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Integrating Design Thinking into an Experiential Learning Course for Freshman Engineering Students

Dr. Mark J. Povinelli, Syracuse University

Dr. Mark Povinelli is the Kenneth A. and Mary Ann Shaw Professor of Practice in Entrepreneurial Leadership in the College of Engineering and Computer Science and the Whitman School of Management at Syracuse University where he is developing and teaching curriculum in innovation and entrepreneurship. Dr. Povinelli current research interests and curriculum development are in experiential team learning approaches to engineering education focused on design thinking and innovation as a basis for building entrepreneurial/business skill sets in undergraduate and graduate students. In particular he is investigating ways in which collaborative multidisciplinary team based student learning across traditional department, school, and college boundaries can enhance student educational outcomes. Dr. Povinelli has extensive professional engineering leadership experience at Texas Instruments, General Electric, and Lockheed Martin in the research, development, and production of airborne radar and EW systems including on the F-22 Raptor and E-2D Advanced Hawkeye programs. He is recognized as having significantly contributed to the research and development of wideband phased array antennas and 3-D computer-aided design electromagnetic simulation tools. In addition he has been a partner in several small business start-ups providing innovation and management leadership. He is the father of three grown children and has lived in central New York since 1985.

Jonnell A. Robinson, Syracuse University

Jonnell Robinson is an Assistant Professor of Geography and the Director of the Syracuse Community Geography Program at Syracuse University.

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Mark J. Povinelli, College of Engineering and Computer Science, Syracuse University

Jonnell A. Robinson, Department of Geography, Maxwell School of Citizenship and Public Affairs, Syracuse University

Introduction

After almost a decade of examining traditional textbook lecture oriented engineering education the call to embrace a greater emphasis on hands-on experiential learning is slowly being adopted [1] - [3]. This textbook based approach, emphasizing scientific analysis and mathematical modeling resulted in a decrease in design, build, and test hands-on engineering education [4]. This post World War II standard pedagogical model of engineering education resulted in an increase in lectures and the passivity of students in courses [5]. This emphasis on narration created students who were alienated from the learning process [6]. The importance of traditional learning pedagogies combined with experiential learning has been shown to increase overall cognitive competency [7] - [9]. To maintain relevancy and competitiveness in engineering education, hands-on learning experiences with a global perspective needs to be integrated into the curriculum [10], [11]. We believe critical skills such as empathizing, weighing ethical considerations and effective communication are needed by graduates to navigate the 21st century global societal needs [12] - [17]. These learning opportunities could allow them to learn and practice empathetical and ethical decision making with people from diverse backgrounds. Central to this capability is to provide the students with experiential learning opportunities and a design process which incorporates these skills.

Increasingly engineers are being challenged to use their knowledge and design skills after empathizing with the people for whom they are designing. We believe this philosophy is tied not only to determining the best way to meet the needs of those they are designing for but critical to practicing the engineering creed embodied in the "advancement and betterment of human welfare"[18]. This statement of principal along with placing "service before profit" and the "public welfare above all other considerations" tells us the critical importance in helping our students learn how to weigh the ethical considerations of the professional work they will engage in and how to approach and design solutions [19]. To prepare students, our experience suggests that we need to provide real world learning opportunities throughout the course of their study starting in their freshman year. Critical among those to promoting a healthy society is the re-engineering of urban infrastructure [20].

This paper describes a collaborative experiential learning course for freshman honors engineering students in which they learned and applied a design thinking process [21]. Students enrolled in the course collaborated with municipal government engineers to undertake research with reciprocal benefits to students and the city: students had the opportunity to learn about intractable engineering challenges and work in multidisciplinary teams while the city gained assistance with data collection and analysis. We contend that experiential learning is an effective way to introduce a design thinking process to engineering student teams. In the subsequent sections of the paper, we first present an overview of the real world problem with which students in the course grappled - the aging sewer system in Syracuse, New York. Next, we outline the collaborative, experiential learning, and design thinking frameworks for the course. In the final sections, we describe the course activities and assess the course outcomes specifically as they relate to the learning objectives for students and to the objectives of the partners from the local municipal government to collect actionable data for the improved maintenance of the city's sewer system. We conclude the paper with a discussion about the opportunities and challenges of university-community partnerships, experiential learning and cross-disciplinary collaborative teaching.

Aging Wastewater Infrastructure

Syracuse, New York is one of many cities in the United States with aging water infrastructure that is need of replacement or significant repair. In fact, the American Society of Civil Engineers Infrastructure Report Card assigns a grade of 'D+' to the country's wastewater system [22]. Most of Syracuse's water and sewer infrastructure was built in the early 1900s with modifications over the years to meet increased demand by Syracuse's mid-century expanding population. Most of these modifications included sewers that are combined systems with both raw sewage and storm water drained into the same network. In Syracuse, these sewers all connect to the Metro Wastewater Treatment Plant, which treats incoming wastewater and discharges it into Onondaga Lake. However, the capacity of the treatment plant is exceeded during heavy rainstorms due to increased storm water flows, and thus some wastewater is discharged into the lake with minimal treatment. There is also direct discharge into Onondaga Creek, which flows into Onondaga Lake. At times, the capacity of the sewer system itself is exceeded, which can lead to sewer backups in residential homes. Water may then overflow from storm water catch basins and/or cracked sanitary and storm water manholes, causing street floods. Some catch basins become plugged with debris (e.g., leaves) which can cause street flooding during heavy rainstorms. Basements of homes and commercial buildings may also become flooded if there are leaky sewage pipes.

