Modernizing an Introductory Civil Engineering Course with Project-Based Learning

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Introduction

The Civil and Environmental Engineering Department at Villanova University previously offered a sophomore-level course introducing students to tools and techniques, such as surveying, understanding maps and plan sets, and field sampling, required for their Civil Engineering curriculum as well as throughout their professional career. This course was originally a project-based course that included many of these core aspects of Civil Engineering but used outdated equipment such as theodolites for surveying and planimeters for measuring areas on maps, rather than modern technologies. Subsequent iterations of the course have included more up-to-date technologies but lacked cohesion, covering a range of topics and Civil Engineering disciplines but not in a way that clearly connected them together.

Project-based learning is a type of inquiry-based learning that involves a major assignment in which students, often in teams, take part in the design and/or creation process[1]. Research indicates that project-based learning can result in gains in student achievement, problem solving capabilities and understanding of subject matter[2]. In addition, it can enable students to have a better understanding of the application of their knowledge in practice and the complexities of other issues involved in professional practice[3]. This type of learning was conducive to understanding and applying the Civil Engineering tools and techniques in the original version of CEE 2604 so it was important to keep this aspect of the course in the redesign. Therefore, the goal of the most recent iteration of this course was to increase the use of modern Civil Engineering technologies while reintroducing the semester-long multi-discipline project-based concept used in the original version of the course.

To model this approach, a constructed stormwater wetland on campus was used to create a project that thematically tied the course together. This project site allowed the incorporation of multiple data sources and field components, creating opportunities for smaller, individual projects using real data that students completed in preparation for the overall design project. The project required student groups to redesign a walking path next to the wetland to make it compliant with the Americans with Disabilities Act (ADA) while also reducing the risk of flooding during future storm events. Modern Civil Engineering technology incorporated into the course included AutoCAD (2019 version) and ArcGIS 10.3.1 as drafting and mapping software packages, respectively, each of which is widely used in the Civil Engineering industry. Furthermore, new Nikon NPL 322+ Reflectorless Total Stations greatly enhanced the course module in surveying, enabling students to collect existing elevation data for the project in a more efficient way that is commensurate with current industry practices. For the design project and throughout the course, important concepts were incorporated or strengthened that faculty in the Civil and Environmental Engineering Department at Villanova University identified as current curriculum weaknesses, including reading, understanding, and drafting of engineering plans, Excel skills, probability and statistics.

This paper summarizes the results of multiple assessments performed to gauge the success of the course redesign. Included in this paper is i) an overview of the individual projects incorporated throughout the course and how they were tied to the overall project, ii) a discussion of the students' proficiency in different technologies introduced/reinforced in the course (i.e. AutoCAD, ArcGIS, surveying) after each respective learning module (assessed via student work), iii) a summary of student survey data regarding their self-identified proficiency in the different technologies both before they were introduced/reinforced and at the completion of the course, as well as their perception of the importance of these technologies to complete the semester-long design project. Student survey data also summarized their perception of the continuity of the semester-long design project (i.e. did the course succeed in merging multiple learning objectives into one cohesive overarching problem).

Course description

CEE 2604 is a required three credit sophomore-level course taught in the Fall semester that met twice a week for a total of four hours per week. One weekly class meeting was for 75 minutes and the second weekly class meeting was for 165 minutes (2 hr 45 min). The objectives of the course are as follows:

1. Define the profession of Civil Engineering.
2. Develop fundamental proficiency in mapping using ArcGIS.
3. Develop fundamental proficiency in graphical communication with AutoCAD.
4. Define common surveying terminology and develop basic surveying skills for land planning.
5. Develop and apply probability and statistics for solving Civil Engineering problems.
6. Develop basic analysis and programming skills in Microsoft Excel.
7. Compile a formal written project report with professionally presented figures, maps, and drawings.

