Development of Infrastructure Materials Course for Undergraduate Students in Civil Engineering

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Abstract

This paper describes the development of Infrastructure Materials course for undergraduate students in civil engineering. The course comprises of balanced lecture and laboratory components and serves as a core course for future civil engineers. The course spans a variety of materials ranging from steel to Portland cement concrete. The lecture component of the course focuses on topics associated with origin and manufacture of materials, physical and mechanical behavior and material design. The laboratory component focuses on evaluation of material properties in accordance with ASTM specifications, making comparisons between different materials and determining whether material meet the necessary requirements for various civil engineering applications.

The course is designed to meet and exceed several ABET required outcomes. The key outcomes assessed through this course include: ability to effectively communicate, ability to conduct laboratory experiments and to critically analyze and interpret data, and ability to function in multidisciplinary teams. Along with details on the development of course syllabus and its implementation, this paper also describes the efforts that were undertaken to evaluate the aforementioned objectives and presents results from two consecutive semesters.

Introduction

The infrastructure materials course is a core course that is commonly offered at sophomore and junior level to civil engineering undergraduate students. At the University of Minnesota Duluth (UMD), this course was developed to be offered at junior level. The development of the course syllabus is discussed in this paper along with results for various ABET outcomes that are being evaluated through this course. The course was offered for first time at UMD during fall 2010 semester. This course is offered twice every year (fall and spring) to ensure that class size is balanced as approximately 35 students. The enrollment during fall semester was 34 students and in subsequent spring semester it was 12 students.

The main objective of this class is to teach students about various types of infrastructure materials. This class is designed to help students gain knowledge on following topics related to infrastructure materials:

- Selection criteria and considerations;
- Behavior of materials for different types of loading and boundary conditions;

- Fundamental and engineering properties of interest and their evaluation through laboratory testing;
- Design of construction materials (Portland cement concrete and asphalt concrete);
- Specifications for acceptance of materials; and
    - Insight on sustainability of infrastructure materials.

In order to achieve the above listed learning objectives the course follows an integrated lecture and laboratory schedule. A total of twelve two-hour long laboratory sessions are conducted through the course of semester. For each lab session, students are asked to review ASTM specifications, follow the procedures from the specifications to conduct experiments, and collect and analyze data.

Course Topics and Organization

The course is broken down into series of learning blocks with established objectives for each block. Students are provided with detailed schedule for each learning block and corresponding objectives at the beginning of the semester. These are also revisited at the beginning of each learning block. While a detailed list of learning objectives for each block is not provided here for brevity, the list of topics, approximate number of lectures and a brief description is as follows:

(1) Behavior of Materials (3 Lectures): This block discusses various types of physical and mechanical behaviors of solids and fluids. Topics such as elasticity and inelasticity, linearity and non-linearity of materials, constitutive equations etc. are discussed during this block. One laboratory session is conducted to familiarize students with various measurement devices as well as to conduct laboratory safety training.
(2) Steel and Aluminum (4 Lectures): Manufacture of steel and aluminum are discussed along with mechanical and physical properties of interest, laboratory procedures to obtain these properties and, commonly used standards and specifications for metals in construction industry. Two laboratory sessions are conducted in this block; experiments include tensile testing of various metals, hardness measurements and toughness testing.
(3) Aggregates (3 Lectures): This block briefly discusses geological aspects associated with mineral aggregates followed by extraction and manufacture. Physical properties and size distributions (gradations) are discussed along with requirements for various construction materials and projects. This block also consists of two laboratory sessions that involve measurements of specific gravities, relative densities, void content, absorptivity, and shape and texture measurements for coarse and fine aggregates.
(4) Portland Cement, Portland Cement Concrete and Masonry (9 Lectures): Cement manufacture and hydration processes are discussed during the initial portion of this block. Effects of admixtures on cement hydration as well as strength gain is discussed next along with laboratory tests for measurement of cement hydration rates as well as setting

times. One of the key objectives of this block is to teach the volumetric mix design method for Portland cement concrete (PCC). Mechanical and physical properties of fresh and hardened PCC are discussed along with various requirements associated with different types of construction projects. Brief introduction is given to masonry and clay bricks as well as tests and specifications associated with them. A total of five laboratory sessions are conducted during this block. These include setting time tests on cement paste, cement mortar testing, PCC mix design, testing of fresh PCC for workability, yield and air content and, mechanical tests on hardened and cured concrete samples.