Over the past few years, residents of the Eastwood neighborhood in Syracuse have raised concerns about sewer backups in residential homes. Eastwood is home to over 10,000 residents as well as commercial development. While some sewers in the neighborhood are separated, sewer backups are still problematic during heavy rainstorms. During the summer of 2015 when there were several heavy rain events, basement and street floods lead to tens of thousands of dollars in damages as well as numerous complaints to the city by residents [23].

Framing the Course through Collaboration, Experiential Learning, and Design Thinking

Given the national and local significance of public infrastructure decline and current policy debates over how to fund replacement and repair, we developed a course that explicitly focused on the problems with Syracuse's aging wastewater system [24], [25]. In order to provide context and relevance, we used a collaborative framework to create an experiential learning project in which student teams collaborated with local stakeholders to explore the real world challenges of maintaining wastewater systems in a resource-constrained city. In addition, we integrated a design thinking process to engage students in empathy/ethics-based methods and approaches to problem solving.

Collaborative Framework

The course emphasized collaboration on multiple levels. First, the course was jointly developed by faculty in the College of Engineering and Computer Science and the Department of Geography in the Maxwell School of Citizenship and Public Affairs. This collaboration was premised on the notion that there is an increasing need for engineers (and thus engineering students) to engage with policy makers because many of society's intractable problems call for innovative solutions that are grounded in science, technology and design. A concrete example from our class that we used to demonstrate this included a hands-on exercise in which students used crowdsourced mapping technologies to assist the city in mapping ADA (Americans with Disabilities) accessible curb cuts in order to create a curb cut replacement plan. Engineers design accessible transportation infrastructure and policymakers implement accessibility policies but often these roles are performed in isolation. Co-teaching allowed us to put engineering in conversation with policy making. We also strategically assembled student teams so that each team was comprised of students from each of the engineering departments[1]. This provided students the opportunity to engage with members of their cohort whom they may have little contact with over the course of their studies as a result of sub-discipline tracking. Importantly, course participants also collaborated with representatives from city and the county agencies charged with managing the local sewer system and a local civil engineering firm. This collaboration grounded the students' experiential learning project in a real world engineering and policy problem.

Experiential Learning

Using experiential learning and design thinking frameworks, we engaged engineering students in efforts to map the locations of sewer infrastructure (i.e. manhole covers and catch basins (also known as street drainage basins) with student prototyped measurement tools and high accuracy Global Positioning Systems (GPS) to evaluate the condition of sewer infrastructure.

The pedagogy of this class was grounded in experiential learning [26]. The Lewinian model of action research which allows for real world experiences to test concepts as a means for immediate personal experience as the focal point of learning was best suited to the prototype tool, data collection and analysis portion of the course [27]. Kolb's cyclical model of experiential learning uses feeling and thinking as a basis for observation and action to achieve learning through adaptation rather than just a set of particular outcomes, provided a good framework for using design thinking in the course. Here feeling serves as a basis upon which the students learn about themselves and others through empathy. Thinking focuses them on recollection and reflective understanding and logical analysis of the problem and tasks. Our course was structured to allow the students to have two continuous cycles of experience: prototype tool development, collection methodology, data collection, and reflection. This process of building episodic

[1] Departments in the College of Engineering and Computer Science include biomedical and chemical engineering, civil and environmental engineering, electrical engineering and computer science, and mechanical and aerospace engineering.

memory (consciously remembered experiences from memory) helps form a continuity in the learning process [28], [29]. The students were able to experience feelings of their own and of the stakeholders and end users they encountered during class and the data collection field trips. The students' reflections focused their learning on what worked and didn't work in terms of their data collection tools, data collection methodology, and how they functioned as a team after their field experiences. Working in teams allowed our students to think about personality types, diversity and communication [30]. Through this process of experience, recollection, and then reflection they were able to modify their tools, methods and team dynamics to strive for better team outcomes. They also shared these thoughts and feelings with all the course teams. This structure of experiential learning also fit well with the design thinking method that we wanted our students to learn as a design process. Here the bridge between experiential learning and design thinking is one of embracing failure and reflective doing.

The Design Thinking Process

We believe it is important for engineering students to learn and practice a design process as part of their formal engineering education. Engineering is replete with numerous design processes that are taught non-uniformly to students [31]. In this course we used a design process that modified the traditional design thinking process [32] - [35]. Design thinking is a process that typically first involves empathizing and understanding with the people that are the focus of the design effort. The term human-centered or human-centric design is sometimes used to emphasize the human and designer relationship and in some cases is meant to describe co-design between them. Importantly design thinking embraces early failure as part of the core philosophy of the design process learning experience. In this course we embrace the idea of students accepting failure and learning from it as part of the experiential process [36]. Our modification to traditional design thinking involved including at the first step in the design process both empathetic and ethical considerations. Including ethical implications in the first step of the design learning process allows the engineering student to consider how they are using their knowledge and skills in regards to its impact on others. We believe this skill needs to be developed alongside of the design process to ensure our engineers can also meet the expectations of the engineering creed and ABET standards [37].

The design thinking process we used had five steps that repeat in an iterative cycle. The steps include: empathy and ethics, definition, ideation, prototyping and testing as shown in Fig. 1.

