EXPLORING STAKEHOLDER MAPPING AS A TOOL TO SUPPORT STUDENT INCORPORATION OF STAKEHOLDER NEEDS IN A SENIOR UNDERGRADUATE MECHANICAL ENGINEERING CAPSTONE COURSE

by

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Dalhousie University is located in Mi'kma'ki,
the ancestral and unceded territory of the Mi'kmaq.
We are all Treaty people.

For Gavin, who always pushes me to do my best.

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ABSTRACT

In this thesis I present a novel method for integrating and assessing stakeholder mapping, a design thinking tool aimed at developing comprehensive understandings of problem contexts, within a capstone setting. This work responds to calls within engineering design education to better prepare engineering graduates for success in industry, where technical skills must be combined with professional capabilities such as communication, teamwork, and problem solving. Within this dialogue, design thinking is often presented as a means by which to facilitate student design capabilities, however empirical evidence linking specific design thinking strategies and positive student outcomes is lacking.

Stakeholder mapping assignments were designed and integrated into a year-long mechanical engineering capstone course held at Dalhousie University in the 2020-2021 academic year. Specific data collection tools, aimed at measuring capstone client satisfaction, and students' conceptions of design, were also employed, and interviews with students were completed. While low levels of participation precluded the analysis of student-created maps and limited the conclusions that could be drawn from available data, the basic efficacy of the selected tools and analysis techniques in differentiating between stakeholder maps, student's conceptions of design, and various levels of client satisfaction is supported by the data collected. Recommendations for future iterations of the study are presented based on this preliminary data gathering and on student opinions collected from interviews. Planned future studies will contribute to conversations regarding the informed use of design thinking tools in supporting engineering students in developing design skills necessary for success in industry.

LIST OF ABBREVIATIONS USED

Asgmt(s)	Assignment(s)
COD	Conceptions of Design
CSQ	Client Satisfaction Questionnaire
DT	Design Thinking
F	Fall 2020 Instance of COD Survey
W1	First Winter 2021 Instance of COD Survey
W2	Second Winter 2021 Instance of COD Survey

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CHAPTER 1 INTRODUCTION

My work responds to the widely recognized need to better prepare engineering students for the social aspects of engineering problems. Contemporary engineering projects involve interconnected social and technical dimensions and can involve multiple stakeholders with diverse and complex needs (Dym, Agogino, Eris, Frey, & Leifer, 2005; McKilligan, Fila, Rover, & Mina, 2017; Walther, Brewer, Sochacka, & Miller, 2020; Watson & Barrella, 2017). Although graduating engineers tend to be well-practiced in tackling technical challenges, they often lack the professional skills necessary to succeed in industry (Dym et al., 2005; Razzouk & Shute, 2012). While this is generally accepted within engineering design education, it remains unclear how to best foster these skills in engineering students.

Design thinking has been proposed as a possible means by which to reorient engineering curricula to better prepare students for the complexities of real-world design problems, however empirical evidence is lacking as to its efficacy in promoting the desired student outcomes (Khalaf, Hitt, Balawi, & Radaideh, 2012; Mabogunje, Sonalkar, Leifer, & Leifer, 2016; McKilligan et al., 2017; Parmar, 2014). In this thesis, I contribute to the empirical analysis of design thinking by presenting a method for integrating and assessing the effects of a specific design thinking tool, stakeholder mapping, within a capstone setting. This method was applied throughout the 2020-2021 schoolyear in a mechanical engineering capstone course at Dalhousie University. Although issues in student engagement and participation limited the analyses possible in this initial application of the proposed research method, important information was gathered that supports its validity and that will be used to inform future iterations of the project.

1.1 PROJECT BACKGROUND & LITERATURE REVIEW

1.1.1 Issues in Engineering Design Education

Engineering education is traditionally based on an engineering-science model (Dym et al., 2005; Razzouk & Shute, 2012). In this framework, students first learn scientific and mathematical principles and then are taught to apply these principles to technical problems for which there exist quantifiable "true" answers (Dym et al., 2005; Parmar, 2014). Problems are solved within an "epistemological approach," in which "known principles [are] applied to analyze and solve problems," (Parmar, 2014) and information gathering and problem solving is used to systematically converge towards this one true solution. The "convergent" thinking associated with this type of problem solving, while sufficient for solving purely technical questions, becomes inadequate in problem contexts involving questions for which there do not exist specific "truthful" answers (Dym et al., 2005). As such, a purely convergent thought process is out of step with design, in which there are often multiple ways to phrase the problem to be addressed, and multiple possible effective solutions to the problem. In such an environment, where problems are not immediately clear and where solutions cannot be reduced to one "true" correct answer, convergent thinking can only act in the presence of recurrent divergent information gathering and assessment. In this divergent thinking "…the questioner attempts to diverge from facts to the possibilities that can be created from them," and in so doing "create[s] the concepts on which the convergent component can act," (Dym et al., 2005, p. 105) by continually constructing and reconstructing a conception of the problem to be solved (Dym et al., 2005; McKilligan et al., 2017).

The focus on scientific principles, when employed in engineering-science at the exclusion of training in divergent thinking and in design in general, has led to "…engineering graduates who were perceived by industry and academia as being unable to practice in industry" (Razzouk & Shute, 2012, p. 330). In response to these shortcomings, which became evident to researchers and educators in the latter decades of the twentieth century, "Project-based-learning," has since become the norm in engineering curricula .This project-based learning can take many forms, including cornerstone courses, capstone courses, and novel sequences of design modules referred to as "spines" (Dutson, Todd, Magleby, & Sorensen, 1997; Dym et al., 2005; Frank, Strong, & Sellens, 2011). These courses aim to better prepare engineering students for industry by exposing students to real-world design challenges, where they must "…build their own knowledge…"(Taajamaa et al., 2013, p. 355) about a particular scenario and then are "…challenge[d]…to apply knowledge from prior coursework toward design solutions…" (Higbee & Miller, 2020). These courses also aim to support students in developing specific skills considered especially necessary in the 21st century workforce, which are alternatively referred to as "soft" skills, "professional" skills, and "working life" skills, among other monikers (Dym et al., 2005; Flus, Rennick, & Hurst, 2020; Qattawi, Alafaghani, Ali Ablat, & Shah Jaman, 2021; Taajamaa et al., 2013).

The problems associated with the 21st century differ from those of preceding decades in their "complexity and interconnected nature," (Walther et al, 2020, p.11), due to their integration within an extremely globalized world, and the high rate of change of the technologies being applied in solving these problems. It is widely accepted that the skills emphasized in engineering education throughout the twentieth century, which as

mentioned above, focused mainly on the application of scientific principles to solving well-defined technical problems, are inadequate in tackling these highly complex and multifaceted issues:

> It is more and more important that engineers master a combination of disparate capabilities – not only technical competencies concerning problem solving and the production and innovation of technology, but also interdisciplinary skills of cooperation, communication, project management and lifelong learning abilities in diverse social, cultural and globalized settings. (Taajamaa et al., 2013, p. 355)

Within this context, accreditation bodies, members of industry, and researchers have identified non-technical skills relevant to engineers (Estell & Howe, 2017; Flus et al., 2020; Parmar, 2014; Taajamaa et al., 2016; Wilson & Marnewick, 2018). Although these skillsets vary between authors and publications, they generally revolve around communication, working as a member of a team, and problem solving, with some institutions also highlighting skills explicitly linked to popular notions of design and business, such as "design thinking" and an "entrepreneurial mindset," in their development of curriculum and intended learning outcomes (Estell & Howe, 2017; Taajamaa et al., 2016).

1.1.2 Design Thinking in Engineering Education

Within this shift toward project-based learning and professional skills training, design thinking (DT) is often proposed as a potential tool to redesign engineering education and to frame student learning and design behaviour (Irfan, Rajamallaiah, & Ahmad, 2018; Khalaf et al., 2012; Mabogunje et al., 2016; McKilligan et al., 2017; Parmar, 2014; Ranger & Mantzavinou, 2018; Razzouk & Shute, 2012; Taajamaa et al., 2016). The

growing prominence of DT is not exclusive to engineering education; it has gained popularity across many fields over the past decade and is pervasive within social discourse in general (Bouwman et al., 2019). Perhaps this ubiquity contributes to the difficulty one finds when trying to define it, as it remains an ill-defined and vague category of study: "no shared definition seems to exist on what design thinking is or what it consists of…" (Taajamaa et al., 2013, p. 354). McKilligan et al. (2017) describe this nebulous character in their definition of DT:

> ...Design thinking refers to a combination of mindsets, processes and toolkits that help people build empathy within the context of a problem, creatively generate insights and solutions, and rationally analyze and execute solutions for the same context…

As this description implies, at its core, DT aims to help one develop an understanding of a problem context and to create and test effective solutions for that context. Beyond this core focus, methods are wide-ranging and ill-defined, with many "toolkits" available, each promising their own brand of innovation.

Two well-known DT toolkits are associated with IDEO, the Silicon Valley-based design consultancy credited with developing design thinking as it appears today, and Stanford University's d. School (alternatively referred to as the "Hasso Plattner Institute of Design at Stanford"). Although phrased in different ways, their design thinking procedures are fundamentally very similar. IDEO's method consists of six steps, and the d. School's of five (Figure 1). These steps are completed recurringly as needed throughout the design process and are each associated with a particular array of tools and mindsets (IDEOU, Stanford University). In Figure 1 one can easily see the correlations

between these two models of design thinking, with "framing" corresponding with "defining," "gathering information" with "empathizing," etc. Considering that IDEO and the Stanford d School were both founded by the same man, David Kelley, who still acts as the Faculty Director of the d. school, the differences between these two models are likely branding choices made to appeal to certain audiences rather than the result of a difference in understanding between the two institutions. This superficial variation between design thinking models is emblematic of the lack of standardization noted above.

