was scheduled for an afternoon when a student in charge of the lab could gain access to the lab and the data acquisition system. Often the duration of the lab exceeded the 150 minutes time scheduled for the week, so formal lectures were replaced with the lab. The class period following the lab was an optional class led by the graduate student and allowed students the opportunity to ask questions and receive guidance for the data analyses necessary for the lab report.

Table 2 presents the assignments, labs and final project developed as part of the course. The three assignments were assigned during the first and second sections of the course, during the first six weeks of traditional lectures. The three assignments were developed to reinforce the material covered in class and help the students apply the information discussed in lectures.

Lab topics for the course where determined in consultation with each of the graduate students. The topic that the individual graduate student was studying for research was modified and used to develop a lab. This ensured that the necessary lab equipment was available to the class and allowed the graduate student to teach the rest of the class about their research procedures, instrumentation and data analyses. This also helped to diversify the course lab topics into different discipline specific areas. When students did not have research topics that could be used to develop a lab, the instructor and the graduate student worked together to develop a lab. This occurred for two instances and led to the creation of the vibrating wire and foil strain gage labs. Due to of equipment availability these labs were offered near the end of the semester. However, these lab should have been some of the first labs offered due to their fundamental nature, and applicability to other instruments. The final lab, “Develop lab” shown in Table 2, was only assigned to the graduate students and required them to develop the lab, write a lab procedure and lab assignment. This was done in concert with the instructor and helped fulfil the University requirement that in a undergraduate/graduate course the graduate students are required to do 20% more work than the undergraduate students. The final project was divided into three parts and is explained in more detail below because it was used to evaluate if the course objectives were met.

Based on student interactions with the instructor it became clear that undergraduate students were not as accustomed to the lab format as the graduate students. Undergraduate labs are typically well defined in scope and come with step-by-step instructions on how to perform the lab. Because the labs in this course were often graduate student projects that were modified to include a lab. They were often question driven and more open ended than a typical undergraduate lab. This required students to apply and think about what instrumentation could be used to answer a specific question. The undergraduate students are certainly capable of performing this work however, they were not as adept to this type of lab as the graduate students. Lab reports were due one week after the lab was completed. While the format of the lab depended on the instruments and set up of the specific lab, each lab report was required to include at a minimum; a description of the test setup, a description of the instruments used and how they worked, an explanation of why the lab was performed (or why the research was being done), and answers to specific questions concerning the data analyses. Specific tables and figures were required to aid in grading and give the students practice in preparing and presenting technical data.

Table 2. Class assignments, lab reports and final project.

| Topic | Subject |
|---|---|
| Assignment 1 | Get to know student, plan labs |
| Assignment 2 | Review mechanics and statistics |
| Assignment 3 | Compare theoretical and measured strains |
| | |
| Lab report 1 | Dust collection |
| Lab report 2 | Streamflow calculation |
| Lab report 3 | Bridge Deformation using fiber optics |
| Lab report 4 | Concrete expansion |
| Lab report 5 | P-wave refraction |
| Lab report 6 | Load and deformation |
| Lab report 7 | Vibrating wire and strain gage |
| Develop lab | Create lab exercise for class[1] |
| | |
| Final project | Culminating semester project |

[1]Assigned to graduate students only.

Other instruments that the authors would like to introduce through labs in the future include; a piezometer, a displacement transducer, a tiltmeter, and a lab on data acquisition. These fundamental labs would be sequenced near the beginning of section three, and offer the students a chance learn basics before full scale field instrumentation labs.

Table 3 presents the rubric used to determine grades for the class. Because of the dual listing and the requirement for graduate students to perform 20% more work that their undergraduate peers, two grading rubrics are necessary. With the CE 5650 grades re-normalized to a 100% scale. The grades are weighted heavily towards the assignments and lab reports. Quizzes were meant to be given each class period, covering material from the previous lecture. The intent was to encourage the students to review the previous lecture material between lectures and then use the quiz's to supplant the need for an in class exam. However, the quizzes where only given weekly and did not motivate the students to study previous lecture material, as the instructor had hoped. The final project was comprehensive and included a laboratory exercise as well as application type questions. The participation grade was used to encourage student attendance and participation in labs and classes.

Future versions of this class will include an exam after sections one and two of the lecture material. This will help motivate students to study the lecture material and give them a foundation to build upon for the laboratory exercises.