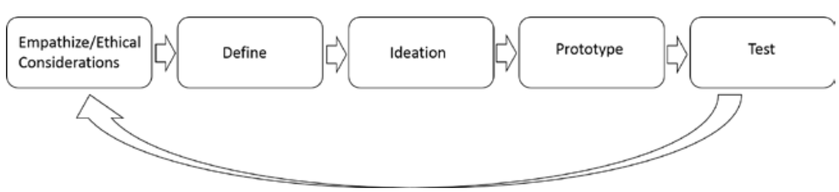


Fig. 1. Design Thinking Process.

The first step in our design thinking process is empathetic understanding and ethical consideration of the human problem being undertaken. Empathy is the process whereby the designer understands the needs, experiences, and motivations of the person(s) they are designing for (end users) and the stakeholders. Both emotional and cognitive empathy play a role in this step. Empathy can be achieved by various actions and activities. This includes observation, immersion, direct interaction with the end- users and stakeholders, reading, and storytelling [38] - [42]. Through this the designer develops a deeper understanding of the people and issues involved. Ethical consideration is a process by which the designer understands the subjective standards of behavior and the way people are treated and impacted by an action [43], [44]. Considerations include: determining who the stakeholders are and what their interests are, dialogue, if the situation could be damaging to someone, what are the obligations of the various stakeholders, and what options are there. Ethical implications can be considered from the specifics of the case, observations, readings, storytelling, documentation, and stakeholder and end user verbal descriptions.

From this step an understanding of the needs of the end users and stakeholders and the ethical implications of action/inaction help to define the problem and opportunities. During the define step problem statements are generated based on research and information gathered during the empathize and ethical consideration step. These problem statements help us to define the central issues to look for solution ideas. In the ideation step we generate ideas based on the "how might we…" problem questions developed in the definition step. There are various ideation techniques including brainstorming to generate numerous "outside of the box" ideas. The next step is taking the best ideas and prototyping them. Prototyping is a way to quickly and inexpensively look at potential problem design solutions. This step can be an iterative cycle looking at how to incorporate all the problem solutions into one design and making changes, refinements and improvements. During this phase certain ideas and prototypes fail and we learn and change direction from these experiences. The next step is to test the final prototype in the environment and obtain end users' and stakeholders' feedback. This starts the design thinking cycle over again until a viable solution is obtained.

Course Description

During fall 2017, 51 incoming honors freshmen enrolled in this one-credit course. The course met weekly for one hour and twenty minutes and required students to participate in two, 3-hour data collection field trips on Saturdays. Traditionally, this course is taught by one faculty member and serves as an introduction to college life for incoming engineering students and explains the field of engineering through textbook readings and classroom activities. However, this experimental course was collaboratively developed and taught by two faculty members in the College of Engineering and Computer Science (ECS), one faculty member from the Department of Geography in the Maxwell School of Citizenship and Public Affairs, and one teaching assistant from ECS. Multiple instructors were involved in order to engage students in a real world project. The lead instructor for the course introduced the idea and facilitated the collaboration between ECS and the Department of Geography and introduced experiential learning and design thinking into the course. He also graded reflection exercises and final projects using rubrics. The instructor from the Maxwell School facilitated and managed relationships with municipal partners, oversaw the ADA curb cut assessment activity, and worked with the partners to compile data collected by the students into a geodatabase for subsequent data analysis. The other ECS instructor handled course logistics (e.g. attendance, gradebook management, etc.) The teaching assistant helped with course logistics. All instructors attended data collection field trips.

We had four specific learning objectives for students enrolled in the course. At the completion of the course, we wanted students to be able to 1) explain contemporary infrastructure problems in urban America and recognize the role of engineers in solving them; 2) apply the design thinking process to engineering; 3) describe engineers' ethical role in tackling societal challenges; and 4) perform data collection, analysis and presentation in order to answer research questions and share research results with a professional audience. The course also emphasized critical thinking, multidisciplinary perspectives, leadership and team-based problem solving. To achieve the course learning objectives, the course focused on problems associated with an aging sewer system, generally, and the lack of local sewer infrastructure data, specifically. This course was experimental in that it introduced design thinking through an experiential learning project early in engineering students' academic careers. Traditionally, design capstone courses are offered toward the end of students' course of study after core courses and textbook competencies have been mastered. The rationale for involving freshmen in a real world experience during an introductory course was to help build an appreciation for the roles that engineers play in solving intractable challenges, and instill design thinking concepts and processes early on in students' college experiences.

From a pedagogical standpoint, we were interested in answering three questions: (i) can freshmen engineering students generate real world, actionable infrastructure data for the municipality? (ii) can students effectively use the design thinking process to engage with an engineering problem?, and (iii) can students work in multidisciplinary teams and effectively engage in a collaborative problem solving process? To answer these questions, students were tasked with prototyping data collection tools and then cataloging and assessing the conditions and locations of sewer and storm water infrastructure in the Eastwood neighborhood of Syracuse.

Students from the college's four sub-disciplines were divided into 12 multidisciplinary teams of 4-5 students. To help set the stage for the project, a municipal representative from the local water authority visited class to provide an historical overview and a synopsis of the current state of the sewer system in Syracuse. Students were encouraged to consider the frustrations experienced by neighborhood residents whose sewer systems would overflow in basements and the angst of city workers who were trying to understand and address the problem with outdated maps and a lack of data. We required students to document their reactions in journal entries. Additionally, we facilitated discussions between students and engineers from the community about the implications of a failing sewer system for the city and its residents and the ethical obligation of engineers to tackle societal challenges. Assigned readings and class discussions emphasized the ethical implications of flooding which included the loss of life and property damage. Spontaneous neighborhood engagement during data collection provided opportunities for the students to empathize with residents and understand the role of engineers in solving societal problems.