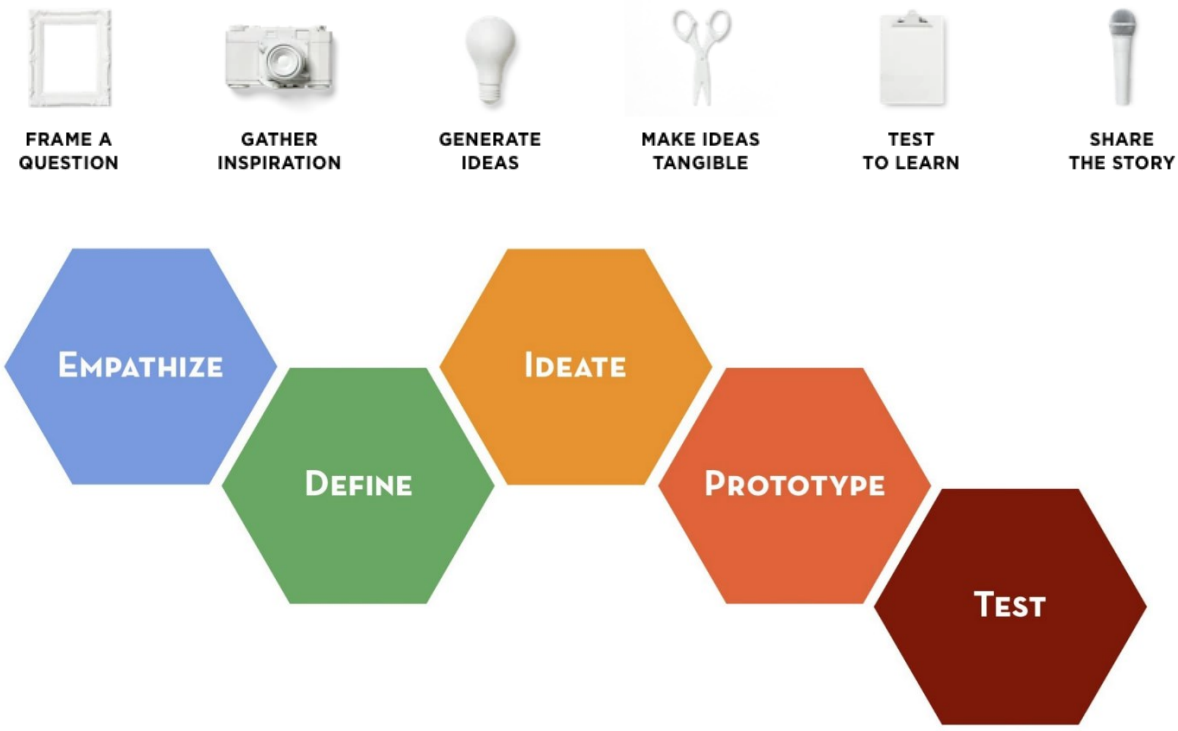


Figure 1 *Design thinking frameworks (top to bottom: IDEO U n.d.; d. Hasso Plattner Institute of Design at Stanford n.d.)*

The lack of a standardized understanding of DT is accompanied in engineering education and elsewhere by a lack of empirical evidence as to its positive effects, where DT's benefits are assumed rather than proven to exist (McKilligan et al., 2017). This is in

fact not limited to DT within the engineering design discourse; researchers have also pointed to the lack evidence for design methodologies in general, which are often based on experiential rather than empirical evidence (Sobek & Jain, 2007). Researchers have begun to respond to this gap in knowledge by attempting to correlate "design thinking" and other design methodologies with design quality and learning outcomes (Gutierrez et al., 2018; McKilligan et al., 2017; Sobek & Jain, 2004). This is the centerpiece of a paper by McKilligan et al. (2017), in which they present plans to integrate a specific design thinking methodology (the "Evolution 6^2 model," based on six steps: Emergence, Empathy, Experimentation, Elaboration, Exposition, and Extension) within the development of engineering courses and the resulting curricula of these courses. Although the results of their study have not yet been published to my knowledge, the research questions proposed by the authors are representative of how broad and undeveloped the state of inquiry is regarding design thinking in engineering education:

1. What are the effects of the design thinking process on various learning outcomes?
2. How does design thinking mediate the learning process? For example, we can relate problem-solving skills to certain characteristics of design thinking which then can be related to increases in exam scores?
3. How is the design thinking process used to help interdisciplinary collaboration in curriculum development and teaching and learning practices? (McKilligan et al., 2017)

Although these questions are phrased as though the authors expect to find a connection between design thinking and learning outcomes (they ask "what *are* the effects" rather than "*is* there an effect"), this very basic premise has not yet been proven. The authors

also do not break down the questions into operationalized variables, however this may be due to the work-in-progress nature of the published paper.

In this study I follow the spirit of the first two questions listed above while responding to the general vagueness of design thinking research to date, by creating a simple research design in which only one design thinking tool is implemented, assessed, and compared with outcomes measured by validated data collection tools.

1.1.3 Stakeholder Mapping

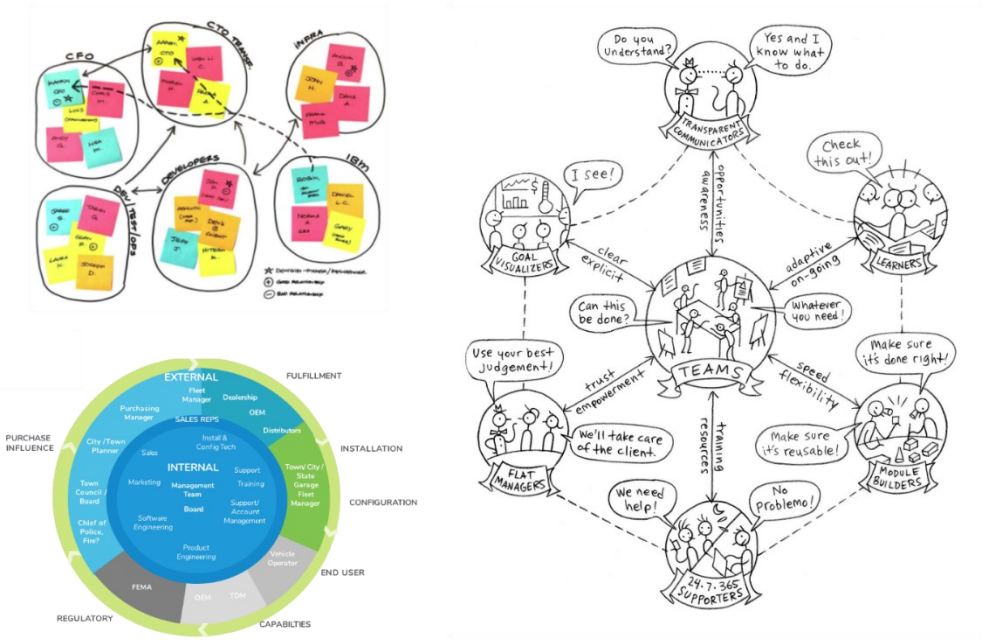


Figure 2 Web and bullseye structures of stakeholder maps, presented in various design thinking toolkits (clockwise from top left: IBM: Enterprise Design n.d.; Interaction Design Foundation n.d.; Design Thinking Salon 2018)

In the interest of contributing to the empirical analysis of design-thinking in engineering education, in this study I have applied a particular design thinking tool, stakeholder mapping (Figure 2), to a year-long mechanical engineering capstone design course. Stakeholder mapping emerged as a candidate for use in this study due to its direct applicability to students' capstone projects, the ease with which it can be administered

and completed virtually (essential during the 2020-2021 schoolyear due to the virtual learning environment imposed by the COVID-19 pandemic), its widespread appearance in design-thinking toolkits, and the course instructors' personal interest in improving students' ability to integrate stakeholder considerations into their design decisions. Its placement within the early stages of design is also important considering the difficulty capstone teams have with needs identification (Flus et al., 2020), and the centrality of problem definition to all subsequent design steps: "Problem identification and formulation is a very important phase, since a wrongly formulated problem will not lead to a successful design solution," (Pusca & Northwood, 2018). The choice of stakeholder mapping as a teaching tool also aligns with recent attempts to "…educat[e] engineering students to become *problem definers* in addition to *problem solvers*," (Taajamaa et al., 2016, p. 1532; emphasis in original) by developing course curricula based on a prolonged situation within the "fuzzy front end" of design (Taajamaa et al., 2016).

Stakeholder mapping methods presented in design thinking toolkits likely derive from "Stakeholder Theory," which originated within the discipline of management. Discussions around the importance of understanding stakeholders in assuring business success began in the 1980s, with R.E. Freeman's landmark work: *Strategic Management: A Stakeholder Approach*, in which he "…begins the construction of a stakeholder model of the firm…" (Freeman 1984, p.27). The was undertaken in response to a changing business environment characterized by the increase in agency of multiple stakeholder groups, including government, "environmentalists" and consumer advocates (Freeman, 1984). Freeman's model, which defines stakeholders as "any group or individual who can affect or is affected by the achievement of the organization's objectives," (Freeman 1984,

quoted in Bryson, 2004, p. 22) has spawned the creation of many “stakeholder analysis” tools, aimed at “…gaining an overall understanding of a system…by means of identifying the key stakeholders and investigating their interests and influences within that system” (Hayes et al., 2021, p.2). These tools include multiple mapping techniques (Bryson, 2004).

This stakeholder analysis discourse holds parallels with engineering education, in the centrality of problem definition and in issues with validating specific techniques. The importance of problem identification to the success of subsequent solutions has been acknowledged within management literature, and the ability to create effective solutions to these problems has been linked to stakeholder analysis through meta-analyses of past projects:

> Failure to attend to the information and concerns of stakeholders clearly is a kind of flaw in thinking or action that too often and too predictably leads to poor performance, outright failure, or even disaster. (Bryson, 2004, p.23)

However, much like design thinking within engineering education, stakeholder analysis within management literature, despite studies like the meta-analysis mentioned above, suffers from a general lack of empirical validation: "…critics might argue with considerable justification that at present there is no overwhelming body of evidence indicating that stakeholder analyses *do* help produce desirable outcomes"(Bryson, 2004, p.47; emphasis in original). This may be connected to a shortage of methods for empirically analyzing stakeholder analysis behaviour; throughout my research, I have failed to discover any procedure for analyzing the structure or content of stakeholder maps outside of their immediate practical use in design and management scenarios.