(5) Asphalt Binder, Asphalt Concrete and Introduction to Flexible Pavements (9 Lectures): This block discusses the extraction and manufacture of asphalt binder, specification methods for asphalt binder, various laboratory characterization tests for binders and issues associated with pavement performance in context of aforementioned tests and properties. In second set of lectures the volumetric design of asphalt concrete is taught along with various mechanical tests and construction issues associated with the asphalt concrete and flexible pavements. A brief introduction is given on design of flexible pavements. One laboratory session is conducted for this block that deals with testing of asphalt binder and determining volumetric properties of asphalt concrete.

(6) Wood (3 Lectures): This block introduces various species of timber along with specifications for structural timber sections. Physical and mechanical properties of interest are discussed along with wood preservation and degradation.

(7) Composites and Sustainability of Infrastructure Materials (3 Lectures): The concept of composite design and use of analytical and approximate models to determine their properties are introduced in this block. Design of engineered systems is discussed along with various measures for evaluation of renewability and sustainability of construction materials.

During the laboratory sessions the students are asked to work in groups of 3 to 4 students. During the course of semester three professional reports are prepared by students. These reports are expected to describe student's lab activities, data collection, data analysis, and findings and recommendations. For each set of labs corresponding to the report a new set of lab groups are assigned. The lab groups are made using a random process. Thus over the course of semester, students work in three different lab groups.

ABET Assessment Objectives

This course satisfies a number of ABET outcomes. For purposes of ABET accreditation, three outcomes are assessed at the end of each semester. ABET outcomes catered through this course are as follows: (Assessed outcomes are indicated)

- An ability to apply knowledge of mathematics, science and engineering;

- An ability to function in multidisciplinary teams; (Assessed Outcome)
- An ability to identify, formulate and solve engineering problems;
- An ability to communicate effectively; (Assessed Outcome)
- An ability to use the techniques, skills and modern engineering tools necessary for engineering practice;
- An ability to apply mathematics through differential equations; probability and statistics; calculus-based physics; general chemistry; and geology
- An ability to apply knowledge in the following four recognized major civil engineering areas: structural engineering, geotechnical engineering, transportation engineering, water resources engineering with a depth of focus in one or more of the four areas;
- An ability to conduct laboratory experiments and to critically analyze and interpret data in the following four (4) recognized major civil engineering areas: structural engineering, geotechnical engineering, transportation engineering, water resources engineering; (Assessed Outcome)
- An ability to apply knowledge of sustainability to civil engineering practice.

Assessment matrices were developed for all three assessed outcomes. The subsequent sub-sections discuss the evaluation methods for each of these.

Outcome: Ability to Function in Multidisciplinary Teams

The evaluation of a student's ability to function in a multidisciplinary team is a challenging problem from an instructor's perspective. In order to conduct quantitative evaluation a peer review system was chosen. After review of various peer review procedures, the web-based evaluation system called Comprehensive Assessment of Team Member Effectiveness (CATME) was selected. The CATME system was specifically developed with the assessment objective of "ability to function in multidisciplinary team" in mind(1). Extensive validation studies have also been conducted for this system(2).

The assessment of this objective was conducted for the second set of lab student groups which included a total of five laboratory sessions and preparation of one comprehensive report. Students are asked to conduct peer evaluations of their group mates using the CATME tool during the course of these labs and corresponding report preparation. In order to minimize the effects of "first time use", students were asked to conduct similar evaluations for their first lab group. The CATME evaluation of each student by their peers also has an effect on their lab report score; it is 10% of their lab report grade.

The specific objectives evaluated for this outcome are same as those evaluated by the CATME system. These include:

- Contributing to team's work;
- Interacting with teammates;
- Keeping the team on track;
- Expecting quality; and
- Having related knowledge, skills and abilities.

For each of the above objectives the CATME system has five score levels. Each student scores himself/herself as well as his/her group mates. Table 1 shows the evaluation matrix, the expected score level for each objective is also shown. The baseline scores considered acceptable are shown shaded in gray.