After learning about the problem and how the class could help, the students began ideating and prototyping tool design. Each team ideated a low cost prototype tool that was later used to evaluate catch basin characteristics and conditions (Fig. 2).

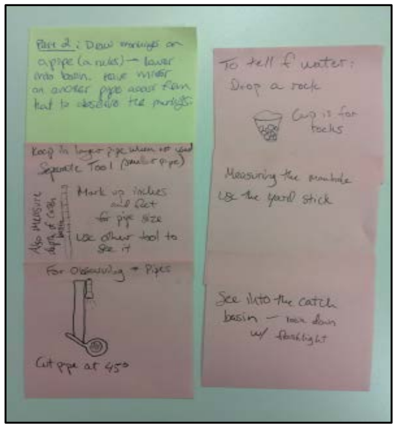


Fig. 2. Student Ideations of Prototype Tools.

Students constructed tools with pre-supplied materials consisting of flashlights, mirrors, duct tape, PVC pipes, yardsticks, binder clips, permanent markers, and colored rope. The constructed tools aided students in seeing into the catch basins to identify the number of in/out pipes, measure the diameters of the pipes, and measure the depth of catch basins. The tools were also used to measure the diameter of manhole covers, evaluate whether manhole covers were flush with the road surface, and to verify connection to the storm or sanitary sewer. Fig. 3 shows examples of prototyped tools.

Fig. 3. Student Prototype Measurement Tools.

The next phase of the course introduced students to data collection and analysis. Working with water authority officials, we designed a sewer infrastructure assessment to collect sewer infrastructure condition data. Students were also instructed in how to use high precision Global Positioning Devices (GPS) to gather location data for manholes and catch basins. The collected data would later become the foundation for the city's sewer asset management database. GPS data would replace spatially inaccurate maps made in the 1960s that approximated the locations of sewer infrastructure using original engineering records from the early 1900s. After data collection training, students collected data during two Saturday field trips in the Eastwood neighborhood. Observational data collected included overall condition ("good," "fair," or "poor.") of manhole covers and rings as well as catch basins. Students also recorded whether manhole covers were cracked and if the cover and ring were paved over. During the first field collection, students noted that the pavement surrounding a manhole was sometimes cracked or had potholes. Students decided that we should include an additional field in the data collection instrument to record the condition of the pavement surrounding infrastructure. Students also examined catch basins to note whether they were clean (empty) or full of water or organics (i.e. leaves or other debris). Each team was accompanied in the field by a class instructor and/or a municipal employee. Municipal employees were available during data collection to answer questions about the sewer system and the variables to be collected.

Each team was given the following during data collection: a map with assigned streets to survey, a Trimble or Leica GPS unit to accurately record the locations and conditions of manhole covers and catch basins, a paper guide to assess manhole cover and catch basin condition (Fig. 4 and 5), and the 1964 Mile Square Maps to help determine catch basin connections to the storm or sanitary sewers.

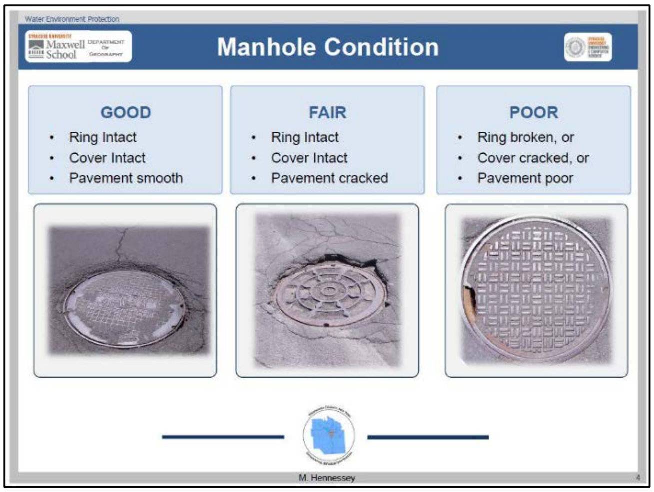
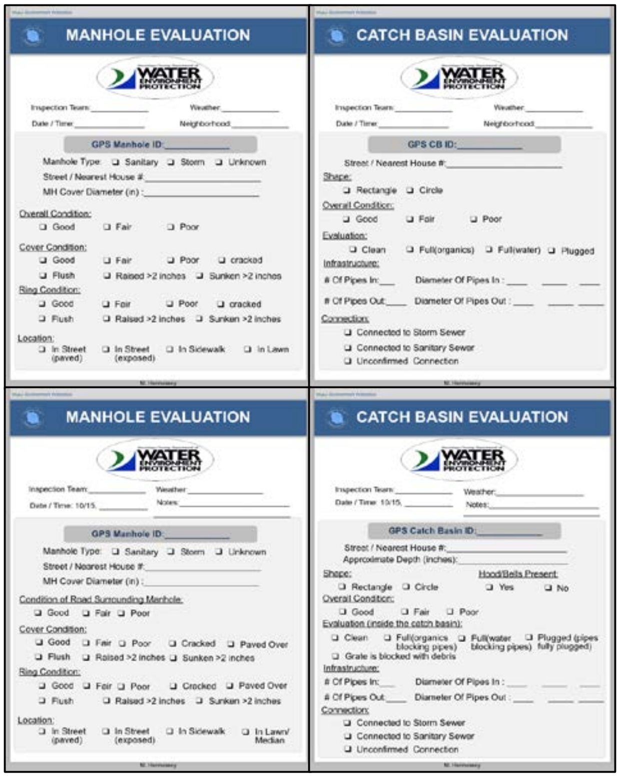


Fig. 4. Manhole Condition Assessment Guide.