Course Evaluation/Final Projects

Table 4 presents the rubric that was used to determine if the course objectives where met based on the final project. It includes evaluation criteria for below expectations, meeting expectations and exceeding expectations. All course objectives are included in the rubric except course objective 2 which is "Deploy/Install sensors for data acquisition". This course objective was not

Table 3. Grading rubric for both the undergraduate (4650) and graduate students (5650).

| 4650 | |
|---|---|
| Assignments | 65% |
| Quizzes | 10% |
| Final Project | 15% |
| Participation | 10% |
| Total | 100% |

| 5650 | |
|---|---|
| Assignments | 54.2% |
| Quizzes | 8.3% |
| Final Project | 12.5% |
| Participation | 8.3% |
| Lab demo with HW | 16.7% |
| Total | 100.0% |

Table 4. Rubric used to evaluate course objectives.

| Course Objectives | **Below Expectations** | **Meets Expectations** | **Exceeds Expectations** |
|---|---|---|---|
| **1. Identify types of instruments and describe how they work** | Unable to identify given instrument and/or not able to describe its operation | Able to identify given instrument and describe its operation | Able to identify given instrument and describe its operation in detail |
| **2. Choose proper instruments to use for a given application** | Unable to identify proper instruments or improper placement | Able to identify proper instruments to use and proper placement or instruments | Able to identify more than one proper instrument with placement and/or give detailed justification |
| **3. Collect data** | Unable to properly record data using data logger | Able to properly record data using data logger | |
| **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 |

evaluated as part of the final project due to the high cost and time required to install permanent instrumentation.

The final project included three parts and was used to assess if the course objectives where met. The three parts included; part I which incorporated sensor short answer and example question, part II required the students to complete a lab exercise, and part III consisted of the analyses of a full-scale instrumentation project. The students were required to work on their own for Parts I and II, and allowed to work in groups for Part III.

Part I of the project required students to recall information about sensors and draw and explain how they operate. It also provided the students with hypothetical examples and asked them to determine the appropriate location and sensor type to use for specific conditions. Part I incorporates cognitive learning within the first three levels of Blooms taxonomy [3] including; remembering, understanding, and applying. This portion of the project was used to evaluate if course objective 1 and 2 were met.

Part II of the final project included a lab exercise where students were required to determine a calibration factor and the weight of a small object. Figure 1 presents the lab setup including a vibrating wire strain gage (Geokon model 4150x) attached to a simple supported beam. The students were provided with a vibrating wire readout module (Geokon model GK-404), various weights, and allowed to look up the manuals for both the readout and the vibrating wire. Part II consisted of the students loading the beam with known weights, obtaining a reading, and using the data to determine a calibration factor. Once obtained the students were asked to use their calibration factor to determine the weight of an object. Part II incorporated higher cognitive learning within the levels of Blooms taxonomy [3] including; apply, analyze and some evaluation. This portion of the project was used to evaluate if course objective 3 was met.

On order to evaluate this outcome the instructor relied upon students coming and asking questions which indicates that the student did not know how to connect and operate the data logger. While students were not allowed to work with others during this portion of the final project, it is possible that students who did not know how to operate the data logger, may have asked fellow students for help, and this would not be reflected in the evaluation.

Part III of the final project included the analyses of data collected as part of a full scale instrumentation program at an excavation site for a new 10 story hotel in downtown Colorado Springs, CO. The data was obtained from a colleague specializing in excavation support and micropile installation. The project involved a retention wall (soil nail wall) and foundation support for two buildings adjacent to the excavation. The owners of the property agreed to instrument the excavation and support structures to ensure the adjacent buildings did not move more than tolerable limits during the excavation. Students were given all pertinent information for the site and instrumentation plans as well as the data collected over about a six month period of time. The students were asked to analyze all the data and answer specific questions that could only be determined after proper data analyses was performed. Part III incorporated cognitive learning within the higher levels of Bloom’s taxonomy [3] including; analyze and evaluate. This portion of the project was used to evaluate if course objective 4 and 5 were met.

Table 5 presents the assessment results of the course objectives. Prior to grading, 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 recognized that a sample size of 11 may not be adequate for a robust evaluation, however it can

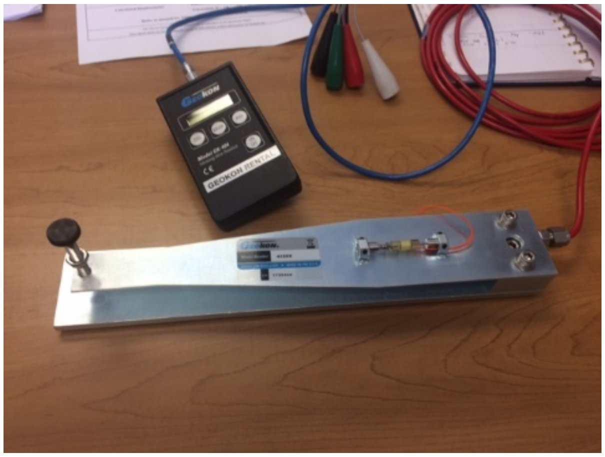

Figure 1. Geokon model 4150X vibrating wire attached to metal bar with Geokon model 404 readout box.

