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Using design thinking to solve a local environmental problem in the context of a university civil engineering course - an intrinsic case study

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ABSTRACT: Engineers are called upon to solve complex technical problems, including environmental problems. For example, the most current climate research suggests that changes to our climate will require people worldwide to adapt in the face of growing environmental problems like drought, food shortages, flooding and water contamination, to name but a few. Does the conventional approach to engineering produce the best possible solutions in the face of such complex problems? Can design thinking lead to better solutions to such problems, especially from a civil engineering perspective? This article presents results from an exploratory case study, where civil engineering students looked to solve a local water contamination problem. Two groups of civil engineering students were compared as they attempted to solve the same environmental problem, one group using the conventional technical-based approach, the other using the more innovative design thinking approach. The study revealed that students who used a design thinking approach seemed to be more competent at finding creative and feasible solutions than their counterparts, focusing more on the needs of the user. The study also offers a comparative view of the overall problem-solving experience in both groups, making the case that future engineers should be taught design thinking as an alternative strategy for solving problems.

Keywords: Design thinking, case study, civil engineering, environmental problems

INTRODUCTION

The present study is part of a larger research project on the application of design thinking as an approach to finding creative and sustainable solutions to environmental problems. Three case studies in total were conducted in 2018-2019 on separate Canadian university campuses. The main objective was to study how Canadian students used design thinking as an applied approach to environmental and social problem solving. This article presents results from one of these three cases, specifically the case of civil engineering students from the Université de Moncton, New Brunswick, Canada, who attempted to find creative solutions to a local water contamination issue using either the conventional conceptual procedure, or a more innovative design thinking approach.

In their profession, engineers are regularly confronted with complex technical problems. More and more, problems engineers are facing are environmental in nature, given the growingly current fragile ecological climate. As they attempt to design applicable solutions to such problems, they should consider the impacts of their decisions on citizens. Focusing on the user is precisely at the heart of what is still a novel, yet increasingly popular approach in engineering circles: design thinking. As an iterative approach, which is simultaneously inductive, deductive and abductive, design thinking focuses inherently on the needs of users (i.e. citizens of a given community), while remaining practical and flexible in terms of trial and error [1].

Essentially creative and analytical in its outlook on innovation and problem solving, design thinking consolidates a range of concepts from the fields of engineering, social sciences, design, business and the arts [2]. Design thinking can also be considered as a manifestation of *collective intelligence*, whereby important consideration is given to the human being, to his or her behaviours and needs, and wherein creativity among participating problem solvers frequently challenges previously suggested solutions [1]. In fact, working within a rigorous framework and using well-defined tools, while fluctuating between divergence and convergence, design thinkers tend to use both creative and analytical modes of reasoning [3]. Moreover, throughout its process, designer intuition plays a significant role, experimentation happens rapidly and involves users, multiple solutions are generated, and failure is seen as a learning opportunity [4].

A problem-solving process, which is centred around concrete needs, creativity and innovation seems well tailored, as an approach, to solving the many environmental problems of current times. From the perspective of civil engineering, where solutions to any problem, including an environmental problem, are often mainly technical in nature, design thinking opens the door to a more meaningful contribution in terms of solutions that are based on user input and practical needs. This exploratory case study looks to compare the learning experiences of two groups of civil engineering students tasked with proposing solutions to a local water contamination issue. The general objective was to study the potential of design thinking for the field of engineering, especially regarding to environmental problem solving. Specifically, the present article examines the processes of problem solving, both from the largely technical approach commonly used by engineers today and from the more user-based design thinking approach.