The course was divided into five general topics: i) Maps and Plans, ii) ArcGIS, iii) AutoCAD, iv) Surveying, and v) Probability and Statistics. Table 1 provides a breakdown of the course topics and their distribution throughout the course. Each of the five general areas was linked to the completion of a semester-long design project that involved redesigning a walking path on campus to make it compliant with the Americans with Disabilities Act (ADA) while also reducing the risk of flooding from an adjacent constructed stormwater wetland during future storm events. Examples of these links include: i) Surveying to obtain the initial elevations along the walking path to determine where the walking path slope exceeded ADA requirements and where the walking path needed to be raised to avoid future flooding, ii) ArcGIS to spatially represented the survey data onto a satellite image, iii) AutoCAD to show the existing walking path profile along with the proposed redesign (including tie in locations, hatched cut and fill areas and proposed slopes), iv) Map and Plans skills to develop a groundwater contour map from boring log data to determine if the groundwater is a source or sink for the constructed stormwater wetland, and vi) Probability and statistics to quantify yearly variations in rainfall per storm event as well as quantify flow rate and pollutant reductions in the constructed stormwater wetland.

Although the majority of the assignments were individual assignment, a final group project written report was due at the end of the semester that linked all of the course topics to the overall walking path redesign project. Course time was allocated throughout the semester for the students to put into context how the information obtained from each of the general topics fit into their overall design project and final report.

Table 1. Course time allocated and learning objectives for each of the five general topics of CEE 2604.

Topics	Course Time Allocated	Learning Objections
Maps and Plans	13.1 h	Reading and interpreting maps and engineering plans; Understanding, calculating and applying scale; Creating and interpreting elevation, plan, profile and cross-section views.
ArcGIS	5.3 h	Understanding GIS workspace and coordinate systems; Viewing, creating and analyzing spatial data; Creating map layouts and establishing scale.
Surveying	6.8 h	Understanding survey terminology; Using total stations to collect traverse and profile data; Calculating elevation and coordinates based on raw survey data.
AutoCAD	8.0 h	Understanding CAD workspace, drawing set-up and structure; Using basic drawing and modifying commands; Setting up drawing layouts and establishing scale.
Probability and Statistics	9.5 h	Understanding common statistical analyses and terminology; Using t-tests, standard normal curves, box and whisker plots and exceedance probability curves to interpret real-world data.
Semester Design Project	8.0 h	Visiting project site to assess existing conditions and design constraints; Working on tasks related to semester-long design project; Understanding and preparing technical reports.

Rational for assessment of student work

This study focused on student proficiency in and assessment of three general topics taught in CEE 2604 (AutoCAD, ArcGIS and surveying) as well as Excel proficiency. Excel was not defined as its own general topic because use of Excel was ubiquitous throughout the course (including the semester-long design project). AutoCAD and ArcGIS were assessed as they were the modern Civil Engineering technology included in the course. Surveying was assessed because this was the first iteration of CEE 2604 that incorporated total stations (as opposed to either theodolites or automatic levels). Excel was also included in the student assessment because Excel Skills was identified by faculty in the Civil and Environmental Engineering Department at Villanova University as one of the curriculum weaknesses.

CEE 2604 had 17 individual assignments throughout the semester. An individual assignment is an assignment that must be the students own work. The instructors opted for the majority of the assignments to be individual assignments as opposed to group assignments to better ensure that each student learned the Civil Engineering technologies emphasized in the course. The number of individual assignments that involved the use of Excel was seven. Of those seven, Excel was considered the primary software in four of the assignments while the other three used Excel as a supplemental application (e.g., processing data for AutoCAD). Four of the individual assignments involved the use of AutoCAD while three of the individual assignments involved the use of ArcGIS. One individual assignment involved the use of surveying. The final report for the semester-long group design project included the use and knowledge of Excel, AutoCAD, ArcGIS and surveying.

Start-of-course and end-of-course student self-identified proficiency in Civil Engineering technologies

An anonymous survey was administered at the start and end of the course to ascertain students' self-identified proficiency in the different technologies targeted throughout the course (Excel, AutoCAD, ArcGIS and Surveying). A two-sample (unequal variance) t-test was used to compare differences in the survey results; one data set was considered significantly less than or greater than another data set if the p-value was lower than 0.05. The survey questions were worded as follows:

- What is your current level of proficiency with Excel?
- What is your current level of proficiency with AutoCAD?
- What is your current level of proficiency with ArcGIS?
- What is your current level of proficiency with Surveying?