Outcome: Ability to Communicate Effectively

This course focuses on the technical reporting component of effective communication skills. Students' outcome is determined by evaluating a series of objectives that represent technical writing skills. The objectives and their brief description are as follows:

- Grammatically Correct Writing: Students should be able to write in grammatically correct manner with complete sentences and use of consistence tense throughout the write-up. This objective is evaluated for the second lab report submitted by students. The evaluation is conducted for write-up on aggregate specific gravities.
- Technical Writing Skills: Students should be able to describe technical matter effectively. Correspondingly students are asked to describe the laboratory experimental procedure for measurement of aggregate specific gravity and absorption. The expectation is that students explain the procedure in technically sound manner with use of passive and indirect voice.
- Presentation of Experimental Results: Students should be able to present the experimental data in efficient manner through use of table or charts. The results should be presented without ambiguity and in correct format. The evaluation of this objective is done through second lab report, specifically in terms of presentation of experimental data from Vicat test result for initial setting time of Portland cement.
- Technical Report Format: Students should be able to develop a technical report that has appealing and professional format. Such report should include: use of proper heading system, inclusion of page numbers, provision of table of contents, numbered figure titles, and numbered table titles. Once again this objective is also evaluated through the second lab report.

A scoring system was developed to quantify each of the above objectives. Table 2 shows the scoring system along with acceptable baseline scores that were established for each.

Table 1: Evaluation Matrix for ABET Outcome of "Ability to Function in Multidisciplinary Teams" (objective description from Ohland et al., 2004)

Score	Contributing to Team's Work	Interacting with Teammates	Keeping the Team on Track	Expecting Quality	Having Related Knowledge, Skills, and Abilities
5	Does more or higher-quality work than expected. Makes important contributions that improve the team's work. Helps teammates who are having difficulty completing their work.	Asks teammates for feedback and uses their suggestions to improve. Provides encouragement or enthusiasm to the team. Makes sure teammates stay informed and understand each other. Asks for and shows an interest in teammates' ideas and contributions.	Watches conditions affecting the team and monitors the team's progress. Makes sure that teammates are making appropriate progress. Gives teammates specific, timely, and constructive feedback.	Motivates the team to do excellent work. Cares that the team does outstanding work, even if there is no additional reward. Believes that the team can do excellent work.	Demonstrates the knowledge, skills, and abilities to do excellent work. Acquires new knowledge or skills to improve the team's performance. Able to perform the role of any team member if necessary.
4	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.
3	Completes a fair share of the team's work with acceptable quality. Keeps commitments and completes assignments on time. Helps teammates who are having difficulty when it is easy or important.	Respects and responds to feedback from teammates. Participates fully in team activities. Communicates clearly. Shares information with teammates. Listens to teammates and respects their contributions.	Notices changes that influence the team's success. Knows what everyone on the team should be doing and notices problems. Alerts teammates or suggests solutions when the team's success is threatened.	Encourages the team to do good work that meets all requirements. Wants the team to perform well enough to earn all available rewards. Believes that the team can fully meet its responsibilities.	Demonstrates sufficient knowledge, skills, and abilities to contribute to the team's work. Acquires knowledge or skills as needed to meet requirements. Able to perform some of the tasks normally done by other team members.
2	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.	Demonstrates behaviors described above and below.
1	Does not do a fair share of the team's work. Delivers sloppy or incomplete work. Misses deadlines. Is late, unprepared, or absent for team meetings. Does not assist teammates. Quits if the work becomes difficult.	Is defensive. Will not accept help or advice from teammates. Complains, makes excuses, or does not interact with teammates. Takes actions that affect teammates without their input. Does not share information. Interrupts, ignores, bosses, or makes fun of teammates.	Is unaware of whether the team is meeting its goals. Does not pay attention to teammates' progress. Avoids discussing team problems, even when they are obvious.	Satisfied even if the team does not meet assigned standards. Wants the team to avoid work, even if it hurts the team. Doubts that the team can meet its requirements.	Missing basic qualifications needed to be a member of the team. Unable or unwilling to develop knowledge or skills to contribute to the team. Unable to perform any of the duties of other team members.