THEORETICAL FRAMEWORK

Design thinking is a rigorous process of problem solving that focuses on understanding the goals, experiences and constraints of the people affected by a given problem. As it compares to traditional scientific investigation, design thinking concerns itself as much with the problem as it does with the solution [1]. In the problem space, importance is given to defining the problem according to the experience, point of view and contextual situation of the user. The problem solver spends a lot of time observing the situational context of the problem, as well as the behaviour of users *in situ*. This is expected to lead to deeper insight into the problem on the part of the problem solver. In the solution space, solvers explore a multitude of solution leads by developing alternative plans and shaping a variety of possible prototypes. Prototypes made quickly and without regard to perfection act as *playgrounds* for discussing and learning about certain solutions [3]. Thus, the problem and the solutions tend to co-evolve in constant interaction. In other words, design thinking happens in specific, yet non-linear stages, where back-and-forth actions (or iterations) intersect, with the ultimate intent of affecting transformative change. Inspired by leading models on design thinking, Figure 1 represents this very juxtaposition of design thinking's six main steps [5][6].

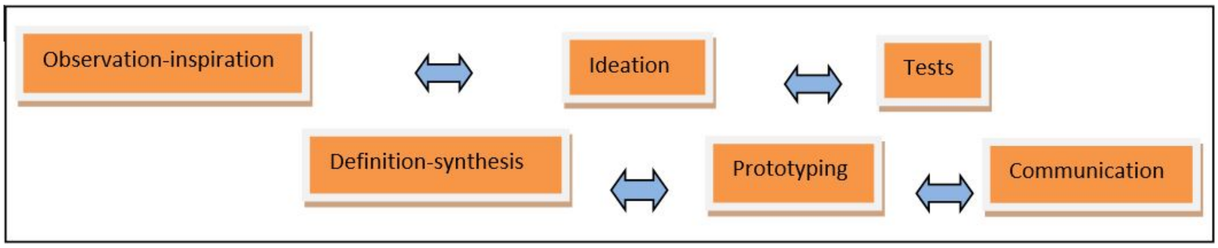

Figure 1: The steps of design thinking.

The six steps of the design thinking process are listed as follows [5]:

1. Observation-inspiration: an ethnographic survey is conducted, while demonstrating empathy for the people affected by the issue (the users), as well as for the problem they are experiencing. Users are observed daily to gain insight into their aspirations and needs.
2. Definition-synthesis: the problem is thoroughly defined and redefined through an iterative process. The goal is to learn information and gain insight into various perspectives surrounding the issue. The information is briefly summarised in order to present the problem succinctly. This visualisation of the concepts involved directs the problem solvers towards a common mutually understood goal.
3. Ideation: many ideas are proposed and some of them are retained, while others are discarded.
4. Prototyping: prototypes are quickly built to emphasise the different ideas that have been generated, and these prototypes are shared with others in order to assess their implementation potential.
5. Tests: prototypes are evaluated by collecting opinions from users as well as experts on the problem at hand and winning prototypes are then refined [6].
6. Communication: the developed solution (or product) is revealed.

Design thinking as a process for solving environmental problems differs from the typical civil engineering strategy, which is, as previously mentioned, primarily technical and based largely on steps more akin to scientific investigation. The typical engineering approach lacks the empathetic quality of design thinking. The Order of Engineers of Québec describes the engineering approach to problem-solving as being comprised of the following steps [7]:

1. Evaluation of the client's need.
2. Development of several concepts to find an optimal solution that meets the client need.
3. Preliminary design based on optimisation of the design parameters.
4. Detailed design containing all the technical specifications.
5. Synthesis including cost estimates and final documentation.

According to experts in solution design processes, design thinking can lead civil engineers to more creative problem-solving [8]. In fact, one of the biggest pitfalls civil engineers face, while problem-solving is working within self-imposed constraints [8]. Furthermore, to inspire truly innovative solutions to complex problems, civil engineers must …*disrupt conventional ways of thinking and take on a more human-centred approach* [8]. This statement is very much aligned with design thinking.