At the start of the course, the students identified with having the highest proficiency in Excel and the lowest proficiency in surveying (Figure 1). The average self-reported proficiency score in Excel was 3.37 ± 0.76 (n=58). All students gave themselves a two or higher regarding Excel proficiency, indicating that they identified with having at least some level of proficiency in Excel. Contrary to the Excel, 10%, 29% and 53% of the students identified with having no proficiency in AutoCAD, ArcGIS and surveying, respectively, with average self-reported proficiency scores of 2.44 ± 0.92 (n=58), 2.10 ± 0.97 (n=58) and 1.73 ± 0.95 (n=58), respectively. Most of the students identifying with having at least some proficiency in Excel, AutoCAD and ArcGIS was expected because 56 of the 61 students enrolled in CEE 2604 had taken a three credit Introduction to Civil Engineering course the previous semester (i.e. Spring Freshman year). Use of Excel was needed for at least part of eight assignments throughout the Freshman course while the students just received a 2.5-hour introductory workshop on AutoCAD and a 2.5-hour introductory workshop on ArcGIS. Therefore, it was not surprising the relatively high self-reported proficiency in Excel compared to the other technologies used in CEE 2604. Three percent of respondents identified as "very proficient" with either AutoCAD or ArcGIS even though a 2.5-hour workshop would not have been sufficient to enable a student to be proficient. These students may have felt overly confident with their proficiency or they may have had prior experience with AutoCAD and/or ArcGIS from a previous course or internship. It is interesting to note that the students who identified as "very proficient" in one (either AutoCAD or ArcGIS) did not identify as also "very proficient" in the other. CEE 2604 is the first course in the Civil Engineering curriculum at Villanova University where surveying is taught. Therefore, it is not surprising that students self-reported to have the lowest proficiency in surveying (with none of the students self-reported as being "very proficient" in surveying) prior to the start of CEE 2604. Any exposure to surveying would have had to come through courses outside of the Civil and Environmental Engineering Department or from prior internship/research opportunities.

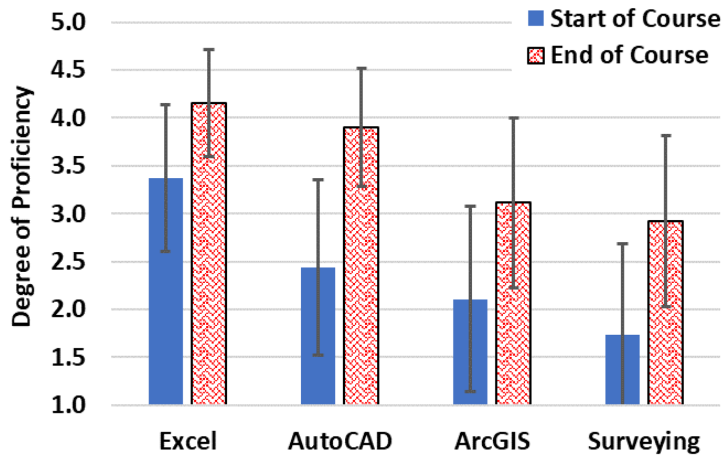

Figure 1. Student self-professed degree of proficiency in Excel, AutoCAD, ArcGIS and surveying at the start and end of the course. Each student rated themselves from a scale of 1 to 5. A score of 1 indicated "no proficiency" and a score of 5 indicated "very proficient".

The average self-reported proficiency scores at the end of the course were 4.16 ± 0.56 (n=61), 3.91 ± 0.62 (n=61), 3.11 ± 0.88 (n=61) and 2.92 ± 0.90 (n=60) for Excel, AutoCAD, ArcGIS and surveying, respectively. There was an increase in self-assessed proficiency in all four Civil Engineering technologies assessed in CEE 2604 ($p\text{-}value < 10^{-7}$) from the beginning of the course to the end of the course (Figure 1). The average degree of self-identified student proficiency rose by 0.78, 1.47, 1.01 and 1.19 for Excel, AutoCAD, ArcGIS and surveying, respectively. It was a bit surprising that the lowest degree of self-identified proficiency increase corresponded to Excel since it was used throughout the course and was required as part of seven of the 17 individual assignments throughout the semester. The greater average rise in self-assessed proficiency in the other technologies assessed could have been due to the students being less proficient in those technologies at the start of the course thus allowing for more room for improvement in understanding those technologies. Of the three technologies associated as a specific topic in Table 1, ArcGIS had the lowest average rise in self-assessed proficiency and AutoCAD had the highest average rise in self-assessed proficiency. It is interesting to note that the magnitude of average rise in self-assessed proficiency for ArcGIS, surveying and AutoCAD positively correlated with time allotted to those topics throughout the semester (Table 1).