Within design thinking toolkits, stakeholder mapping is presented as "a way of diagramming the network of people who have a stake in a given system," (LUMA Institute, n.d.-b). It aims to better acquaint whoever is completing the map with the general context of the problem that they are generating solutions for; by identifying and describing interactions between individuals within a problem context, it purportedly "…helps you understand the extent and impact of your design decisions," (LUMA Institute, n.d.-b). Its use, in a variety of forms, appears in the literature of a diverse range of disciplines, from public service-design to veterinary medicine, and has recently been applied within engineering education research to inform curricular design. A sample of maps collected from this body of literature is shown in Figure 3. Based on my review of available design thinking toolkits, stakeholder maps tend to be introduced as either a web or bullseye structure within these toolkits, with stakeholders arranged based on either their relationships to one another or the strength of their connection to a particular issue or project (Figure 2; Design Thinkers Group Team, 2018; Design Thinking Salon, 2018; IBM, n.d.; Interaction Design Foundation, n.d.; LUMA Institute, n.d.-b). As mentioned earlier, there also exists other mapping techniques within other disciplines. An example of this is "power influence grids" in management literature, in which stakeholders are mapped on a two-dimensional spectrum based on their interest in and power over a particular project (Bryson, 2004). Although such mapping techniques may have some applicability to engineering and may be of interest to future researchers, for the purposes of this study only the web and bullseye structures closely associated with DT toolkits are explored.

Although the application of stakeholder maps can be found in a diverse range of literature, as mentioned above, their analysis is generally limited to their immediate application within specific projects. However, empirical examination of the effect of stakeholder mapping on student outcomes, unless one plans to simply compare the outcomes of groups of students who either did or did not complete mapping activities, requires a procedure for differentiating between maps and mapping behaviours. In order to implement such an examination, in this study I borrowed from the field of "concept mapping" in planning my analysis of stakeholder maps.

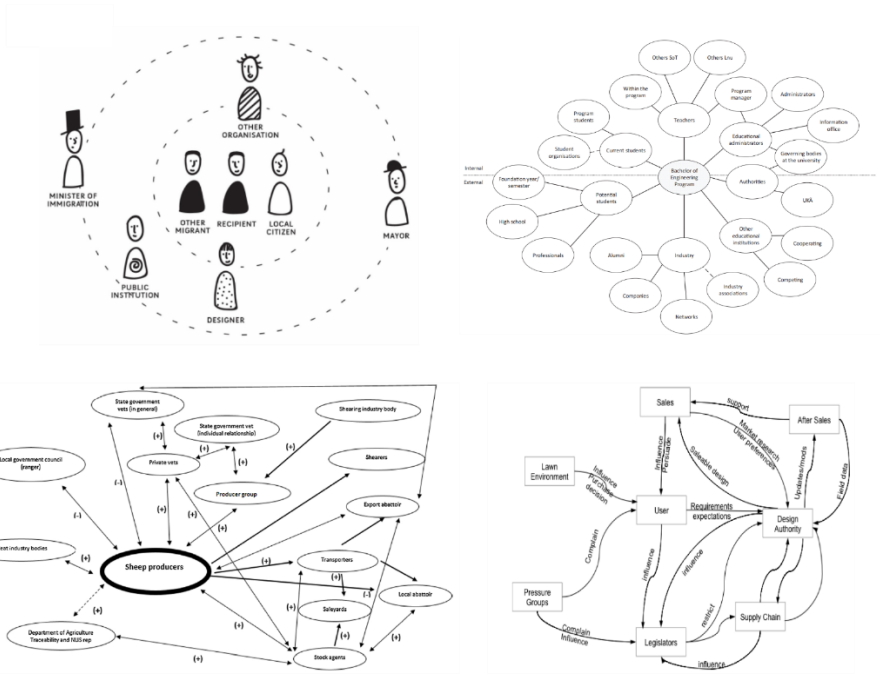


Figure 3 Application of stakeholder mapping in diverse scenarios (clockwise from top left: Giordano et al., 2018; Kans 2021; Burge 2011; Hayes et al. 2021).

1.1.4 Concept Mapping

Consisting of individual concepts linked together by lines and phrases that describe their relationships to one another, concept maps are "a way to diagrammatically represent one's knowledge and understanding of a particular topic or domain," (Shallcross, 2016).

Concept maps have been used across many disciplines, both to facilitate student learning and to evaluate student understanding of complex topics. They have recently been used within engineering education to gauge student understanding of sustainable development, a topic in which social and technical aspects are closely intertwined (Shallcross, 2016; Watson & Barrella, 2017). They have also been used in engineering and design education as a means for student teams to collectively organize their knowledge base regarding design projects (Foley & Plante, 2018; Rambo, Schendel, & Richter, 2007).

Based in David Ausubel's "Cognitive Learning Theory," concept mapping aims to promote "meaningful learning" by prompting students to continuously integrate newly acquired knowledge into their existing knowledge structures and to "…articulate and externalize the actual state of their knowledge" (Segalas, Ferrer-Balas, & Mulder, 2008, p. 298) (Cañas, Reiska, & Möllits, 2017; Reiska, Möllits, & Rannikmäe, 2016; Watson & Barrella, 2017). As such, they are based in and support a "constructivist" vision of knowing, in that the map creator's knowledge is continually being reframed as they add to and rearrange their map (Kinchin, Hay, & Adams, 2000). This iterative construction of knowledge is similar to divergent thinking and to the problem defining required during the "fuzzy-end" of design, in which there exist multiple understandings of a given problem and multiple possible solutions to any such problem. In these scenarios, students must first construct a working understanding of the problem (which is flexible and iterated upon in response to new information) before trying to solve it:

> A design problem keeps changing while it is treated, because the understanding of what ought to be accomplished, and how it might be accomplished is continually

shifting. Learning what the problem is IS [*sic*] the problem. (Rittel, 1987, quoted in Pusca and Northwood 2018, p.50; emphasis in original)

Concept maps and stakeholder maps are similar both in purpose and structure, in that both involve relating nodes to each other to iteratively develop and express one's understanding of a specific topic. Due to these similarities, I expect that parameters common to the structural analysis and evaluation of concept maps will also be relevant to the analysis of stakeholder maps.

As concept maps have been widely studied, an extensive literature exists regarding their analysis. This analysis generally involves consideration of the map's content and structure. As concept maps are typically based on topics that are fundamentally knowable, their content can be compared against known entities and thereby be judged as "correct" or "incorrect" (Shallcross, 2016). For example, if students were asked to create a concept map about the force of gravity, there would be certain statements that could clearly be labeled as true/false based on widely accepted scientific understandings. In contrast, stakeholder maps are not based on fully verifiable entities and relationships; each is highly localized and involves multiple people who may have contrasting opinions of the problem context being studied. As such, the content of stakeholder maps does not permit classification in terms of "correctness" and does not lend itself to concept map content-analysis. Thus, in this study I have only explored the structural analysis of concept maps.

Structural analyses of concepts maps are generally based on a combination of quantitative and "morphological" characteristics, where morphology refers to the overall shape of the resulting map (Marriott & Torres, 2016). An example of this morphological

classification, of which much subsequent work within the concept mapping discipline is based, is the differentiation of "spoke," "chain," and "net"/"network" structures first described by Kinchin, Hay, and Adams 2000 (Figure 4).

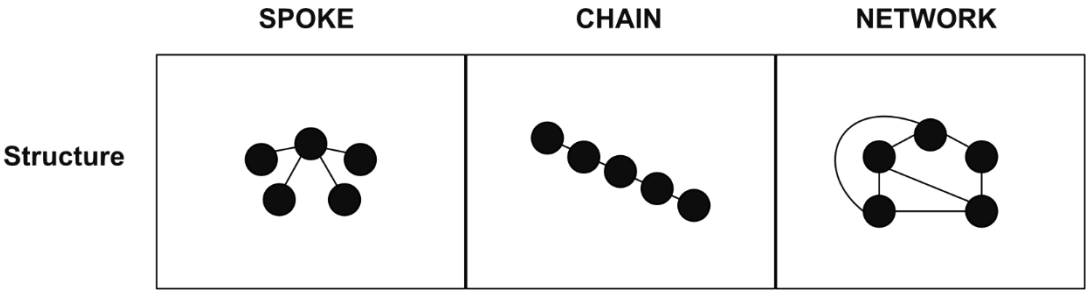


Figure 4 Spoke, chain, and network structures, from Hay, Kinchin, and Lygo-Baker 2008.

Here, spoke structures are those consisting of one root concept connected directly to multiple lone nodes, chain structures are those consisting of nodes in direct sequence to one and another, and network structures are those involving multiple interconnections between nodes. Of these three structure types, networks are believed to represent the most flexible and robust understanding of a given concept:

> For the student with a net framework…access to a particular concept may be achieved by a number of routes, making the knowledge more flexible. However, this requires understanding of the associated concepts beyond their link with the core concept and so implies a wider understanding. (Kinchin et al., 2000, p. 48)

This morphological categorization based on interconnectivity is echoed in many other concept mapping researchers' descriptions of map structure, such as Yin et al.'s classification based on five levels of "structural complexity," (Figure 5) where "Hub," "Linear/Tree" and "Network" structures directly correspond to the "spoke," "chain," and "network" described by Kinchin et al. 2000 (Buhmann & Kingsbury, 2015).

