Work in Progress: Integrating Civil Engineering Design Software into the Curriculum to Enhance Career Readiness Skills

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Abstract

The professional practice of Civil Engineering relies on both the understanding of fundamental engineering concepts and the ability to use software for efficiently designing buildings, bridges, roads, sites and infrastructure pipe networks. The Civil Engineering Department at the University of Hartford has embraced the challenge of updating many of our courses to include the use of Civil3D into all four years of the students' curriculum to enhance learning and to improve students' success in landing a career. Based on advice from the Department's Advisory Board, Civil3D was selected as the software platform that is used throughout the civil engineering industry.

This initiative supports the overriding theme of the Third Edition of the Civil Engineering Body of Knowledge that is "focused on preparing the future civil engineer for entry into the practice of civil engineering at the professional level [1]." Specifically, the use of design software enhances the Engineering Fundamental Outcome of Critical Thinking & Problem Solving and the Technical Outcome of Design. The assignments used in junior and senior level courses focus both on the technical (e.g. size and slope of pipe) and constructability/maintainability (e.g. proximity to other utilities and access for maintenance) aspects of design that engineers face in practice.

The Department leveraged a faculty development grant to pay professors to learn the software and to build it into the curriculum for their classes. The Department also partnered with Eagle Point Software to make their on-line training platform available to every civil engineering student and faculty member to provide on-demand assistance with Civil3D and AutoCad commands and work flows.

In its second year of implementation, we have observed significant improvement of Computer-Aided Design and Drafting (CADD), problem solving, and design skills in our senior class. Our Advisory Board members and alumni have advised us of the importance of frequent use of computer design skills to achieve fluency in applying the skills for the practice of engineering at the professional level. Assessment of the project is achieved through review of project assignments and project deliverables with working professionals who have and will continue to provide feedback relating to the skills our students are demonstrating and through the direct polling of current students. We also intend to begin polling employers of recent graduates about the level of preparedness for the job.

Introduction

The University of Hartford Civil Engineering Department recognizes the importance of continual improvement to meet the expectations and needs of the employers of our graduates. This corresponds to the Civil Engineering Body of Knowledge that is "focused on preparing the future civil engineer for entry into the practice of civil engineering at the professional level [1]." The ability of the Department to attract students is enhanced by a reputation of providing graduates

who can demonstrate their fundamental engineering knowledge through computer skills that are in demand in the workplace. The University's College of Engineering, Technology and Architecture convened a workshop among faculty, industry professionals, alumni and advisory board members to discuss and brainstorm on the broad topic of enhancing the readiness of our graduates for the workplace.

The resounding conclusion from our industry partners was to have our graduates be familiar with computerized design tools that are commonly used in the workplace [2]. These tools include software for modeling, analysis, design and drafting. More and more companies are relying on engineers to use computerized design and drafting software directly, producing engineering drawings with no or minimal involvement from a drafting department.

Our industry partners also stressed the importance of thinking and designing in three dimensions. The ability to visualize and mentally rotate three-dimensional objects based on two dimensional drawings is also known as visual-spatial skills and these are different from other forms of intelligence such as verbal ability, reasoning ability, and memory skills. Spatial skills are linked to professional and academic success [3], [4]. For example, when designing or constructing a pumping station or piping systems within a treatment plant, it is always challenging to develop a three-dimensional mental picture of the space when looking at plan view and section views of a space. Those who are skilled in developing that clear mental picture make fewer mistakes and are more efficient designers or constructors. Spatial training has been shown to have a strong impact on developing these visual-spatial skills as measured by success on standardized spatial skills tests [5], [6]. Furthermore, one researcher concluded that there is "no wrong way to teach spatial skills" and that spatial training helps with retention in STEM majors including engineering [5].

In a study of the Irish Engineering program, Farrell et. al. identified that completing the Design and Computer Graphics program in secondary school was the strongest predictor of success in spatial skills tests [6].