Assessment of student work

Three assessments were performed to ascertain the students' proficiency in surveying, ArcGIS and AutoCAD. Excel was not specifically assessed for this study. Surveying was assessed using a question from a quiz where students were provided with raw survey data including total station coordinates and elevation; slope distance, azimuth, and zenith angles to a surveyed point; as well as instrument and target heights. The students were required to sketch an elevation and plan view of the survey layout and to use the field data to calculate the elevation, horizontal distance, and vertical distance to the surveyed point from the total station, as well as the survey point coordinates. Proficiency in this assessment required that the drawings were properly sketched and dimensioned and the numerical values were calculated correctly.

The second and third assessments related to specific parts of the final report for the semester-long group design project that required using either ArcGIS or AutoCAD. The part of the final report that assessed students' proficiency in ArcGIS involved the creation of a photo location map of their project site. For the assignment, students were required to use photos taken from a smart device with GPS location services enabled and to import the spatial data from the photo file and layer it on to a basemap using the appropriate coordinate system. Proficiency in this assessment required that photo locations were identified with an appropriate symbol in their correct spatial locations on top of a basemap showing current site conditions. Additionally, photo location labels were required, corresponding by number to photos presented within the report. Students were also required to provide a complete title block and to print the map to an appropriate engineering scale.

The part of the final report that assessed student proficiency in AutoCAD involved creating an AutoCAD drawing of the concrete box outlet structure at the constructed stormwater wetland. Students were required to create three orthographic views (top view, front view, and side view) using their own field measurements and site photographs. Proficiency in this assessment required that the views were placed in standard orthographic view positions on the drawing sheet (top view above front view, side view beside front view); that drawings were complete with all visible and hidden lines shown, properly dimensioned, and drawn to scale; and that a title block with all appropriate information was provided.

The survey assessment was an individual assignment (n=61) and the other two assessments were group assignments (n=11 and n=12 for the ArcGIS assessment and AutoCAD assessment, respectively). Assessment criteria was as outlined in Table 2. All three assessments had comparable average scores (survey – 83.6%, ArcGIS 86.4%, AutoCAD 83.1%) and comparable percentages of complete mastery for each assessment (Figure 2). All groups were able to perform at a satisfactory level (i.e. C) or higher regarding ArcGIS and AutoCAD proficiency. However, it is important to note that just because the group work was at a satisfactory level or higher does not mean that all students in each group had a satisfactory or better attainment of the knowledge. The surveying assessment, which was the only assessment of the three that was an individual assessment, did have 18% perform at less than satisfactory level. Regardless, the results indicate that, in general, the majority of students at the end of the course had at least a satisfactory level of attainment of the surveying, ArcGIS and AutoCAD skills introduced in the course. This corresponds with the increase in self-assessed perceived level of proficiency between the beginning and end of the course (Figure 1).

Table 2. Designation of assessment criteria.

Category	Corresponding grade
Complete mastery of concepts	A (90-100)
Mastery of concepts with minor errors	B (80-89)
Satisfactory attainment of concepts	C (70-79)
Limited attainment of concepts	D (60-69)
Unsatisfactory attainment of concepts	F (below 60)

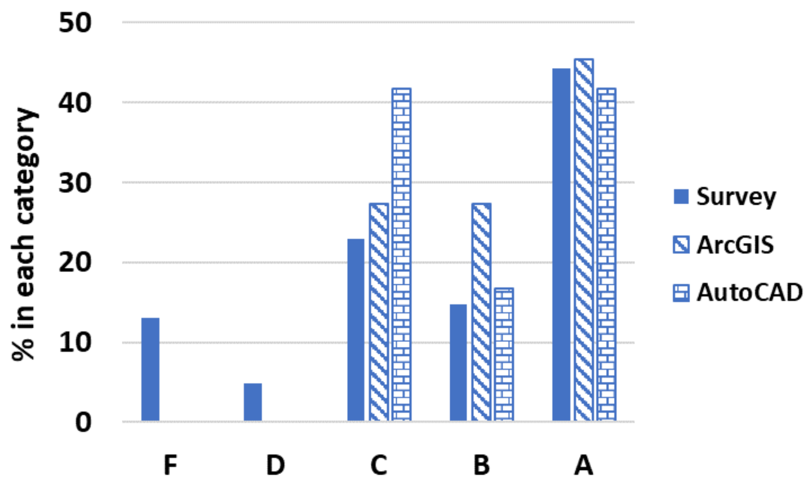

Figure 2. Assessment results from three separate assignments. Assessment criteria is outlined in Table 2. The survey assessment was from an individual assignment (n=61) and the ArcGIS (n=11) and AutoCAD (n=12) assessments related to specific parts of the final report for the semester-long group design project.