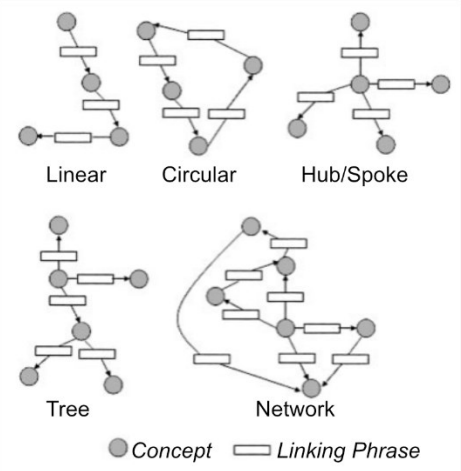


Figure 5 "Structure complexity. Five key concept-map structures," from Yin et al. 2005.

This preoccupation with complexity, and especially with the interconnectivity of concepts within maps, stems from the positive correlation between map complexity and expertise in studies comparing expert- and student-created maps (Watson & Barrella, 2017; Yin et al., 2005). In line with the flexibility of knowledge associated with "network" structures described by Kinchin et al. 2000, interconnectedness is believed to be "…an important network characteristic because it increases one's ability to access concepts, and is a key feature that differentiates expert and novice knowledge frameworks" (Watson & Barrella, 2017). It is therefore not surprising that interconnections are the cornerstone of quantitative analysis of concept maps, which generally measure parameters such as number of concepts, number of links, number of cross-links (as a measure of interconnectivity), and the relative displacement of nodes from the root concept (Buhmann & Kingsbury, 2015).

In this study I employ a particular method from concept mapping literature, Buhmann and Kingsbury's Holistic Framework (2015), as the basis for the structural analysis of stakeholder maps, as it considers both quantitative and morphological aspects

of map structure and as such is expected to provide an in-depth and broad description of student-created maps. This is described in more depth in the Methods I: Research Implement Design (Ch. 2).

1.1.5 Characterizing Design Behaviour and Outcomes

In order to make empirical assessments on the effects of specific learning interventions and design thinking tools, their use must be compared against some measure of student learning or project outcomes. Within capstone engineering, and in engineering design education in general, these measures often include grades received on specific course deliverables, attainment of predefined learning outcomes by students, "design quality" of project outcomes, student perceptions of what they have learned, and similarity of student behaviour to that expected from experts or accepted "best practices," (Atman et al., 2008; Hussain et al., 2020; Sobek & Jain, 2004; Taajamaa et al., 2016). Within this study, I focus primarily on design quality and expert versus novice behaviour, as both are associated with validated instruments which avoid the subjective nature of student interviews and individual grades.

1.1.5.1 Expert versus Novice Behaviour

Comparisons between expert and novice designers are a very common feature of engineering education, and continue to be of interest within the design education discipline (Goldstein et al. 2019; Razzouk & Shute, 2012). These studies help identify common areas where students struggle, which can then be used to create teaching interventions or to better predict the learning trajectories that novice designers are likely to follow throughout their design education (Crismond & Adams, 2012; Loweth et al., 2020; Newstetter & McCracken, 2001). Studies of expert behaviour can also be used as

benchmarks by which to compare student behaviour in a research setting, such as in a recent study by Loweth et al. (2020), in which the authors analyzed student conduct during their meetings with capstone stakeholders, compared student information gathering behaviours to those defined as "best practices" in previous research, and presented the resulting comparison chart as a tool to "…develop targeted pedagogy related to gathering information from stakeholders and domain experts." Other instances of comparing novice and expert behaviour include eye-movement studies of expert and novice designers during the "analysis and interpretation of technical systems," time-use studies of novice and experts completing the same design challenge, and comparison between novice prototyping behaviour with best practices (Atman et al., 2007; Deininger et al., 2017; Ruckpaul et al., 2015).

Within this realm of study, Crismond and Adam's "Informed Design Teaching and Learning Matrix" is a landmark text which has been the basis of much subsequent inquiry and rubric design (Calabro, 2018; Crismond & Adams, 2012; English, 2019; Higbee & Miller, 2020). The matrix contrasts the behaviours of novice and "informed" designers within nine "observable design strategies." Here, "informed designers" are those who have a solid foundation in design but have not attained the "expertise" associated with years of career experience. The design behaviours associated with this category are meant to designate the goal to which educators should aim when teaching students in years K-16 how to design.

The matrix was created through a broad review of engineering design literature, from which Crismond and Adams identified seven "key performance dimensions" integral to successful design (Table 1), and "…nine observable design strategies that are

fundamental to the[se] performance dimensions of informed design…" (Crismond & Adams, 2012, p. 746). Within each of these nine observable behaviours, the authors then contrasted behaviours expected from beginner and "informed" designers, as drawn from their literature review, and identified learning goals and strategies which could be used to support "beginner" designers in shifting their behaviour towards that expected form an "informed" designer (Figure 6).

Table 1 *"Key performance dimensions of informed design" identified by Crismond & Adams, 2012.*

Key Performance Dimensions
1. Learning while designing
2. Making and explaining knowledge-driven decisions
3. Working creatively to generate design insights and solutions
4. Perceiving and taking perspectives intelligently
5. Conducting sustained technological investigations
6. Using design strategies effectively
7. Integrating and reflecting on knowledge and skills

Since its creation, the matrix has been the basis of many assessment rubrics and research studies (Calabro, 2018; English, 2019; Flaherty et al., 2015; Higbee & Miller, 2020; Taleyarkhan et al., 2016; Vo & Hammack, 2021). Due to its continued relevance within engineering design education research and its foundation in a comprehensive literature review of novice and expert design behaviours, I have used the "Informed Design Teaching and Learning Matrix" in the design of this research project. This will be discussed in greater detail in Methods I – Research Implements (Ch. 2).

Design Strategies	Beginning vs. Informed Designer Patterns		Learning Goals where students…	Teaching Strategies where students…
	What Beginning Designers Do	What Informed Designers Do		
Understand the Challenge	**Pattern A. Problem Solving vs. Problem Framing**		Define criteria and constraints of challenge. Delay decisions until critical elements of challenge are grasped.	State criteria and constraints from design brief in one's own words Describe how preferred design solution should function and behave Reframe understanding of problem based on investigating solutions
	Treat design task as a well-defined, straightforward problem that they prematurely attempt to solve.	Delay making design decisions in order to explore, comprehend and frame the problem better.		
Build Knowledge	**Pattern B. Skipping vs. Doing Research**		Enhance background knowledge, and build understandings of users, mechanisms and systems.	Do info searches/read case studies Write product history report Do studies/research on users Reverse engineer existing products Conduct product dissections
	Skip doing research and instead pose or build solutions immediately.	Do investigations and research to learn about the problem, how the system works, relevant cases, and prior solutions.		
Generate Ideas	**Pattern C. Idea Scarcity vs. Idea Fluency**		Generate range of design ideas to avoid fixation. Know guidelines/reasons for various divergent thinking approaches.	Do brainstorming and related techniques to achieve idea fluency Relax real-world constraints or alter original task to see it in new ways Do generative database searches
	Work with few or just one idea, which they can get fixated or stuck on, and may not want to change or discard.	Practice idea fluency in order to work with lots of ideas by doing divergent thinking, brainstorming, etc.		
Represent Ideas	**Pattern D. Surface vs. Deep Drawing & Modeling**		Explore and investigate different design ideas via sketching, modeling solutions, and making simple prototypes.	"Mess about" with given models Use words, gestures, artifacts to scaffold visualizing solutions Do rapid prototyping using simple materials or various drawing tools Conduct structured review of ideas
	Propose superficial ideas that do not support deep inquiry of a system, and that would not work if built.	Use multiple representations to explore and investigate design ideas and support deeper inquiry into how system works.		

Figure 6 Portion of Crismond & Adams' "Informed Design Teaching and Learning Matrix," from Crismond & Adams, 2012.

Comparisons of expert and novice design behaviour have also extended to how each group perceives specific design activities. The "Conceptions of Design" (COD) survey has been used by researchers to compare perceptions of design between students and experts, between different cohorts of students, and to measure changes in student perceptions of design over time (Adams & Fralick, 2010; Atman et al., 2008; Goldstein, Adams, & Purzer, 2018; Goldstein, Omar, Adams, & Purzer, 2017; Goldstein et al., 2019). It was first published by Mosborg et al. 2005 , in a study examining design activities considered important by expert designers. In its first use, the survey asked 19 "expert" designers, identified as such based on years of experience and opinions of colleagues, from six engineering disciplines, to pick what they considered to be the six "most" and six "least" important design activities from a list of twenty-three (Figure 7). These twenty-three tasks draw from design processes, activities, and philosophies, and

are partially derived from a survey performed by Newstetter and McCracken 2001, which was used to identify misconceptions in novice designers' understanding of design.

- ❑ Abstracting
- ❑ Brainstorming
- ❑ Building
- ❑ Communicating
- ❑ Decomposing
- ❑ Evaluating
- ❑ Generating alternatives
- ❑ Goal Setting
- ❑ Identifying constraints
- ❑ Imagining
- ❑ Iterating
- ❑ Making decisions
- ❑ Making trade-offs
- ❑ Modeling
- ❑ Planning
- ❑ Prototyping
- ❑ Seeking information
- ❑ Sketching
- ❑ Synthesizing
- ❑ Testing
- ❑ Understanding the problem
- ❑ Using creativity
- ❑ Visualizing

Figure 7 Design activities included in the Conceptions of Design Survey. Respondents are asked to pick what they believe to be the six "most" and "least" important design activities (Adams & Fralick, 2010).

The results of Mosborg et al.'s initial inquiry have been used as a baseline by which to compare student perceptions of design to those of "experts" in subsequent studies, which are generally time-sequenced, with the survey being administered as a "pre" and "post" test to bookend a specific teaching intervention or period of academic study (Adams & Fralick, 2010; Atman et al., 2008; Goldstein et al., 2017, 2018, 2019). Survey responses can then be analyzed to determine whether student conceptions change over the course of the specific intervention/study period, and whether these responses resemble those expected from experts more closely after the allotted period. As part of a longitudinal study investigating student learning within engineering programs at four American universities, Atman et al. (2008) collected COD responses from eighty-nine undergraduate engineering students in their 1st year and again in their 4th year of study. The authors then identified statistical changes in responses between these two timepoints and compared student responses to those collected from experts in Mosborg et al. (2005).