Notwithstanding the complexity of environmental problems facing humanity today, day-to-day living is becoming more and more complex due to the current context of globalisation and rapid technological progress. Because of this growing complexity, artistic, linguistic, mathematical and scientific skills no longer suffice to enable today's youth to reach their full potential and, ideally, develop the skills needed to solve the complex environmental problems they will inherit from previous generations. For them to become active and connected citizens of the world, all the while taking part in the building of sustainable societies that are sensitive to human and environmental issues, learners today must acquire a multitude of competencies, most of which are part of the 21st Century skills framework [6]. These skills include problem-solving through innovation, collaboration, communication and creativity [1]. The iterative and encompassing process of design thinking effectively requires the use of several competencies; therefore, this approach has the potential to develop many of the 21st Century skills currently sought by employers in a wide range of industrial sectors [1].

METHODOLOGY

The methodological approach guiding the present study is rooted in the qualitative research paradigm. It is exploratory in nature and follows an instrumental case study design [9]. More specifically, the case studied was that of civil engineering students using design thinking as an approach for solving a local environmental problem. The present case study also contributes significantly to the body of research in civil engineering and represents an opportunity to examine and document a relatively understudied phenomenon in the field; namely, that of using design thinking to solve complex engineering problems [10].

The study followed students from the Water Treatment class of the Université de Moncton's (Canada) civil engineering programme over their four-month 2019 semester. They were tasked with solving a water quality problem in a nearby rural community, where the water supply contains a higher than normal concentration of arsenic. The class of 17 students was randomly divided into two distinct groups, one using typical engineering problem-solving strategies ($n = 8$) and the other using a design thinking approach ($n = 9$). In a qualitative inquiry, it is the quality of the data rather than the quantity that usually determines the number of research participants. In this case study, no sampling was necessary as there was only one class on water treatment and the entirety of enrolled students ($N = 17$) participated in the study. By conducting collective interviews with one of two smaller study sub-groups, the methodology is in line with the recommendations that a focus group interview should consist of between six and 12 participants [11].

Data was collected over four months, through semi-directed group interviews at every step of both problem-solving approaches. The instructor and core searcher also kept a research journal, in which observations and continued analytical thoughts were recorded for each group over the entire experimentation period. Finally, a research assistant was present during all stages, for both groups, and recorded his observations specific to competencies demonstrated by students during problem-solving. By collecting and analysing data from multiple sources (i.e. various collection tools or techniques), the reliability of the study results is enhanced through triangulation [12][13].

Thematic content analysis was applied to transcribed interviews in order to decode participants' answers and build a comparative picture of environmental problem-solving outlooks and strategies for both groups. Observations from research journaling, done throughout the study, served as corroborative data. Thematic analysis is a qualitative analytical process whereby patterns or themes are identified within qualitative data. More specifically, the researcher develops codes, words or phrases that serve as labels for sections of data, ultimately leading to identification of emergent themes [14]. As expected in all research with individuals from the public, ethical procedures are required. It should be mentioned that the appropriate ethical clearance for this study was secured through the University's Research Ethics Committee.

A semi-structured interview questionnaire was comprised of five main questions, which served to guide group discussions, without strictly directing responses. By asking the same five launch questions at every stage interview (there was a separate interview at each of the four studied stages for both groups), a comprehensive comparative picture of participating students' experiences was established using their respective approach to problem-solving. Due to logistic and time considerations, the present study focused on the first four steps of the design thinking approach, comparing them to the corresponding first four steps of the typical technical approach used in civil engineering. Here are the questions asked at each stage of the study, for both the design thinking group and the typical approach group:

1. What have you learned from your experience during this stage of the problem-solving procedure?
2. What have you learned about your own problem-solving abilities during this stage?
3. What challenges did you encounter during this stage and how did you overcome them?
4. What are the positive aspects or strong points of this stage, in your experience?
5. Which personal or collective competencies did you leverage during this stage?

RESULTS AND DISCUSSION

Table 1 presents a breakdown of the different themes that emerged from thematic content analysis of collective interview responses, organised according to the questions asked at each stage of the problem-solving process as experienced by each participating group.