Table 2: Evaluation Matrix for ABET Outcome of "Ability to Communicate Effectively"

Score	Number of Writing Errors	Technical Writing Skills	Presentation of Experimental Data	Technical Report Format
4	All sentences are grammatically correct, complete and with correct structure.	Experimental procedure is correctly described in concise, non-repetitive and proficient manner with use of correct voice.	Vicat test (initial setting time) data is presented in efficient and clear manner through use of table and/or figure.	Report includes: Page numbers, table of contents, well-defined heading system, figure titles, table titles.
3	Between 1 and 3 sentences are grammatically incorrect, incomplete or lacking proper structures.	The correct experimental procedure is conveyed in legible manner, but there is lack of conciseness and proficiency. (Minor deviations from good technical writing.)		One of the format items are missing.
2	Between 3 and 6 sentences are grammatically incorrect, incomplete or lacking proper structures.	The correct procedure is conveyed in legible manner, but there is significant lack of conciseness and proficiency. (Significant deviations from good technical writing)	Vicat test (initial setting time) data is presented in an inefficient and/or unclear manner.	Two format items are missing.
1	Between 6 and 9 sentences are grammatically incorrect, incomplete or lacking proper structures.	The experimental procedure is conveyed in ambiguous manner.		Three format items are missing.
0	More than 9 sentences are grammatically incorrect, incomplete or lacking proper structure.	The experimental procedure is conveyed incorrectly.	Test data is not presented.	Four of more format items are missing.

Table 3: Evaluation Matrix for ABET Outcome of "Conduct Laboratory Experiments and to Critically Analyze and Interpret Data"

Score	Reported Lab Procedure	Data Collection	Data Analysis	Measurement Accuracy	Theoretical Interpretation	Data Interpretation and Recommendation
3	Lab procedure is correctly reported. Any deviations from ASTM procedure are clearly indicated in report.	All three measured weights are reported. Weights follow generally observed trend.	All three properties are correctly evaluated using measured data.	Measured gravity is within 0.1 of actual value	Derivation is correctly shown for both dry and SSD bulk specific gravities.	Data is correctly interpreted (high slump = high workability). Recommendations are made for changing workability.
2	Lab procedure is correctly reported, however deviations from the ASTM specifications are not stated in report.	All three measured weights are reported. Weight data is inconsistent. (Example Dry Weight > SSD Weight)	Two out of three properties are correctly evaluated.	Measured gravity is between 0.1 and 0.2 of actual value	Derivation is correctly shown for dry and SSD bulk specific gravities. Some derivation steps are missing.	Data is correctly interpreted. No recommendations are made.
1	Incorrect lab procedure is reported, with at least 1 important step eliminated.	At least one weight measurement is not reported.	One property is correctly evaluated.	Measured gravity is between 0.2 and 0.5 of actual value	Partial derivation is shown (correct approach is used but derivation is not complete)	Data is correctly interpreted. Incorrect recommendations are made.
0	Lab procedure is not reported.	All measurements are not reported.	No properties are correctly evaluated.	Measured gravity deviates more than 0.5 of actual value	Derivation is incorrect or not shown.	Data is incorrectly interpreted.

Outcome: Ability to Conduct Laboratory Experiments and to Critically Analyze and Interpret Data

The title of the outcome is self-explanatory as far as the objective of this component of assessment. In order to conduct the assessment once again a number of objectives were developed and quantitatively evaluated. The assessment objectives, their brief description and procedure for evaluation are as described below:

- Reported Lab Procedure: Students should be able to follow the ASTM specified lab procedures for conducting experiments. This objective is evaluated using ASTM C127 specifications for determining the specific gravity of coarse aggregate. The evaluation is conducted by comparing the reported procedures used by students with the actual ASTM specified procedure.

- Data Collection: Students should be able to correctly collect data required for evaluation of a material property. Data collection should be done with procedures indicated in ASTM specifications. This objective is also evaluated using coarse aggregate specific gravity test specified as ASTM C127.

- Data Analysis: Students should be able to correctly determine the material properties using experimentally collected data. Similar to above objectives the ASTM C127 procedure for determining specific gravity of coarse aggregate was used.

- Measurement Accuracy: Students should be able to accurately determine the bulk (dry) specific gravity of coarse aggregate sample by following the ASTM C127 test procedure. The specific gravity provided by the aggregate manufacturer was utilized as the value for comparison. The manufacturer's results were cross-checked by instructor and teaching assistant to ensure the correctness.

- Theoretical Interpretation of Lab Procedure and Analysis: Students were asked to demonstrate that experimentally determined bulk specific gravities (dry and SSD) calculated using various weights (dry, SSD, and submerged) match the theoretical definitions of the specific gravities for coarse aggregate.