In Figure 8, we can see this graphical comparison of expert (dark grey), 4th year (light grey) and 1st year (white) responses.

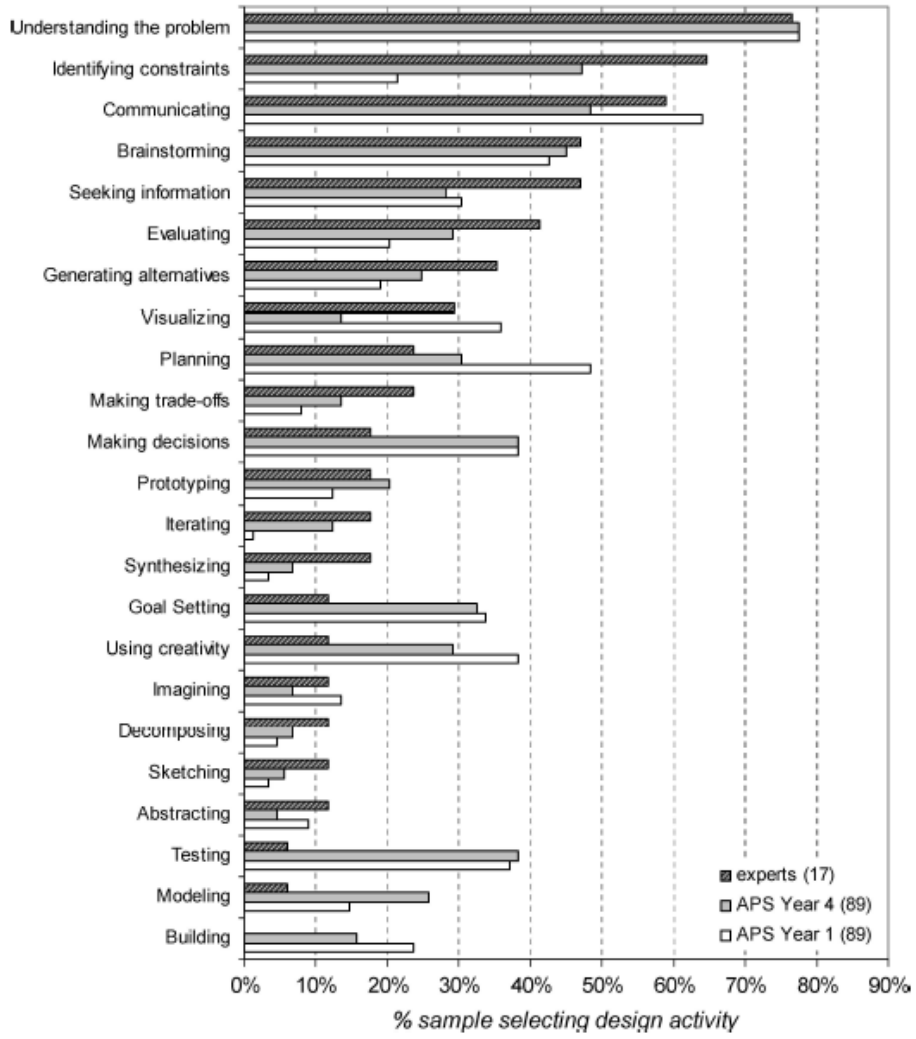


Figure 8 "Comparison of design activity priorities of experts and first- and fourth-year students," from Atman, Kilgore, and Mckenna 2008.

The results of these surveys can also be compared with student behaviour in order to link specific behaviours with certain perceptions of design. In a recent paper by Goldstein et al. 2019, COD surveys were given to high-school students before and after completing a design project. Similarities between student and "expert" responses within these surveys was measured using a scoring protocol, in which a point was awarded to a

student's score for each activity chosen that was expected from experts and a point was detracted for each activity picked that was associated with "novices." The authors then compared student COD scores and changes in COD scores over time to the level "reflectivity" displayed in student responses to prompts given as part of the in-class design project mentioned above. In this thesis study, I follow a similar practice in that COD scores are intended to be compared to student behaviour as it appears in the structure and content of student stakeholder mapping assignments. This is discussed further in Methods I (Ch. 2).

1.1.5.2 Assessing Capstone Outcomes

Evaluating success in a capstone setting is not standardized and continues to be an area of development and research interest: "Assessing the quality of student design work can be non-trivial as an engineering design concept inventory does not present itself in the literature as universal," (Higbee and Miller 2020). This lack of a standardized measure is thought to be linked with the lack of empirical evidence supporting various design processes; without a quantifiable outcome with which to correlate these processes, their efficacy remains untestable (Jain & Sobek, 2006; Sobek & Jain, 2004, 2007). This dearth of assessment criteria contributes to the continued development of new rubrics and assessment protocols within engineering design education literature (Estell & Howe, 2017; Higbee & Miller, 2020; Hussain et al., 2020), which are based on a variety of parameters such as specific learning outcomes, prototype demonstrations, and "informed" design behaviours.

Within this constantly developing field, I have chosen a validated measure of design quality, "The Client Satisfaction Questionnaire" as a proxy for student success in

this study due to its basis in capstone design and its focus on client perceptions of student success. As the goal of the stakeholder mapping assignments was to broaden and deepen student understanding of the problems given to them by their clients, I considered the clients' perceptions of their groups' success as extremely important, as they have more knowledge about the project than for instance, a professor or academic advisor, and should be in a better position than a professor to evaluate the potential of the design in solving their given problem.

The Client Satisfaction Questionnaire was developed by Sobek & Jain (2004), in an effort to better assess the "quality" of design outcomes in capstone design. The survey includes twenty short-answer and multiple-choice questions, which address six parameters of client satisfaction: quality, cost-benefit, involvement (of the student team with the client), technical complexity, accuracy/quality of deliverables, and overall satisfaction. The authors developed this tool in response to a lack of empirical evidence supporting the efficacy of different design processes in promoting quality design within engineering education. They hoped to develop a standard way of assessing this "quality" to then empirically examine which elements of student design behaviour are correlated with better quality designs. The survey was internally validated and applied to a study in which the authors collected design journals completed by capstone students over the course of their class projects, coding the journals for evidence of specific design activities and comparing the proportion of total time allocated to these activities (estimated by the frequency of appearance in the journals) to measures of design quality expressed in the client questionnaires (Jain & Sobek, 2006; Sobek & Jain, 2004). Their results are consistent with the importance of problem definition and staying in the "fuzzy end" of

design, with time spent in conceptual and systems-based problem definition and idea generation activities positively correlated with client satisfaction, and time spent in "detailed" design either negatively correlated or not correlated with client satisfaction. These results, which suggest "… that student designers should perhaps focus more on activities that help define the problem scope and system architecture issues related to concepts under consideration" (Jain & Sobek, 2006, p.67) are congruent with the aims of stakeholder mapping, and will provide an interesting point of comparison for the results of future iterations of this research study. The particular application of this questionnaire within this study is discussed in Methods I & II (Ch 2 & 3).

1.2 RESEARCH QUESTIONS

As discussed throughout this introduction, while design thinking is popular within and beyond engineering education, a knowledge gap exists between its purported and proven benefits. The goal of this study is to contribute to the empirical analysis of design thinking tools in promoting successful design and in preparing students for success in industry. It has two parallel subgoals: to support current and future students in Dalhousie University's mechanical engineering capstone course, and to conduct a preliminary empirical evaluation of stakeholder mapping in a capstone setting. The first goal, supporting students, is addressed in this study through semi-structured interviews conducted with capstone students. The goal of these interviews was to give current students an avenue to voice concerns regarding the assignments, and to collect information which could help inform improvements to the assignments for future iterations of the study. The interviews were designed with the following question in mind:

Q1: How do students perceive/experience stakeholder mapping assignments?

The second goal, empirical assessment of stakeholder mapping, aimed to explore two overarching questions regarding stakeholder mapping activity within the capstone course:

Q2: Is stakeholder mapping activity correlated with project success?

Q3: Is stakeholder mapping activity correlated with how students think about design?

Here, "stakeholder mapping activity" is operationalized as the structure and content of the stakeholder maps created by students, "project success" as client responses to a "Client Satisfaction Questionnaire", and "how students think about design" as student responses to a "Conceptions of Design Survey." Considering this operationalization, the research questions can be organized as such:

Q2: Is stakeholder mapping activity correlated with project success?

Q2a: Is the structure and content of student stakeholder mapping exercises correlated with client satisfaction?

Q3: Is stakeholder mapping activity correlated with how students think about design?

Q3a: Is the structure and content of student stakeholder mapping exercises correlated with student conceptions of the relative importance of design activities?

Q3b: How do student conceptions of the relative importance of design activities change over the course of a year-long senior capstone course?

Q3c: Do student perceptions of design activities align more closely to those expected from experts after completing the course?

Q3d: Is the structure and content of student stakeholder mapping exercises correlated with changes in students' conceptions of design activities?

While questions Q3b and Q3c do not related explicitly to the stakeholder mapping assignments, they are necessary in that if there are no changes in conceptions of design throughout the course, Q3d: "Is the structure and content of student stakeholder mapping exercises correlated with changes in students' conceptions of design activities?" is irrelevant.

While most of these questions could not be addressed during this first implementation of the proposed research project due to low levels of participation, it has functioned as pilot for future iterations of the study. This thesis outlines how the proposed research method was implemented throughout the 2020-2021 schoolyear within an upper-level mechanical capstone course and makes recommendations on how to best apply it in future years based on information collected throughout the study's application.

CHAPTER 2 METHODS I – RESEARCH IMPLEMENT DESIGN

In this chapter, I describe the process by which I designed the stakeholder mapping assignments, present novel scoring protocols for the analysis of stakeholder assignment content and "Conceptions of Design" responses, and elaborate on the data collection tools presented in the Introduction (Ch. 1). The modes by which these assignments, analysis techniques, and data collection tools were administered throughout the 2020-2021 school-year are discussed in Methods II (Ch. 3).