Table 1: Main themes identified through content analysis of interview responses

Questions	Stages	Emergent themes	
		Typical engineering approach group	Design thinking approach group
[Q1 and Q2] What have you learned from your experience during this stage?	1	- Defining the problem takes time. - Tendency to go directly to a solution.	- Requires adaptability and open mind. - Importance of empathising with users.
	2	- Many difficult concepts to learn. - Hard to associate them to solutions.	- Solutions will be better since they will come from expressed user needs.
	3	- Rather quick stage. - Find the solution to fit the concepts.	- Multiple solutions are generated. - Solutions can be non-technical. - Imagination plays a big role.
	4	- Relatively simple stage. - Important to pay attention to detail.	- It is important to validate solution ideas with users (simple vocabulary). - Validation process can take time.
[Q3] What challenges did you encounter during this stage and how did you overcome them?	1	- Lots of information to process. - Many terms and concepts to learn.	- Consulting the user takes time. - Lots of logistic considerations.
	2	- Understanding the many technical concepts involved takes time.	- Managing the information (concepts and consultations) takes time.
	3	- Finding written documentation to support concepts integration.	- Being open to original solution ideas. - Respecting user input (needs).
	4	- Environmental problems can require solutions not usually seen.	- It takes time to produce various prototypes and solution models.
[Q4] What are the positive aspects or strong points of this stage, in your experience?	1	- Analysing technical needs helps to better define the problem.	- Inspiration for solutions comes from user needs and concerns.
	2	- The problem becomes clearer with more research on concepts.	- Easier to define the problem after consulting users.
	3	- Offers opportunity to use *AutoCAD* and other technical tools.	- Leads to a diversity of solutions. - Leads to better solutions, which were based on real needs.
	4	- The concept-driven solution can be produced rather quickly.	- Ideas came from actual user input. - Solutions will likely be more feasible.
[Q5] Which personal or collective competencies did you leverage during this stage?	1	- Collaboration; task management; communication (mostly written)	- Collaboration; adaptability; communication (interpersonal)
	2	- Collaboration; research; communication (interpersonal).	- Organisation; communication (interpersonal).
	3	- Analysis; critical thought; communication (written)	- Creativity (imagination); innovation; perseverance.
	4	- Communication (written and interpersonal).	- Communication (written and interpersonal); critical thought.

Data collected from the end of stage group interviews and *in situ* observation reveals that civil engineering students who used design thinking to solve the given environmental problem seemed to find more creative solutions than their counterparts. This finding of more creative solutions is based on indicators for creativity used in other research related to 21st Century competency development [15].

Creativity is an essential skill based on expected engineering competency, as well as on the impact of engineering on society and on the environment [16][17]. More specifically, creativity was flagged as a competency in students who demonstrated indicators like originality, open-mindedness, flexibility and divergent thinking. That design thinking students came up with more creative solutions echoes findings from numerous studies, which have highlighted the positive effects of design thinking on creativity [18][19].

In contrast to the habitual technical solution found by the *typical engineering approach* group (for example, one team simply proposed to share with the users various water filters technology already in available in stores), the *design thinking* group came up with solutions, which not only accounted for the resident's concerns and needs, but also involved consultation with municipal and regional authorities.

Furthermore, the solutions proposed through a design thinking process of problem-solving were more feasible, according to the course professor. This was likely due to the solutions from design thinking being more actively based on the needs expressed by the users. In other words, having invested more time talking with the citizens of the affected community in the early stages of their problem-solving process, the design thinking group likely gained deeper insight into the needs of the people. Still regarding competencies in both groups of students, students from the *typical engineering approach* group tended to be more calculated and analytical, while the *design thinking approach* group showed more of an inclination towards innovation and adaptability. Finally, despite these noted differences, both groups did share some demonstrated competencies in their respective approaches (see Q5 in Table 1); namely, collaboration and communication (written and interpersonal).

Aside from examining the demonstrated competencies in both study groups, the study aimed to better understand the problem-solving experience in each group by comparing them in terms of their perceived learning experience (Q1 and Q2), the challenges they encountered in solving the given problem according to their assigned approach (Q3) and the positive aspects of their assigned approach (Q4).