MANHOLE EVALUATION

WATER ENVIRONMENT PROTECTION

Inspection Team: ____ Weather: ____
Date / Time: ____ Neighborhood: ____

GPS Manhole ID: ____

Manhole Type: ❑ Sanitary ❑ Storm ❑ Unknown
Street / Nearest House #: ____
MH Cover Diameter (in) : ____

Overall Condition:
❑ Good ❑ Fair ❑ Poor

Cover Condition:
❑ Good ❑ Fair ❑ Poor ❑ cracked
❑ Flush ❑ Raised >2 inches ❑ Sunken >2 inches

Ring Condition:
❑ Good ❑ Fair ❑ Poor ❑ cracked
❑ Flush ❑ Raised >2 inches ❑ Sunken >2 inches

Location:
❑ In Street (paved) ❑ In Street (exposed) ❑ In Sidewalk ❑ In Lawn

CATCH BASIN EVALUATION

WATER ENVIRONMENT PROTECTION

Inspection Team: ____ Weather: ____
Date / Time: ____ Neighborhood: ____

GPS CB ID: ____

Street / Nearest House #: ____

Shape:
❑ Rectangle ❑ Circle

Overall Condition:
❑ Good ❑ Fair ❑ Poor

Evaluation:
❑ Clean ❑ Full(organics) ❑ Full(water) ❑ Plugged

Infrastructure:
Of Pipes In: ____ Diameter Of Pipes In : ____ ____ ____
Of Pipes Out: ____ Diameter Of Pipes Out : ____ ____ ____

Connection:
❑ Connected to Storm Sewer
❑ Connected to Sanitary Sewer
❑ Unconfirmed Connection

MANHOLE EVALUATION

WATER ENVIRONMENT PROTECTION

Inspection Team: ____ Weather: ____
Date / Time: 10/15. ____ Notes: ____

GPS Manhole ID: ____

Manhole Type: ❑ Sanitary ❑ Storm ❑ Unknown
Street / Nearest House #: ____
MH Cover Diameter (in) : ____

Condition of Road Surrounding Manhole:
❑ Good ❑ Fair ❑ Poor

Cover Condition:
❑ Good ❑ Fair ❑ Poor ❑ Cracked ❑ Paved Over
❑ Flush ❑ Raised >2 inches ❑ Sunken >2 inches

Ring Condition:
❑ Good ❑ Fair ❑ Poor ❑ Cracked ❑ Paved Over
❑ Flush ❑ Raised >2 inches ❑ Sunken >2 inches

Location:
❑ In Street (paved) ❑ In Street (exposed) ❑ In Sidewalk ❑ In Lawn/ Median

CATCH BASIN EVALUATION

WATER ENVIRONMENT PROTECTION

Inspection Team: ____ Weather: ____
Date / Time: 10/15. ____ Notes: ____

GPS Catch Basin ID: ____

Street / Nearest House #: ____
Approximate Depth (inches): ____

Shape:
❑ Rectangle ❑ Circle

Hood/Bells Present:
❑ Yes ❑ No

Overall Condition:
❑ Good ❑ Fair ❑ Poor

Evaluation (inside the catch basin):
❑ Clean ❑ Full(organics blocking pipes) ❑ Full(water blocking pipes) ❑ Plugged (pipes fully plugged)
❑ Grate is blocked with debris

Infrastructure:
Of Pipes In: ____ Diameter Of Pipes In : ____ ____ ____
Of Pipes Out: ____ Diameter Of Pipes Out : ____ ____ ____

Connection:
❑ Connected to Storm Sewer
❑ Connected to Sanitary Sewer
❑ Unconfirmed Connection

Fig. 5. Manhole Cover and Catch Basin Evaluation Forms.

The GPS units were pre-programmed with data collection fields that more or less mirrored the paper-based data collection forms. At least one student was assigned the role of handling the GPS, another student completed the paper evaluation forms, and the remaining students made observations and measurements using their prototyped tools. Fig. 6 shows one of the teams performing data collection in the field.

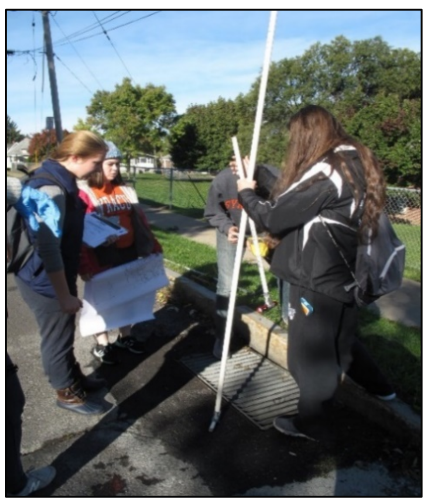


Fig. 6. A Team of Students in the Field.