2.1 DESIGN OF STAKEHOLDER MAPPING ASSIGNMENTS

Eight stakeholder-based assignments were designed for the purposes of this study, of which five were assigned to students throughout the Fall 2020 semester, and three in the Winter 2021 semester. While the Fall assignments were designed with analysis in mind, the Winter assignments were created based on student feedback and were not intended for subsequent analysis.

2.1.2 Fall 2020 Assignments

The stakeholder mapping assignments were based on stakeholder mapping methods presented in popular design thinking toolkits, with special reference to those described by the LUMA Institute, which is a company and online-platform providing human-centered design training to individuals and businesses such as Autodesk and Genpact (LUMA Institute, n.d.-a). LUMA's stakeholder mapping process, while not unique, was especially useful in the context of this project as its steps are delineated and well-defined, lending themselves to the development of individual assignments (LUMA Institute, n.d.-b). These six steps, outlined in Table 2, were used to create five assignments for the Fall 2020 semester, outlined in Table 3. Although each step is accounted for within these

assignments, they include two departures form LUMA's original procedure: the number of iterations of the map, and the timing of step two: "flag core/critical stakeholders."

Table 2 *LUMA Institute's Stakeholder Mapping Procedure (note: these steps were retrieved from LUMA institute in summer 2020; they may differ slightly from newer versions of the method) (LUMA Institute n.d. -b.).*

LUMA Stakeholder Mapping Method (in chronological order)
1. List all possible stakeholders
2. Flag core/critical stakeholders
3. Visualize each stakeholder
4. Draw and describe relationships between stakeholders
5. Describe stakeholder mindsets through speech bubbles
6. Delineate different groups of stakeholders

As my supervisors and I wished to support students not only in identifying and thinking about stakeholders, but also in talking to stakeholders and in integrating the information they gathered into their understanding of their problem contexts, I inserted time breaks between the steps presented by LUMA, to give students time to gather more information before finalizing their maps. This resulted in three iterations of the basic stakeholder map, the first of which focused on step four of the LUMA procedure, and the second and third incorporating steps four through six of the LUMA procedure (Table 3).

Under the guidance of the capstone course instructors, who did not want to encourage students to narrow in on "core" stakeholders so early in the stakeholder mapping process, I also moved step two of LUMA's procedure, "flag core/critical stakeholders," to the last assignment, where it is incorporated into a "Bullseye" shaped stakeholder map. The instructors had observed throughout their experience in teaching design courses that students tend to narrow in early on in their information gathering investigations, acting largely on their own assumptions rather than searching for new information. This observation aligns with existing research examining novice versus

design behaviour, and with the observed tension between divergent and convergent thinking within engineering education itself, discussed in the Introduction (Ch. 1) (Crismond & Adams, 2012; Dym et al., 2005; McKilligan et al., 2017).

Table 3 Fall 2020 Assignments and their corresponding steps of the LUMA stakeholder mapping procedure.

Fall 2020 Assignments	***Corresponding LUMA Institute Step(s)***
1 – List of Stakeholders	1 – List all possible stakeholders
	3 – Visualize each stakeholder
2 – Stakeholder Map 1	4 – Draw and describe relationships between stakeholders
3/4 – Stakeholder Maps 2/3	4 – Draw and describe relationships between stakeholders
	5 – Describe stakeholder needs through speech-bubbles
	6 – Delineate different groups of stakeholders
5 – Bullseye Diagram	2 – Flag core/critical stakeholders

The resulting assignments are included in full in Appendix A and are described briefly here. Assignment 1 (Appendix A-1) combined steps 1 and 3 of LUMA's procedure. In it, students were asked to identify 12-13 stakeholders, which included anyone influencing or being affected by the problem given to them by their client. They then had to pick three or four stakeholders to talk to in the following two weeks (the interim before their next stakeholder assignment was due), and to draft questions to ask them. Students were instructed to formulate open-ended questions concerning the context surrounding the problem given to them by their client.

In assignment 2 (Appendix A-3), students were asked to arrange the stakeholders identified in the previous assignment according to their relationships with one another. This corresponded with step four of LUMA's method "draw and describe relationships

between stakeholders." As per LUMA's instructions, students were asked to describe two one-way relationships between each pair of stakeholders, and these relationships were to be described using action-words. Since the mapping assignments were arranged iteratively, students were also asked to differentiate between relationships confirmed through information gathered, and assumed relationships. The goal of this was to help students identify gaps in their knowledge, and to direct them towards areas that needed more information gathering.

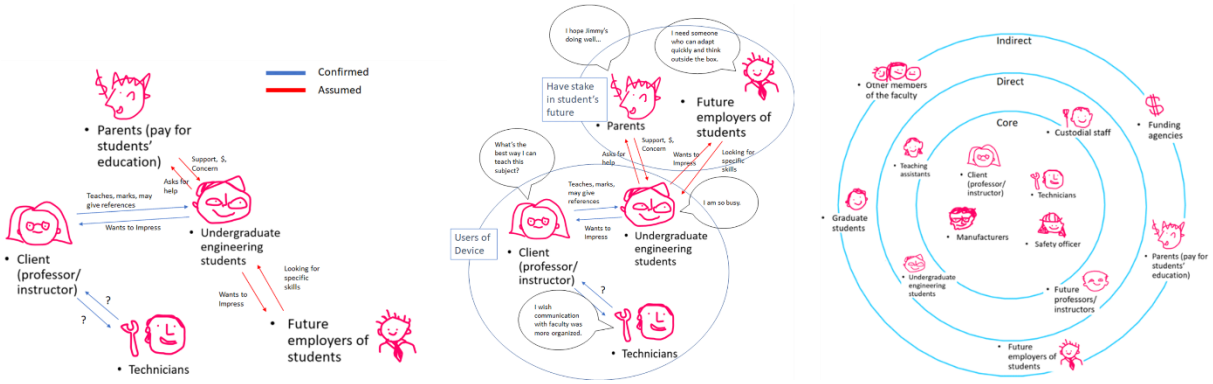


Figure 9 *Stakeholder maps created for instructive purposes. These are based on a past capstone project and illustrate the type of work expected from student groups in Assignments two through five.*

Assignments 3 and 4 (Appendices A-4 and A-5) incorporated steps 4, 5, and 6 of LUMA's mapping procedure. In both of these assignments, students were free to make changes to the structure of their initial maps (corresponding with step four of the LUMA method) and were asked to incorporate speech bubbles describing the main needs of stakeholders in regard to their problem (step five) and to group stakeholders (step six).

The fifth assignment was a Bullseye diagram, meant to mimic step two of LUMA's procedure: "flag core/critical stakeholders." The bullseye diagram is a common form of stakeholder map found on online design thinking tools (Design Thinkers Group

Team, 2018; Design Thinking Salon, 2018). Students were asked to arrange their stakeholders in a target, with core stakeholders in the centre, stakeholders with a direct link to the problem in the second ring, and those with an indirect link in the outer ring (Appendix A-6).

2.1.2.1 Reflective Prompts

In attempting to support student information gathering and integration, I provided prompting questions in assignments two though five, which students responded to in a short report accompanying each map submission. These were meant to spur student reflection on the information they had gathered in the weeks preceding each assignment; where they had obtained the information, how they had incorporated it into their map, whether/how it had influenced their understanding of the problem context, and how their next steps would respond to it.

Structured reflections have been used in engineering education, both as learning tools and as sources of data for subsequent analysis (Abu-Mulaweh et al., 2020; Goldstein et al., 2019; Mckenna & Hirsch, 2008; Walther et al., 2020). Reflection, a metacognitive activity through which one examines one's own thought processes, is considered by some design researchers as "…critical for effective knowledge integration and is instrumental in learning" (Patel & Dasgupta, 2019). Reflective prompts include anything that makes students consider their own thinking process and the actions they are taking/have taken, and can be as simple as "How will you do that?" or "what must be changed?" (Patel & Dasgupta, 2019) The particular questions used in my assignments are based on those used by Jariwala et al. 2020 in a "mini-mester" course aimed at teaching students rapid prototyping techniques. In one of the main projects for this course, student

groups each designed a product for another student group. Hence, for each project there was a "designer" and "user" team of students. After each iteration of the products' development, "designer" and "user" groups met and filled out critiques of the prototypes presented. Of particular interest to me when creating these assignments were the questions posed to "designer" groups, as they asked students to reflect on their own work process, on the products of that process, and to identify possible areas of improvement and define paths by which they could attain these improvements:

1. Why did we create this prototype?
2. Which fabrication processes were used and why?
3. What do you think was successful about the prototype?
4. What aspects of the prototype do you think could be improved?
5. What is your next step? (Jariwala et al., 2020)

I structured the questions included in assignment two through five in a similar fashion. In each of these assignments, students were asked to reflect on why they completed the associated map as they did (with special reference to what specific information and reasoning lead to their current map), how any new learning had impacted their understanding of the problem context, and how they would act according to that new understanding. Within this planning of "next steps," I also asked them to discuss the reasoning behind choosing specific stakeholders to speak to, and to plan questions aimed at obtaining the information desired. These questions were meant to help students act intentionally as their moved from one assignment to the next. Reflective prompts for each assignment are outlined in Table 4, and are also included as they appeared in the assignments in Appendix A. The questions included in these assignments diverge from

those used in Jariwala et al. 2020, in that these reflective prompts are directed explicitly towards developing an understanding of the problem to be solved, rather than on solving a given problem. This emphasis on problem framing is congruent with current research and teaching interventions within design education aimed at promoting problem defining as a skill among undergraduate engineering students alongside problem solving (Downey, 2005; Flemming & Johnston, 2019, 2020; Pusca & Northwood, 2018; Taajamaa et al., 2016).

Table 4 Reflective prompts included in Assignments 2-5.