Civil Engineering faculty agreed that the suggestions from our stakeholders provided us with an opportunity to differentiate our program and to give our graduates a competitive edge in the job market by incorporating the use of computer-aided design and drafting (CADD) tools in multiple courses throughout the 4-year curriculum. Incorporation of 3-dimensional CADD throughout the curriculum also provides an opportunity to enhance the spatial training that has been shown to be predictive of academic and career success [3], [6]. Civil Engineering faculty applied for and received a University Technology Grant to support the effort of incorporating CADD throughout the 4-year civil engineering curriculum and have completed year two of a four-year implementation period.

Comparison to Other Engineering Programs

Prior to working in academia, the author spent over 25 years with a consulting engineering firm, where he had the opportunity to interview dozens of students and recent graduates from Universities throughout New England, New York and beyond. Most universities offer an introductory course in CADD, usually AutoCad, taught in the first or second year. For most

students, their experience with AutoCad ended there, while others were able to build on that introductory knowledge through a single class project, capstone project or internship experience. None indicated that their program provided follow-up classes or focus on continuing to build the CADD skills to enhance critical thinking and problem-solving skills, such as using 3-dimensional design to help envision the constructability and maintainability of a design, through class projects. None of the programs or students that we contacted indicated that their program incorporated CADD to provide a more holistic design experience.

The United States Military Academy at WestPoint initially incorporated CADD into their Civil Engineering curriculum in the 2007-2008 academic year in a junior-level site design course and a senior-level capstone course. Challenges associated with teaching and learning the design software limited the ability of the student design teams to succeed in using the software to the desired extent. Improvements for the following academic year involved faculty software training during the summer and additional class and laboratory time dedicated to software learning using tutorials for students during the semester. Student feedback on the use of tutorials was positive as measured qualitatively through student feedback and quantitatively through evaluation of course work products and exams. WestPoint faculty also recognized that the incorporation of the CADD software into additional CE courses would strengthen the learning. [7]

Choosing the CADD Platform

One of the struggles faced by faculty at any institution is selecting a specific software product. In the case of CADD, our stakeholders preferred either Civil3D, an AutoDesk product, or Microstation, a Bentley product, for "horizontal" work and Revit for vertical work [2]. Those that preferred Microstation were generally firms that served state transportation agencies while most firms in all other "horizontal" markets prefer Civil3D.

Educators at WestPoint initially implemented PowerCivil, a Bentley product, in 2007 and found that it was very powerful but had a steep learning curve that was difficult to ascend during a single semester course [7], [8]. In 2011, the institution decided to change to Civil3D as it offered a more intuitive user interface that facilitated a shorter learning curve [8].

We ultimately decided on Civil3D, which is based on AutoCad, as our preferred platform based on the following:

- Introduction to AutoCad was already part of our first-year Graphic Communications course
- Stakeholders agreed that Civil3D skills would be valuable background from which to learn Microstation
- AutoDesk provides free copies of all their products, including Civil3D, to students and faculty
- Civil3D seems to be used more broadly among site design and water infrastructure firms than Microstation, which, in this geographic area, is generally used primarily by firms working in the state and federal highway market

Leveraging On-Line Training/Tutorials

While some of our Civil Engineering faculty had previous experience with either AutoCad or Civil3D, none were proficient enough to teach students how to efficiently use it for civil engineering design applications. Therefore, 3 out of 4 faculty members teaching surveying, transportation, water resources and environmental engineering began in-person Civil3D training with an experienced civil engineer. After one session, faculty realized that since each had different levels of proficiency and each would be implementing the software differently (site grading, road layout, pipe networks, etc.), small group training was inefficient. It was also clear that individual one-on-one training for faculty members would be cost prohibitive. We therefore looked to on-line training as a potential solution.

Eagle Point Software Corporation offers the Pinnacle Series, a learning and productivity platform for maximizing the use of Autodesk software including AutoCad and Civil 3D. The Pinnacle Series includes training videos and workflows designed to provide "just-in-time" learning for practicing architects and engineers. The University subscribed to the product and works with Eagle Point Customer Success to provide the learning platform to all Civil Engineering students and faculty. Using the Pinnacle Series, faculty members have improved their own Civil3D skills and have created customized learning paths within the Pinnacle Series platform for students in their classes.