Table 5. Evaluation of course outcomes.

| Course Objectives | Below Expectations | Meets Expectations | Exceeds Expectations | % of Meet or Exceeds |
|---|---|---|---|---|
| **1. Identify types of instruments and describe how they work** | 3 | 5 | 3 | 73% |
| **2. Choose proper instruments to use for a given application** | 2 | 8 | 1 | 82% |
| **3. Collect data** | 1 | 10 | N/A | 90% |
| **4. Analyze data** | 3 | 8 | 0 | 73% |
| **5. Interpret data** | 8 | 3 | 0 | 27% |

provide an indication of successes and areas of future improvement. Future courses will increase this number to 80% after implementing the lessons learned from this pilot course.

Table 5 shows that 8 of 11 students met or exceeded expectation for course outcome 1. The 3 students that performed below expectations were able to identify the proper instrument but could not describe its operation in sufficient detail. Course objective 2 yielded 9 of 11 student who met or exceeded expectations with only 2 students unable to choose the proper instrument for application, or indicate the improper placement of the sensor. Course objective 3 was met by all but one student, whom was only able to collect data after the instructor spent time helping the student.

Course objectives 4 and 5 were determined based on two of the problems within part III of the final project. Objective 4, analyze data, was based on the students ability to calculate the correct strain from a vibrating wire strain gage attached to a micropile, along with the date the micropile was loaded. Eight of the 11 students were able to properly determine the date and magnitude of the applied load. 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, were able to properly analyze this data. This allowed for a proper determination 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. Unfortunately only 3 of the 11 students were able meet this expectation. Clearly interpretation of results is an area for future improvement within the course.

It is possible that objective 5 shows such a low level of understanding because of the difficulty of the interpretation, or the fact that this was the 1$^{st}$ time students had been asked to analyze and interpret tiltmeter data. However, the instructor believes that a gap in the students ability to relate the recorded data to the physical situation is more likely the culprit. An effort to correct this deficiency will include reinforcement of this concept through discussion of completed homework's and lab reports.

Course Evaluations

Due to a clerical error, the course evaluations where not performed for the class. However, an informal evaluation, conducted by the instructor, was performed near the 11$^{th}$ week of the course. The students were asked to anonymously write down one thing they would change about the course, and one thing they liked about the course. For improvement, eight out of the eleven students mentioned scheduling a dedicated lab time each week for the lab. Two students requested pre-lab questions, or a short review of the instrumentation that would be used in lab that day. Positive comments from the class indicated high interest in the subject material or approval of the pace of the course.

Conclusions

Most of the course objectives where met, which is an important indication that the course was an overall success. While not diminishing the overall success of the course there are some changes and adjustments that could improve the course. These include:

1. Setting up the course for a once a week 150 minute period of time.
2. Incorporate an exam into the curriculum, near the end of the section I and II of the course.
3. Rearrange the labs to start at the most fundamental topics near the beginning of the section 3.
4. Provide time for group and class discussions following lab reports to reinforce learning and incorporate proper interpretation of results.

Combining graduate and undergraduate students in a course has inherent challenges. One of the challenges was introducing content at the appropriate level. While the sample size for this class was very small, three undergraduate and eight graduate students, it was clear from office visits and personal interactions with the students that the graduate students had a better grasp on nearly every aspect of the course content. This was also evident in the final grades with the undergraduate students overall grades being an average of 7% less than the graduate students. Future courses will work to close the gap between the graduate and undergraduate student by incorporating mixed group work.

Prior to this course the instructor had very little experience with instrumentation, so in preparation for the development of this course the instructor enrolled in the American Society of Civil Engineering (ASCE) workshop "Instrumentation and Monitoring Bootcamp", which gave the instructor some idea of the appropriate course content that could be used. The author encourages others who would like to develop a similar course to consider three specific challenges that the instructor was not prepared for; 1) the author is currently unaware of any text that can be used specifically for a civil engineering instrumentation course, 2) instrumentation is a truly multi-disciplinary field and requires knowledge beyond the discipline specific area that most university faculty are trained in and 3) in order to successfully teach a course on instrumentation, the proper equipment must be obtained which can require a large initial investment.

Although this pilot course had many challenges, it also resulted in the successful course development for the application of instrumentation in civil engineering. The informal survey indicated student interest in the course content, and this combined with growing amount of instrumentation being used in civil engineering applications make this an important course for future engineers. The authors look forward to continuing to develop this course, and evaluating its applicability to students' education.

References

[1] M. Iskander, (ed) E. Yu, and N. Yakubov, *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.

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

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