After the first data collection day, students participated in in-class reflections to discuss what they learned. Teams also assessed the functionality of their prototype measurement tools, the data collection process, and the dynamics of their team. Students had the opportunity to iterate their tool design for use on the second data collection day as well change the data collection forms and roles of their team members. Interactions between students and residents of the neighborhood were also discussed as part of the data collection process reflection. While collecting data, students were approached by residents who were curious about their activity in the neighborhood. Interactions with neighbors compelled students to articulate the goals of our work and to hear resident feedback firsthand. During class reflections after the first day of data collection, one student team related their encounter with a neighborhood resident while inspecting a catch basin in his front yard. The resident told the students that every time it rained, his lawn and basement flooded. After inspecting the catch basin, the students explained to the resident that it was because the catch basin had no outtake pipes, or pipes that drain collected water into the storm drain system. These types of interactions provided students opportunities to empathize with neighborhood residents and understand the role of engineers in positively impacting people's lives. They also demonstrated that they could articulate the problem and explain the need for data collection and analysis in solving the problem.

Students also suggested changes to the data collection instruments that the county had created. Once in the field, many students found that terms such as “full” and “condition” could be subjective. In response, the data collection forms as well as corresponding GPS fields were revised before the second field day. The ability to reflect on the data collection experience and to redesign data collection tools provided students a tangible opportunity to learn about the iterative nature of design thinking, data collection and research,.

After location and condition data were collected, the GIS Analyst from the county agency and the course’s co-instructor from the Geography Department downloaded GPS data into a GIS database. Using the 1964 Mile Square Maps, sewer connection information (i.e. storm, sanitary or combined) collected by the students was verified. Data inputted into the GPS units was also cross referenced with hand-written data collection forms. When GPS data fields were missing, the hand-written forms were used to fill in missing data.

One of the co-instructors from ECS then provided an overview on data analysis and visualization. Using the dataset generated from observations and GPS measurements, each student team produced a written report which discussed the design process and included data analysis, observations, and recommendations. After receiving feedback, student teams created professional posters and presented them to an audience of city officials and guests from the College of Engineering and Computer Science, Department of Geography, and honors program.

Results of Student Data Collection and Analysis

With guidance from municipal sewer crews and course instructors, and working in small teams, student teams gathered sewer infrastructure location and condition data street by street. Table 1 summarizes catch basin characteristic data collected by the students including overall condition (structural integrity of basin), cleanliness (i.e. full of organics or water), the presence of 5-6 inch pipes, and the presence of hoods/bells.

TABLE I
Summary of Catch Basin Evaluation Data

Condition of Surrounding Pavement (second day only)	Number of Observations
Total Observations	83
Poor	10
Cover Condition	
Total Observations	362
Poor	23
Cracked	15
Paved over	63
Sunken/Raised	39
Ring Condition	
Total Observations	378
Poor	23
Cracked	13
Paved over	63
Sunken/Raised	34

There were 453 catch basins evaluated across both field collection days. Out of the total evaluated, 147 (roughly 30%) catch basins were deemed to be "full" and possibly clogged. Table 2 shows pertinent manhole cover and ring characteristic data from both field collection days.

TABLE II
Summary of Manhole Cover Evaluation Data

Total Observations	83
Poor	10
Cover Condition	
Total Observations	362
Poor	23
Cracked	15
Paved over	63
Sunken/Raised	39
Ring Condition	
Total Observations	378
Poor	23
Cracked	13
Paved over	63
Sunken/Raised	34

The ring and cover conditions are shown separately with each category consisting of the number of rings/covers that were in poor condition, cracked, paved over, and sunken or raised two inches relative to the surrounding pavement. There were 362 manhole covers evaluated across both field collection days. Approximately 23 of them were in "poor condition" (less than 10%), 15 were cracked (less than 5%), 63 were paved over (roughly 17%), and 39 were sunken or raised two inches relative to the surrounding pavement (about 10%). The student teams then analyzed the data and produced graphs typical of those shown in Fig. 7 and 8.

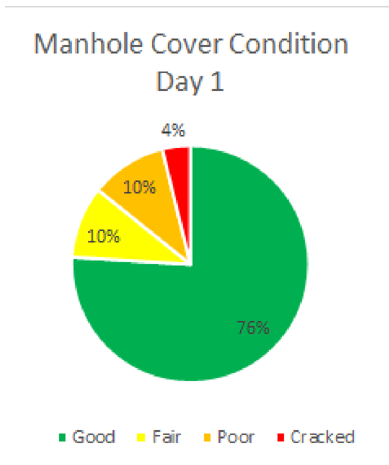


Fig. 7. Manhole Cover Conditions Day 1.

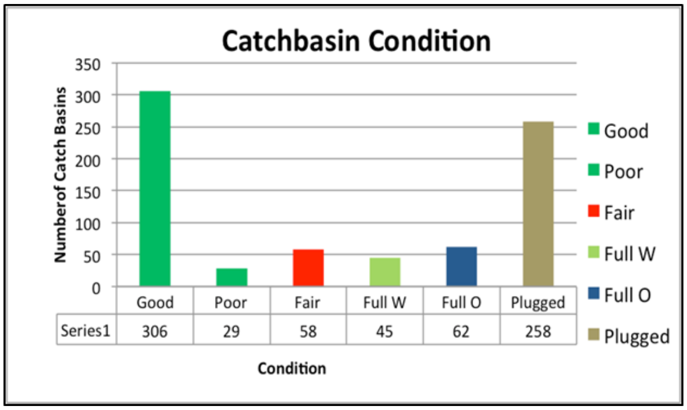


Fig. 8. Catch Basin Conditions.