The on-demand, web-based learning platform allows students to access the training materials as needed while they are working on a design assignment. Therefore, students' learning of the software is project based and it is implemented with a hands-on assignment for enhanced learning.

Incorporation within the Curriculum

Proficiency in any skill requires practice and repetitive use of the skill, else it is easy to forget. However, within a Civil Engineering program, it is not feasible or desirable to add skill-based courses to the curriculum. Instead, we wanted to incorporate and emphasize the use of CADD simply as a tool to be used in the engineering design process in much the same way that a calculator is a tool used to complete calculations. Therefore, it was essential to develop, within existing courses in each of the four years of the curriculum, projects that would require the use of Civil3D. The incorporation of CADD into the engineering curriculum at the University of Hartford described below is the vision of where we want to be at the end of a four-year implementation period. Table 1 illustrates the implementation period for this project.

Table 1: CADD Implementation at the University of Hartford

Year	Class	Graphic Communication (Freshman)	Surveying (Sophomore)	Transportation (Junior)	Water Resources (Junior)	Water Quality (Senior)	Capstone Design (Senior)
1	2014-18	Spring 15				Fall 17	Spring 18
2	2015-19	Spring 16			Spring 18	Fall 18	Spring 19
3	2016-20	Spring 17	Fall 17		Spring 19	Fall 19	Spring 20
4	2017-21	Spring 18	Fall 18	Fall 19	Spring 20	Fall 20	Spring 21

The introduction to the AutoCad CADD software begins in a freshman Graphic Communication class, where students learn the basics of creating a drawing, drawing lines and shapes and learning how to depict three-dimensional objects on a two-dimensional drawing.

In the sophomore year, students in the Introduction to Geomatics course use three-dimensional design tools. From basic understanding of coordinate geometry and making reliable survey measurements to drafting in AutoCad and importing points into Civil3D, this course helps students develop a basic understanding of three-dimensional design software and data. Initial course homework assignments provide guidance and exercises on importing points, creating surfaces, and creating maps including elevation contours. Building on these assignments, several lab exercises require field measured lab data be presented in Civil3D. At the end of the semester, the final project requires each student group to work as a team to develop a real dataset that they import into Civil3D to create the final map for the project. These assignments help instill in students the need to work with the software as a design and analysis tool and to persist through software challenges.

During the junior year, Transportation Engineering I students use Civil3D to create a road alignment and grade the proposed road into the existing topographic surface. They also learn how to create profile and section views of the roadway and to create plan sheets. Use of the software for the road design project and the ability to view the design in a 3-dimensional rendering affords an opportunity for the students to visualize the horizontal and vertical geometry that they are learning about in class. This course has recently been approved for addition into the required Civil Engineering curriculum, creating a two-course transportation progression instead of a single transportation course. It will be first taught during the 2019-2020 academic year.

Also in the junior year, students in the Water Resources Engineering course use Civil3D to create a storm sewer pipe network and to create and grade a stormwater detention basin. Students follow the Connecticut DOT Drainage Manual for sizing, spacing, and layout of the manholes, catch basins, pipes, and outlet. Also, faculty present a lecture on "Good Storm Sewer Pipe Network Design Guidelines" to be used as a reference for finalizing pipe slopes, invert inlet/outlet elevations, and ground cover. Final output of the project are 40 scale plan and profile sheets.

Students are taught to use the Object Viewer feature within Civil3D to help them visualize, in three dimensions, the elements that they are designing. This helps them to develop the spatial awareness skills that are important for success in engineering [3] – [6].

Seniors use Civil3D in a Water Quality Engineering course to design a water distribution main, gravity sanitary sewer pipe network and a sanitary sewer force main. The assignment requires students to follow published design guidelines and to address some of the practical aspects of real-life design like:

- Creating horizontal and vertical pipe alignments that are not in conflict with other utilities
- Determining appropriate sewer depth to maximize the ability to serve properties by gravity while being cognizant of construction cost and constructability

- Placing manholes to facilitate connections from intersecting streets and to maintain straight pipe segments
- Creating air and vacuum release structures on pressure networks

Final output for the design project is plan and profile construction drawings to convey necessary information to contractors for bidding.