Assignment(s)	***Reflective Prompts***
2&3 – Stakeholder Maps 1/2	*Reporting Changes*
	1. For each change to map:
	a. What is the reasoning behind this change?
	b. What information prompted this change? How was the information obtained?
	c. Has this change influenced your understanding of the problem context? If so, how?
	d. How will this change influence your next steps?
	Next Steps
	2. Who are you planning to talk to?
	3. Why do you want to talk to them? What types of insights do you think they can provide?
	4. What questions will you ask in order to access these potential insights?
4 – Stakeholder Map 3	*Reporting Changes*
	1. For each change to map:
	a. What is the reasoning behind this change?
	b. What information prompted this change? How was the information obtained?
	c. Has this change influenced your understanding of the problem context? If so, how?
	d. How will this change influence your next steps?

Assignment(s)	***Reflective Prompts***
4 (con't) – Stakeholder Map 3	*Overview of Problem Context*
	2. How will the different stakeholders be affected by the outcome of your project?
	3. How will you take stakeholder needs into account as you develop you solution?
	4. How has your understanding of the original given problem changed over the past six weeks?
5 – Bullseye Map	*Reporting Changes*
	1. Explain the reasoning behind the choices you made in the bullseye map.
	Next Steps
	2. Explain what role each stakeholder group will play as your project moves forward:
	a. How will you keep in touch with them?
	b. What information do you plan to share with them?
	c. What types of insight/information do you expect them to provide?
	3. Explain how you plan to address the needs of these stakeholders in your prototypes/solutions.

2.1.3 Winter 2021 Assignments

The winter assignments were created in response to broad feedback that two of the course instructors received from students throughout the Fall 2020 term in relation to that term's stakeholder mapping assignments. While the Fall 2020 assignments were designed with the intent of collecting data for subsequent analysis, the Winter 2021 assignments were developed primarily in the interest of supporting students in thinking about their stakeholders/users as they continued to work through their capstone projects. Despite these assignments' primary role as a teaching tool, they remain important to this study in that student opinions of the Winter assignments gathered from one-on-one interviews help point to what aspects of these assignments they found useful or not, which can help researchers design assignments more thoughtfully in future years.

The feedback received by instructors in relation to the Fall assignments was mainly based on the amount time/effort required to complete the assignments and the perceived usefulness/redundancy of them. According to the two course instructors, students felt like they were spending too much time on the stakeholder mapping assignments, due to their frequency and the amount of writing necessary for each, and they did not necessarily see how the assignments connected with their projects. In response to such comments, I created three assignments instead of five for the Winter 2021 term, all of which required much less writing than those offered in the fall.

The first was a journey map chart. The use of this tool, and of the "interaction summaries" discussed below, were suggested by a co-supervisor of this study who is an experienced product designer and who has used similar tools in his own design courses. Students were provided with a very detailed template (Figure 10), representing their design's life, from the beginning of the problem which prompted the design, to the conception of the design, through the resulting product's use and maintenance, to its death and decomposition. I explicitly prompted students to identify stakeholders who they expected to interact with their designs at multiple points throughout this timeline. This is evident in Figure 10 in the blue nodes and their associated questions. Students simply had to fill in the name of the stakeholder/stakeholder group for each of these timepoints; there was no written portion beyond that.

The second and third assignments of the winter term were "interaction summaries." Students were asked to pick two stakeholders appearing in their journey maps and to interview them in order to answer the following questions about how they would interact with the students' design:

1. Who is the stakeholder?
2. What are they doing?
3. Where are they doing it?
4. When are they doing it?
5. Why are they doing it/why are they important to your design?
6. How are they doing it/how does their interaction affect others?

Students were given a template page, with these questions written on it. They simply had to fill in the answers to these questions (Appendix B-2).

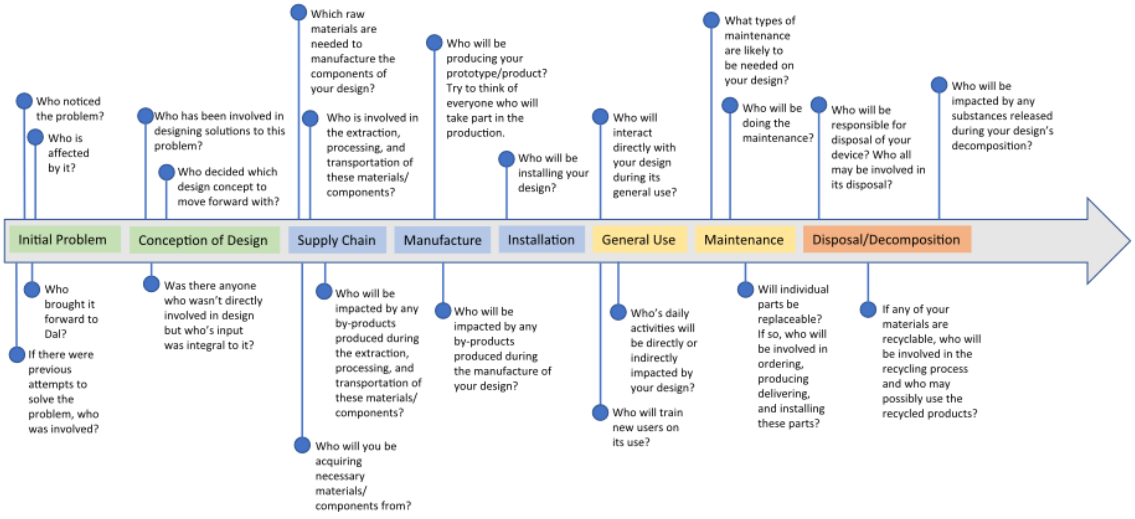


Figure 10 Journey map template provided to students in the first of three Winter 2021 Assignments (a full-scale image of this template is included in Appendix B-1).

2.2 ANALYZING MAP STRUCTURE: BUHMANN & KINGSBURY'S HOLISTIC FRAMEWORK

As mentioned in the introduction of this thesis, I have chosen a particular method from concept mapping literature, Buhmann & Kingsbury's (2015) "holistic framework for concept-map analysis," as the basis for the structural analysis of stakeholder maps, due to its consideration of both quantitative and qualitative map features. This framework was

created with the goal of combining quantitative descriptions of maps, considered inadequate in capturing "holistic" map characteristics, with description of "global structures," which define the overall shape and connectivity of the maps. It consists of three steps: "structural and topological normalization," "quantitative analysis," and "morphological classification."

2.2.1 Structural and Topological Normalization

The first step of Buhmann and Kingsbury's framework, "structural and topological normalization" stages subsequent quantitative and morphological analysis. According to the authors, concept maps created by students do not follow a standardized format and as such display a wide variety of overall shapes which obscure the underlying structural characteristics of the maps. I expect that student-created stakeholder maps will follow a similar pattern, possibly augmented by the fact that students are encouraged to complete the maps by hand, introducing individual drawing styles into the variations between maps.

Two examples of "structural and topological normalization," which I performed on stakeholder maps collected from literature, are shown in Figure 11. In this step, maps are stripped of their content, leaving only nodes and connecting lines. The root concept of each map, which in the case of these two maps are the stakeholders most central to the systems under analysis, is demarked by a square while all other nodes are marked by circles (1b and 2b in Figure 11). Nodes are then ordered based on several criteria, including proximity to the root concept, the length of the "branch" nodes are associated with, how many subbranches they are associated with, and how many cross-links they are associated with:

- Place the deepest (longest) branch first.
- For branches of equal length, place the branch with the largest total number of concepts first.
- For branches with an equal number of concepts, place the branch with the largest number of longest sub-branches first.
- For branches with an equal number of concepts, place the branch with an equal number of such sub-branches first.
- For branches with equal numbers of sub-branches of the uppermost concept, place the branch with the largest number of cross-links first. (Buhmann & Kingsbury, 2015, p. 23)

This stage is depicted in 1c and 2c of Figure 11. Although not described in the original framework, I have added colours in this figure denoting the distance of nodes from the root concepts, with those directly connected to the root concept in blue, those removed from the root concept by one intermediary node in yellow, and those removed by two nodes in white. This helps differentiate branches in terms of branch length, which is integral to node ordering.

The maps are then redrawn with the central concept at the top, and all nodes emanating from it arranged based on their ordering. Each row of the resulting map is associated with a particular distance from the root concept, and "cross-links," links extraneous to the fundamental structure of the map, are marked by dotted lines (1d and 2d of Figure 11). This gives a standardized format which allows for easy quantitative analysis and for qualitative comparisons between map shapes.