Incorporation of Civil Engineering technologies into the semester-long design project

Another important goal of the course redesign was to create a semester-long Civil Engineering project that incorporated the use of Civil Engineering technologies emphasized throughout the course. The anonymous survey administered at the beginning and end of the course also related to the students' perceived need for Excel, AutoCAD, ArcGIS and surveying to complete the semester-long project. The beginning-of-course survey was administered after the students were introduced to the semester project but before they worked with the above technologies. The end-of-course survey was administered after the students handed in their final report for the project. Below are the beginning-of-course questions. The end of course questions were similar except the questions were changed to past tense. A two-sample (unequal variance) t-test was used to compare differences in the survey results; one data set was considered significantly less than or greater than another data set if the p-value was lower than 0.05.

- How essential do you think Excel will be for the completion of your design project?
- How essential do you think AutoCAD will be for the completion of your design project?
- How essential do you think ArcGIS will be for the completion of your design project?
- How essential do you think surveying will be for the completion of your design project?

A score of 1 indicated "not essential" and a score of 5 indicated "very essential". The average beginning-of-course score regarding how essential Excel, AutoCAD, ArcGIS and surveying would be for the completion of their design project was 4.26 ± 0.69 (n=58), 4.50 ± 0.60 (n=58), 4.47 ± 0.71 (n=58) and 4.28 ± 0.77 (n=58), respectively. The results indicated that most of the students thought each technology would be essential to some degree for completing the final project. The average end-of-course score regarding how essential Excel, AutoCAD, ArcGIS and surveying was for the completion of their design project was 4.46 ± 0.72 (n=61), 4.95 ± 0.22 (n=61), 4.55 ± 0.72 (n=61) and 4.46 ± 0.72 (n=61). There was no increase in how essential the students thought Excel, ArcGIS and surveying was to their semester project between the beginning of the course to the end of the course (*p-value* > 0.05). However, the students' perceived essentialness of AutoCAD to the semester-long project (which was already relatively high at the beginning of the course) increased by the end of the course (*p-value* $< 10^{-6}$) indicating that their perception of the importance of AutoCAD for the design project was even greater at the end of the course. In addition, the end-of-course survey identified AutoCAD as more essential for the completion of the design project than each of the other three technologies (*p-value* $<10^{-4}$). The end-of-course student survey also asked if the students agreed or disagreed that "the semester design project connected all course topics in a cohesive way". A score of 1 indicated that they "strongly disagreed" and a score of 5 indicated that they "strongly agreed". The average score of the student responses to this question was 4.45 ± 0.68 (n=61). The relatively high score on this question indicated that the course did succeed in merging multiple learning objectives into one cohesive overarching problem.

Conclusion

A Civil Engineering sophomore-level course was redesigned to emphasis multiple Civil Engineering technologies while incorporating them into a semester-long Civil Engineering project that redesigned an existing walking path to make it Americans with Disabilities Act (ADA) compliant while also reducing the risk of flooding from an adjacent constructed stormwater wetland during future storm events. Four of the Civil Engineering technologies included in the redesign (Excel, AutoCAD, ArcGIS and surveying) were assessed through an anonymous student survey at the start and end of the course. The goal of the survey was to better understand how the students' self-assessed proficiency in the four Civil Engineering technologies changed from the start to the end of the course and how essential these technologies were to the completion of the semester-long project. Student attainment of proficiency in surveying, AutoCAD and ArcGIS as related to the course was also assessed. Results indicate that there was an increase in the self-assessed proficiency in Excel, AutoCAD, ArcGIS and surveying between the beginning and end of the course. These results corresponded with the majority of the students having a satisfactory or better level of attainment on the Civil Engineering technologies assessed indicating that the use of the project-based semester long design project was a valid method for student learning of the Civil Engineering technologies introduced in the course. Finally, the student survey indicated that the majority of the students felt that Excel, AutoCAD, ArcGIS and surveying were essential to the semester-long project and that the course did succeed in merging multiple learning objectives into one cohesive overarching problem.

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