In the final semester of the senior year, students complete a capstone design project that can focus on one or several civil engineering disciplines. Most of the projects require a design component where use of CADD is required. Students use the CADD skills developed through their other courses to facilitate the design process and to illustrate their final design product, just as they will when they enter their career.

Faculty Impressions

Faculty have enjoyed the challenge of learning new software tools using the Pinnacle Series tutorials yet have struggled to learn enough to stay ahead of the students. Our observations of students are that most enjoy the challenge of learning the software, as they see the power and efficiency of using CADD skills in the application of their engineering knowledge.

Assessment

Currently, in year two of a four-year implementation, we are progressing toward the goals described above. The class of 2018 had completed the gravity sewer pipe network in Water Quality Engineering and, in some cases, Capstone Design. The class of 2019 will have completed pipe networks in both Water Resources Engineering and Water Quality Engineering and Capstone Design.

To assess progress, the Department assembled a volunteer CADD advisory panel of practicing civil engineers (and alumni) to discuss and review course assignments and to review some of the students' work product. The goal is to make the classroom assignments and expectations as close to real-world engineering projects as possible so that our graduates are well-along on the learning curve when they enter their careers.

Student Feedback

In March 2019, faculty solicited feedback from juniors and seniors in the civil engineering program through an on-line survey to which six seniors and twelve juniors responded. Among other questions, students were asked to rate their Civil3D proficiency when they entered our program and to rate their current proficiency, using the criteria in Table 2. As shown in Figures 1 and 2, most students believe that their Civil3D proficiency has improved. We hope that the juniors will continue to improve and, next year, at least some of them will rate themselves at the "proficient" level. Achieving the "experienced" level is unlikely unless the student has had an internship.

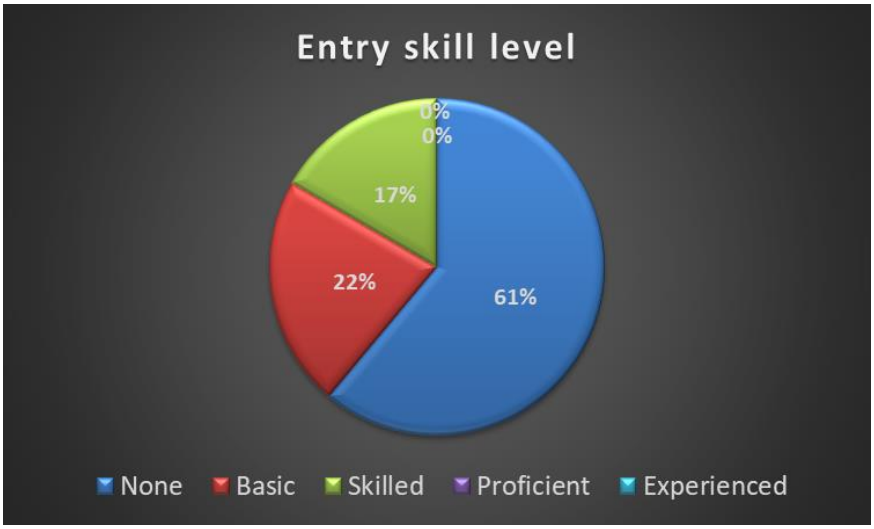

Figure 1: Self-assessed Civil3D skills upon entering University

Figure 2: Self-assessed Civil3D current skill level

Table 2: Descriptions of Skill Levels

Skill Level	Description of Skill Level
None	No experience at all
Basic	I know how to open drawings and execute basic drawing commands in 2D
Skilled	I can create and edit 3D drawing objects and create profiles and sections
Proficient	I can create and edit complex 3D inter-related elements such as surfaces, alignments, and pipe networks and produce plan, section and profile drawings in paper space
Experienced	Fluent in the above, with advanced knowledge of drawing commands, design analysis, troubleshooting, etc. Comfortable working and designing on my own

Fifty percent (9 of 18) of the respondents indicated that they had taken advantage of the Pinnacle Series tutorials in learning the software and completing assignments and 8 of those indicated that the Pinnacle Series tutorials were helpful. Open response comments were also solicited. When asked if the Civil3D assignments in multiple courses helped improve and hone skills, 12 of 18 responded affirmatively, although many had suggestions for improvements. Three did not respond to that question and three indicated that the assignments had not helped them.