As one would expect, during interviews at the end of each procedural stage, the *typical engineering approach* group spoke of their experience as being rather familiar, since they essentially applied an already established approach. Throughout the stages of problem-solving, these students shared that they tended to focus on the most logical solutions from the outset, spending more time on the early stage of defining and researching the principle theoretical concepts associated with the problem than on later stages of solution testing.

On the other hand, students from the *design thinking approach* group described their experience somewhat differently, allocating more time in the early stages on understanding the problem from the user's perspective. This meant that they invested more time not on initial conceptual research around a quickly generated technical solution idea, but on interviewing the users and defining the problem according to the needs of these users, thus welcoming a variety of more practical and imaginative solution ideas. In fact, students from the design thinking group shared that most of their time was spent on interacting with the users (i.e. interviewing users and validating solution ideas with them in the *prototyping* stage). These students also mentioned that their problem-solving experience through design thinking required them to be more imaginative and open-minded, leading to the production of more solution ideas than they were used to, including non-technical ideas.

When asked about the challenges each group faced during the problem-solving process, the answers were, again, quite different. The *typical engineering* group seemed to find it difficult to identify and research the underlying theoretical concepts associated with the few solution ideas they themselves generated early in the process, struggling with the scope and depth of the technical information they were uncovering. As for the *design thinking* group, challenges seemed to be related to the allocation of time. More specifically, these students found it difficult to manage the time needed for user interviews during the *observation-inspiration* stage and for follow-up meetings at the *prototyping* stage. They also mentioned that it was difficult, at least initially, to consider more original solution ideas, including non-technical ones.

Finally, when asked to specify the positive aspects of their problem-solving experience, the answers from each group differed again, mostly in terms of the ways in which they defined the problem and the impetus behind generated solutions. Consistent with results from other interview questions, the *typical engineering* group spoke to what was most familiar to them as a result of their training, that concept-driven solutions are more quickly generated, research helps to define the problem and technical solutions offer opportunities to use technical tools, such as *AutoCAD*.

For their part, the *design thinking* group spoke of the problem as easier to define through user consultation, a step which led to a better understanding of the needs and concerns of those directly affected by the problem. Most interestingly, the students from this group mentioned that design thinking led them to generate more ideas and, ultimately, to produce more diverse solution possibilities which, for the most part, were more feasible and based on real needs.

CONCLUSIONS

The lessons learned from this intrinsic case study can be applied to engineering education in general, offering insight into design thinking as an alternative approach to solving environmental problems, as well as other problems related to civil engineering. As shown by the study results, engineering students who use design thinking to solve environmental problems can find it challenging to collect the users' input during the problem-solving process (e.g. interviewing users, travelling to multiple users' homes, etc); however, these same students also revealed that they found the solutions generated from the users' concerns and needs were more diverse (even giving way to non-technical solution ideas), more imaginative and more feasible.

Indeed, students who used design thinking to solve the given environmental problem demonstrated more creativity in their approach to solutions, as indicated by their propensity for divergent thought, open-mindedness and adaptability, all characteristics observed *in situ* and corroborated during the end of stage group interviews.

It should also be mentioned that the professor grading the final solutions also confirmed a higher degree of creativity in the design thinking group's work, adding to a triangulation of results in terms of data collection strategies. These same students also shared an appreciation for design thinking's focus on the users' needs, something that is not as prevalent in the typical approach to problem-solving in their training as engineers. They particularly liked the way in which working more closely with the users guided their solution ideation and contributed to a more tailored and imaginative solution.

Finally, based on the study results, using design thinking more widely as an approach to problem-solving in civil engineering, especially as it relates to environmental problems, can lead to more innovative solutions to problems that are typically difficult to address given their complexity and scope. Lastly, since results from this study are qualitative and exploratory in nature, more research is warranted.

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BIOGRAPHIES

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