All the student teams wrote a research paper in which they described the problem, discussed the design method and analyzed the collected data. A map showing catch basin locations and their condition is shown in Fig. 9.

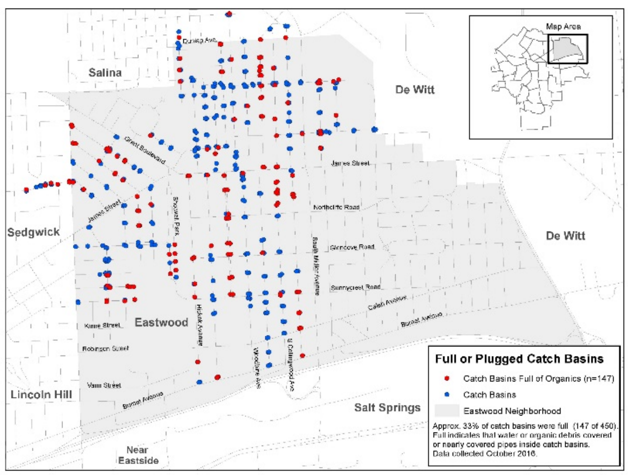


Fig. 9. GIS Map Showing the Locations of Mapped Catch Basins (all dots) with those that were Full (red dots).

Course Outcomes

To assess whether students achieved the course learning objectives, we evaluated students' individual journal entries, prototype tools, team reflection guides, and final written reports and oral presentations. The rubric for prototype tools included functionality and sturdiness. The rubric for data collection assessed whether students collected all possible observational data and accurately entered collected field data in Excel. Assessment of the report and presentation evaluated whether student teams effectively analyzed the data, produced meaningful data visualizations, and cogently presented the data, their findings and recommendations in writing and orally. We also observed reflection discussions in class and in the field. During these discussions, we observed students demonstrating their understanding of learning objectives 1 and

3 as described above. Evaluations of their prototyping, reports and presentations suggest that students demonstrated comprehension of learning objectives 2 and 4.

At the completion of the class, we conducted an open-ended, qualitative assessment to gain feedback on students' attitudes about the class and experiential learning components. The summative evaluation asked seven questions:

1) What aspects of this course did you find most interesting?
2) How did this course enhance your ability to work in teams?
3) How useful were the hands-on learning activities?
4) How did this course enhance your professional skills (ability to communicate, write reports, etc.)?
5) Do you feel that you contributed something beneficial to the local community in this course? If so, how?
6) If one of your friends was considering this course, would you suggest him or her to enroll? Why or why not?
7) What changes would you suggest if this course is offered in the future?

Students were also given the opportunity to provide additional comments and feedback.

Because this was an experimental course, we were interested to gather in-depth feedback from the students about what resonated with them and what did not. Qualitative evaluation is increasingly recognized by engineers who study the scholarship of teaching in engineering as an effective way to measure learning outcomes. For example, Leydens, et al. state that "quantitative results are limited in that they provide numerical descriptions rather than detailed accounts and generally provide less elaborate accounts of human perceptions or motivations than do qualitative findings." [45] With our class evaluation, we were interested to gain more "thick description" of student attitudes. We did not collect generalizable, quantitative student evaluation data but instead, we collected qualitative data that could help identify ways in which we could refine the course based on student feedback.

The experiential nature of the course, the design thinking process, working in teams across departments, and the ability to contribute to a real world challenge were among the aspects of the course that students appreciated most. Most of the 51 students in the course expressed an appreciation for the opportunity to engage in a real world project. Many students also expressed their enthusiasm for learning the design process starting with empathizing with the residents and using ideation, prototyping, testing and iteration. Working in teams and collaborating with city engineers and "learning about the city and how the infrastructure was developed" also appealed to students. They felt that it was "eye opening" to get out into the community and rewarding to lend a hand to important work in the city. In addition, students were able to find a sense of self-value in the fact that as future engineers they can serve a vital role in solving complex community challenges. One student expressed feeling "valued as a student that I possess enough knowledge to be a part of solving such a big issue".

With regard to students' opinions about the design process, many expressed appreciation that the course allowed them to iterate their prototype designs. Students found it beneficial to learn about “how many steps went into designing our tool and collecting data”. They also shared perspectives on team work. One student reflected that the teamwork experience would be helpful professional preparation, “[the class] had us put in teams with new people, which is something we’ll have to do for our jobs”, and “every part of the project you had to rely on team members, especially when collecting data- team communication was important”.

As stated, an important goal of this course was to encourage students to empathize with end users and consider the ethical imperatives of engineers to engage with societal problems. Students indicated their empathy through statements like “work may save a citizen from dealing with the property damage associated with flooding”. Students reported “seeing what the community deals with” and “bad infrastructure is a life/death situation and by updating this poor infrastructure, we are saving lives”. They saw their role as “using our engineering knowledge to positively impact the community” and helping “by preventing future flooding”. Students also reported in the field that “as we collected data, many residents thanked us for our work” and the positive impact of “collaboration and interactions with the community”.

A final goal was for students to learn to collect and analyze data in order to answer research questions and to present findings and actionable data to a professional audience. Students reported that the course provided “real life experience and we had to work hard because the City is using this data” and “our info will help city workers locate problem areas and better understand system connections”. Students indicated the benefit of “going out into the field and collecting our own data as opposed to just reading from a textbook” and “actually being able to be in the field and collect the data in person”. Students reported positive learning outcomes in analyzing data: “it familiarized me with excel and the process of creating graphs from datasets” and “taught how to properly compose graphs, charts, reports, and posters”. They also report increased capabilities in communication skills: “it helped me a lot in writing reports and to be able to communicate our ideas to others”.