Specific positive feedback included:

> "Yes- the flownet in Geotech taught me how to create a surface in 3D. The projects in Water Resources and Water Quality taught me how to draft and show profile views of pipe networks."
>
> "Having to do a flownet in Civil3D for … helped me advance my skill."
>
> "Yes, the coursework helped hone my skills. It is best to learn by completing projects on your own."

A few of the responses pointed to the fact that faculty need to continue to improve their own skills. For example, one student offered:

> "Some of the assignments help but I don't think the instructors know Civil 3D well enough. The best way to teach is show us once, make an assignment with everyone working at the computer, and walk around helping people."

Another student pointed out that we can improve our instruction with respect to the underlying fundamental design principles:

> "Although they helped me gain the basic knowledge of how AutoCAD works, I do not think it allowed me to understand what I was doing. As we completed assignments in class it was more of just doing things that we were told to do rather than understanding why we were doing each thing."

Finally, we asked students to suggest improvements to the overall Civil3D program. Most of the responses suggested improvements to the first-year Graphics Communication class to focus more heavily on Civil3D, while others suggested additional time and additional practice opportunities.

Adjustment

Feedback from our informal CADD advisory panel has been used to adjust the assignments. Faculty was initially concerned about overlap in the assignments from course to course, (e.g. creation of pipe networks) but the advisory panel encouraged it since repetition reinforces learning, particularly in the case of becoming proficient with a skill such as CADD.

The advisory panel reviewed students' drawings from the Fall 2017 Water Quality class, Spring 2018 Water Resources class and Fall 2018 Water Quality class and noted a marked improvement in design completeness and in the aesthetic presentation of the design on the 2018 drawings. Faculty believe this is due to both improvements in our instruction and the improvement that

comes with increased iterations of using the CADD software. Panel members indicated that they would be very impressed if an entry-level candidate showed the plans during an interview.

Opportunities for improvement still abound despite the progress that has been made. Additional emphasis is needed on critical design elements such as appropriate pipe depths and slopes, the number of pipes entering a given structure, and optimizing distances between structures.

Improvements can also be realized in the area of drawing aesthetics. It would be helpful to develop a standard border for the University and some simple drawing standards such as:

- Layer management and naming
- North arrow placement and style
- Scale bar placement and style
- Placement of labels and leaders
- Positioning of profile view and profile labeling convention

Conclusions and Lessons Learned

The Civil3D initiative at the University of Hartford has been successfully implemented into the civil engineering curriculum. Web-based "Pinnacle Series" training videos provided by Eagle Point Customer Success helped faculty overcome a major hurdle of lacking proficient CADD skills. The web-based training videos, workflows, and cheat sheets provided faculty an efficient means for learning the CADD skills needed to incorporate constructability and maintainability constraints into design projects that previously only concentrated on design calculations. Students also benefited from the web-based videos by providing them a learning tool that showed step-by-step procedures for creating civil engineering infrastructure. This provided students with the satisfaction of being able to complete professional looking plans while also providing them an efficient means for investigating multiple solutions to the proposed problem.

Assessment of student design and plans by a panel of practicing engineers indicated that they would be very impressed if an entry-level candidate showed this quality of plans during an interview. More work is needed to further develop the students' critical design skills as well as drawing aesthetics. The faculty are currently working on a "Department Drawing Standard" just as engineering firms have a standard set of requirements for plans that are delivered to their clients.

Additional benefits include that working with students on these CADD projects has translated into increased engagement in the classroom that facilitates learning in all aspects of their courses. We anticipate that further assessment will show that these skills will help our students win internships and full-time positions with a long-term benefit of being able to attract more highly talented students to our civil engineering program.

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