- Data Interpretation: Students should be able to correctly interpret the experimental findings and provide recommendations based on the findings. This objective is evaluated using PCC workability results evaluated using slump cone method specified as ASTM C-143 procedure.

Table 3 shows the scoring matrix for this outcome. For each of the objectives described above different baseline acceptable levels were established. These are also shown on the table (shaded in gray).

ABET Assessment Results

This section presents the results for three assessed ABET outcomes as described in previous sections. The results are reported for fall 2010 and spring 2011 semesters. Figure 1 shows the average of the each outcome as well as the baseline values. Please note that in order to make fair comparison all values are converted to percentages. It can be seen from the results that for fall 2010 semester the student performance exceeded the baseline expectations on an averaged basis. This is also true for first two outcomes during spring 2011, however for the outcome that evaluates ability of students to conduct experiments and critically analyze and interpret the data, the scores are about 20% below the anticipated baseline on averaged basis. It should also be noted that during the spring semester there were considerably smaller number of students in the course as compared to fall 2010 (12 versus 34).

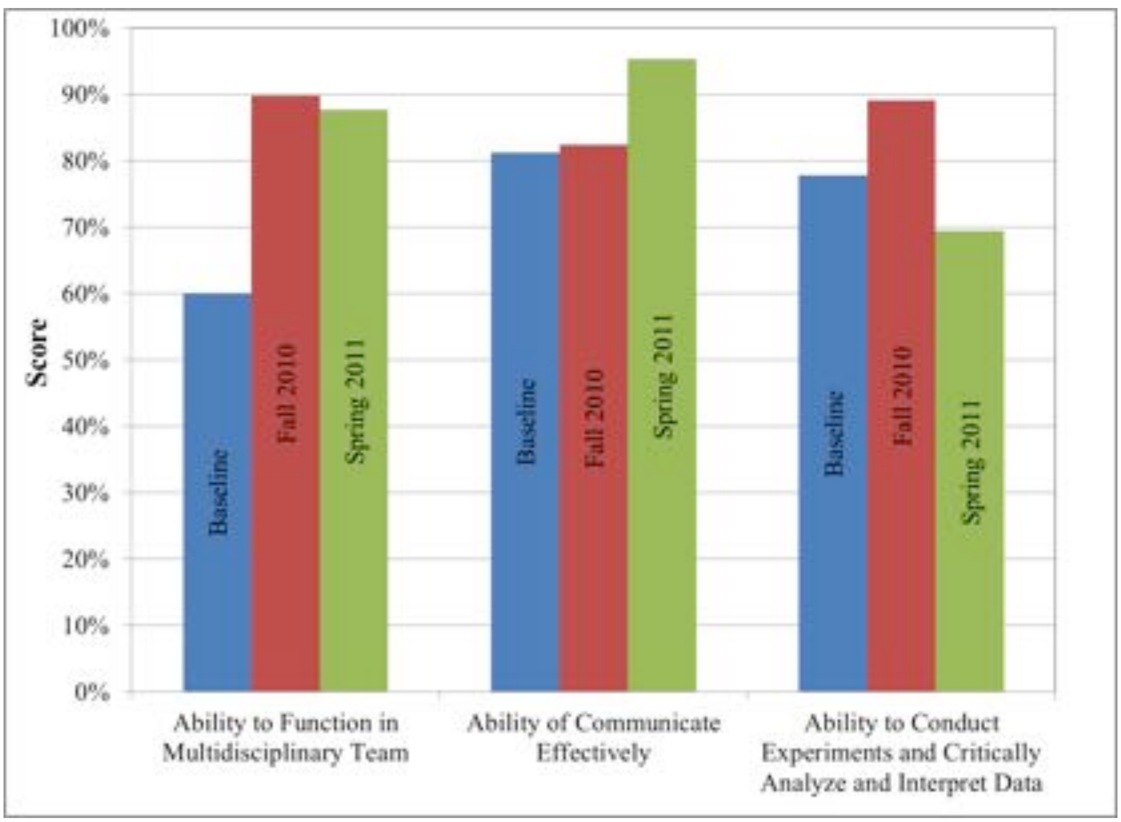

Figure 1: Average Scores for Each Assessed Outcome (Acceptable Baseline, Fall 2010 and Spring 2011 are shown).