Students also expressed some concerns with the class. Several students expressed frustration that the class project privileged a civil engineering problem and that it was less relevant to their own anticipated field of study. Some thought there should be more autonomy in choosing projects. Many students complained about the large volume of work (in relation to the single credit they received) and the inconvenient scheduling of mandatory data collection on Saturdays. If this class is offered again, it is more appropriate as a 3-credit course. A small number of students described the classwork or learning objectives as busywork, or “free labor”.

Reflection and Discussion

It is important to acknowledge that this was an experimental class. There were many important lessons learned and positive outcomes. Yet, there were challenges:

- 1-credit course not enough time; some students felt overtaxed and we felt it wasn’t adequate time to explore issues in depth
- Multidisciplinary teams were useful in developing rapport between students who may interact little in college but some students who were not interested in civil engineering felt the class didn’t expose them to their specific sub-field

- Getting students from all the departments to understand the universality of the design process and skill sets they were learning
- While the GPS data that the students collected was useful, there were too many errors and subjectivities with the condition data to make meaningful conclusions about where there might be infrastructure problems. That said, the process of organizing teams to collect infrastructure data in the field provided valuable insight into the data collection process that the city would need to undertake for the entire city.
- While we feel that it is advantageous to engage students in experiential learning early and regularly, freshman students may not be ready to undertake such an extensive project. That said, the students demonstrated professionalism and a willingness to work hard.

Overall, this course demonstrates how experiential learning and design thinking can be integrated into engineering curriculum beginning in students' freshman year. Assessments, student reflections and course evaluations indicate that the learning objectives of the course were largely achieved. Students acquired both hard skills and soft skills such as empathy and an ability to articulate ethical obligations of engineering professionals to society at-large. The majority of students reported positive outcomes as related to learning about a real-world contemporary infrastructure problem and understanding the role of engineers in solving it; engaging in design thinking approach to engineering; working in multidisciplinary collaborative teams; empathizing with end users; learning to collect and analyze data in order to answer research questions; and presenting findings and actionable data to professional partners.

Implications for the City of Syracuse

Overall, the data collected was useful in piloting a data collection protocol for Syracuse's sewer infrastructure. The short term implications for the city from this university-city collaborative project include improved manhole and catch basin location data in the study area. The GPS data collected by students were used to update approximate locations in the county's sewer system GIS database. The GIS database was also updated to include information on whether catch basins are combined or separated. The condition assessment data collected by students was less useful, however. In hindsight, the condition assessment criteria left too much room for subjective interpretation. Although the condition data collected by students was not deemed reliable, the data collection protocols developed for the class will guide the city's efforts to collect accurate and up-to-date information on sewer infrastructure location and condition. As the city begins to explore options for how to efficiently and cost effectively collect these data, this project helped to illuminate challenges and opportunities for engaging university students or another third party (such as a workforce development program for youth) in data collection. From the current study, the city now has a better sense of how long it will take, how much human power is necessary, and what condition information is necessary.

Conclusions and Future Research

Engineering students need real world experiences early in their educational careers to serve as a foundation upon which they can apply their subsequent theoretical education. It is helpful to front-load experiential learning (as opposed to tacking it on at the end of their educational careers) so that students go into their four year program with a tangible example of the roles that engineers play. Further, we argue that experiential education that incorporates real world problem solving can also benefit society at large. Cities like Syracuse that have experienced population loss and resultant declines in revenue to maintain their infrastructure could use assistance in gathering and analyzing data so that they can prioritize their limited resources. Cities across the US are confronting challenges associated with aging and failing infrastructure as well as limited resources to deal with aging infrastructure efficiently and effectively. Therefore, this is a widespread and tangible engineering problem that provides an opportunity to engage students in ways that will benefit their learning and that will benefit the city's operations. Furthermore we believe that these types of learning experiences need to be embedded throughout the students’ multiyear curriculum.

Our engineering students come from diverse backgrounds and social norms. It is paramount we embrace a more holistic view of engineering curriculum that emphasizes both the traditional core curriculum and so called soft skills. A main motivation for initiating this class was to provide an experiential learning opportunity that would introduce students to a design process that starts with empathy and ethics.

This was a pilot course and further outcome data could be obtained by using survey assessments of the students who participated through their senior year to determine whether this course experience had a sustained impact. While we believe this type of course is critical in helping students learn skill sets necessary for engineering careers, educators face significant institutional challenges when integrating experiential learning with traditional pedagogies. Further work is needed to achieve acceptance and institutionalization for experiential learning pedagogies within existing engineering educational frameworks. This type of collaboration across colleges and schools and outside entities also requires universities and colleges to support and value educators who take on the logistical and institutional challenges associated with providing students with this type of real world learning experience. It also requires bold visionary leadership to activate change at institutions which embrace more traditionally rooted pedagogical philosophies. Future research could also consider the leadership shifts in emerging engineering education institutions occurring outside the United States.

The implications of this course are that there are mutually beneficial partnerships that could be formed between engineering colleges and municipalities across the country looking at aging infrastructure. These partnerships have the potential to engage students in experiential learning opportunities about the challenging engineering problem we face in the 21st century. These experiential learning courses tied with a robust design process can have a powerful impact on how successfully they will face our societal problems.

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