The assessment data collected from the two semesters is also analyzed to determine what percentage of students are meeting and exceeding the baseline requirements. This data is presented in Figure 2. The results show that the students have very good capability to effectively work in multidisciplinary teams. From written communications perspective, the results show significant improvement in spring 2011 semester as compared to fall 2010. This is partly due to added efforts by the instructor to provide good samples of technical writing as well as spending approximately half lab session to give good technical writing tips to the students. The results also show that during fall 2010 students exhibited good ability to conduct experiments and to analyze and interpret the experimental findings. The results from spring 2011 were not satisfactory in this aspect with 50% students not meeting the baseline expectations. A detailed look at the raw data indicated that the main shortcomings were from "measurement accuracy" and "theoretical interpretation" point of view. In future semesters more emphasis will be given to these aspects. In particular teaching style will be slightly modified as well as additional discussions will be added.

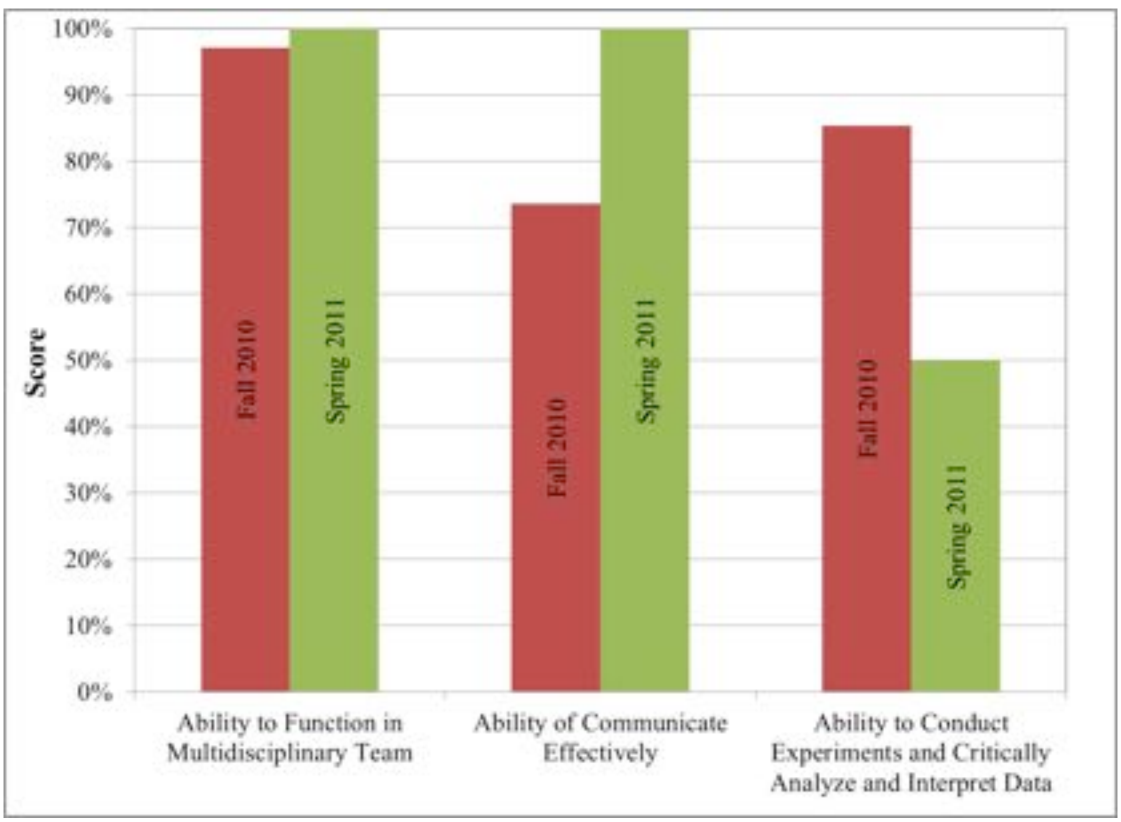

Figure 2: Percent Students Meeting and Exceeding the Baseline Requirements.

Summary

This paper describes the development of "Infrastructure Materials" course at University of Minnesota Duluth. The paper briefly describes the course objectives, syllabus topics and course organization. The second half of the paper describes the development and assessment methods for three ABET outcomes evaluated through this course. The evaluation results for first two semesters are also presented. Based on the assessment results it was observed that improvement is needed to increase the ability of students to conduct experiments and critically analyze and interpret data.

References

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Biographical Information

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