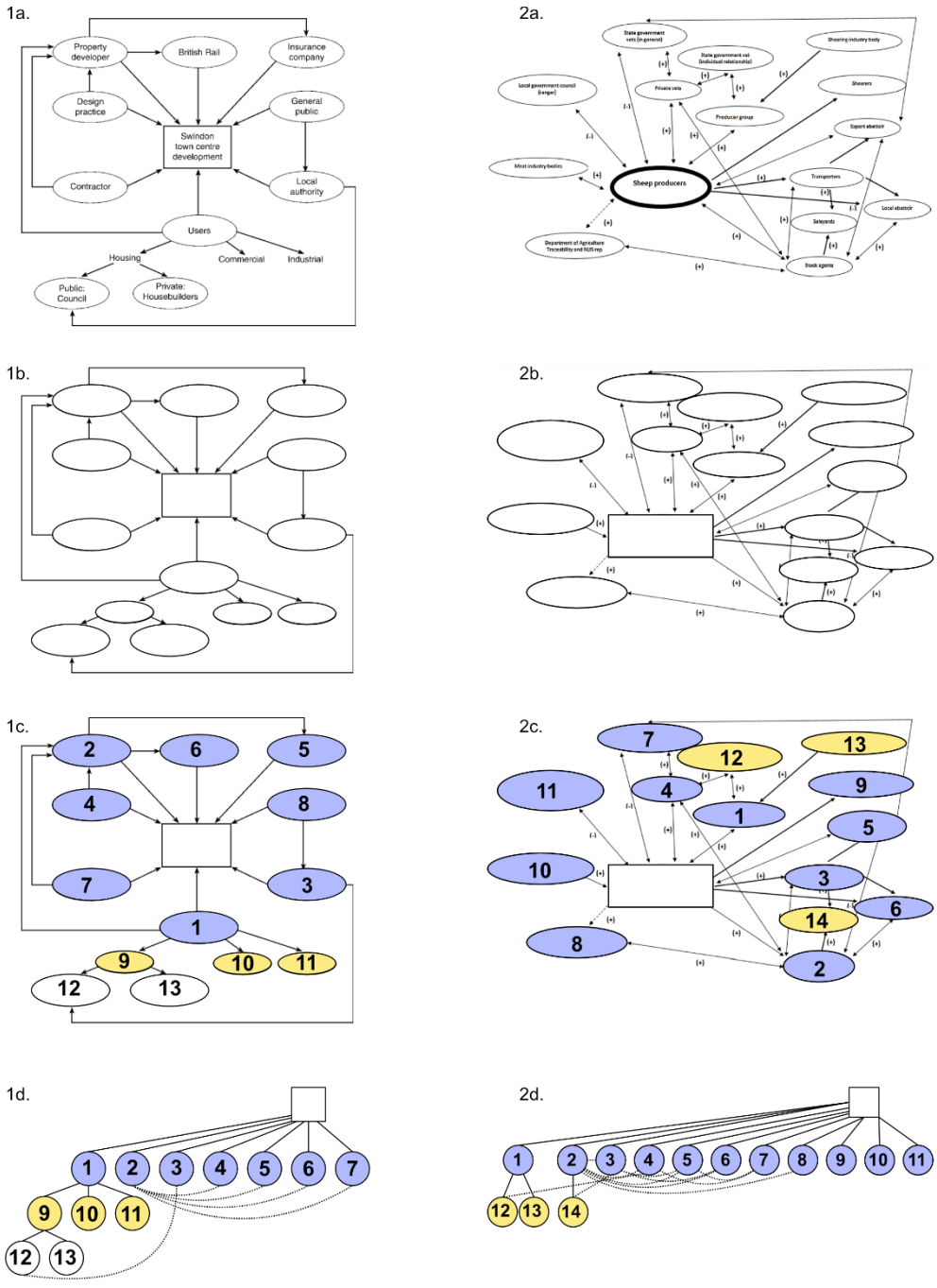


Figure 11 Structural normalization of two stakeholder maps (1. Newcombe, 2003, 2. Hayes et al., 2021) using Buhmann and Kingsbury's Holistic Framework (Buhmann & Kingsbury, 2015).

2.2.2 Quantitative Analysis

The second stage of Buhmann and Kingsbury's framework is "quantitative analysis." In this stage, each map receives a score for each of nine parameters: number of concepts, number of links, diameter, in- and ex-radii, degree sequence (how many nodes each node is connected to), cross-linkage (the relative frequency of cross-links versus normal links), dimension (a comparison between number of concepts and map breadth), and balance (a comparison of in- and ex- radii) (Buhmann & Kingsbury, 2015). This analysis describes the structure of maps numerically, allowing quantitative comparisons to be made between maps. Figure 12, an image appearing in Buhmann & Kingsbury's 2015 paper, demonstrates how these quantitative parameters can be derived from a topologically normalized map.

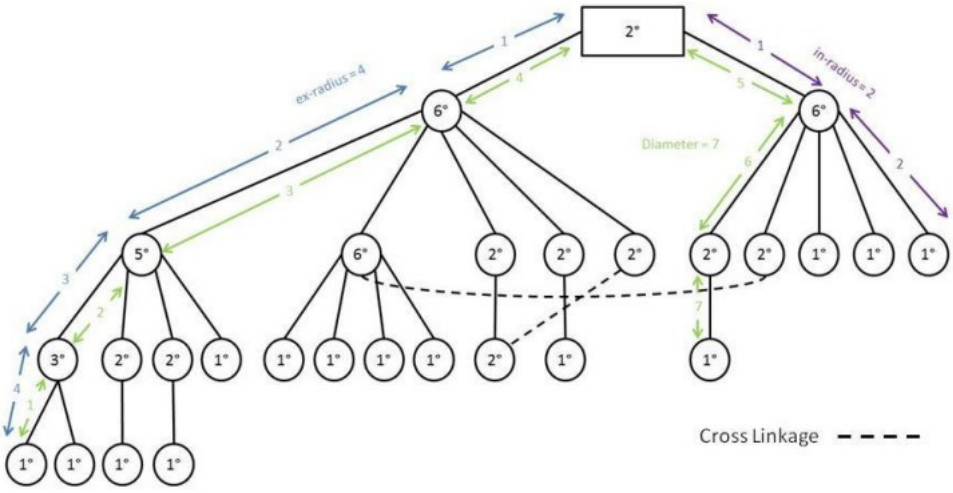


Figure 12 "Quantitative analysis of normalized concept maps" from Buhmann and Kingsbury, 2015.

A variable of particular interest to this study is "degree sequence." In analyzing this parameter, each node is assigned a "degree" equal to the number of nodes it is connected to (displayed in the centre of each node in Figure 12). Buhmann & Kingsbury introduce this parameter as an elaboration of previous work involving map structure and its connection to "meaningful learning.". An example of such work is the differentiation of "spoke," "chain," and "network" map structures discussed in the Introduction (Ch. 1), where "network" structures are associated with greater flexibility and depth of student knowledge (Hay et al., 2008; Kinchin et al., 2000). The "degree sequence" of Buhmann & Kingsbury complements this classification of maps in that a high proportion of 1^o nodes indicates a spoke structure, a high proportion of 2^o nodes indicates a chain structure, and a high proportion of nodes of $\geq 3^o$, indicates a network structure. This correlation is shown in the second row of Figure 13, where the degree sequence of each of Hay et al.'s example maps are given; as is apparent, the network structure is characterized by a high frequency of 3^o nodes, the chain with 2^o nodes, and the spoke with 1^o nodes.

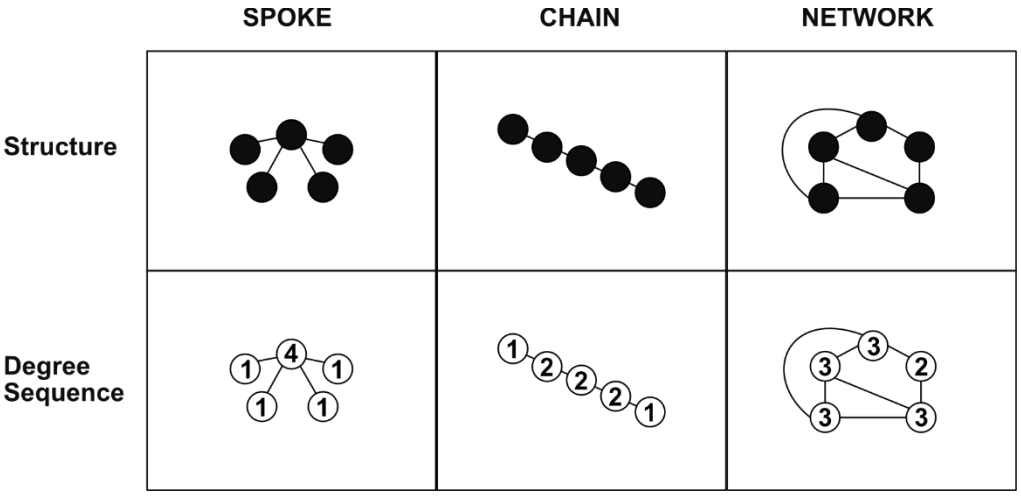


Figure 13 Spoke, chain, and network structures. Row one, "structure," copied from Hay et al. 2008; row two, "degree sequence" added by author.

Given this correlation with well-known map structures, Buhmann and Kingsbury presume the degree sequence of a given map (especially when analyzed in terms of relative proportion of 1^o, 2^o, and $\geq 3^o$ nodes) to be related to the level of understanding held by the map maker on the topic in question. This metric may function similarly in the analysis of stakeholder maps, as a more flexible conception of the problem context can be expected to allow teams to be nimbler with their design concepts and iterations.

Another variable of interest to this study is cross-linkage, which measures the percentage of links extraneous to the basic structure of the concept map in question; if these links were to be removed from the map, no nodes would be left unconnected to any others. As such, they represent connectivity beyond the minimum required to "…hold the concept [or stakeholder] map together…" (Buhmann & Kingsbury, 2015) with increasing cross-linkage representing increased connectivity. It is calculated in the Buhmann & Kingsbury framework with the following formula:

$$Cross\ linkage = \frac{(\#\ links - \#\ concepts + 1)}{\#\ links} * 100\% \quad (1)$$

Within this formula, "1" is added in the subtraction of number of concepts from number of links $(\#\ links - \#\ concepts + 1)$, as the root concept does not require any links to maintain its position in the map. The importance of this addition is clearly illustrated in spoke-based maps. For instance, in the "spoke" map shown in Figure 13, there are five concepts and four links. If the formula were to be applied without this additional "1," the resulting cross-linkage of this map would be calculated as -25%, even though there are no detached nodes in the map. Adding the "1" allows for the root concept to be disregarded,

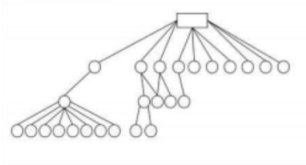
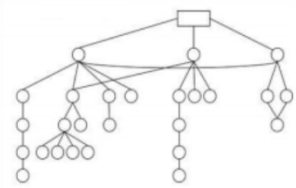
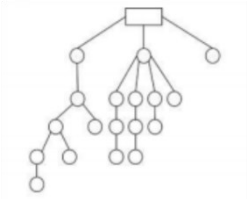
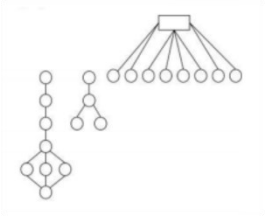
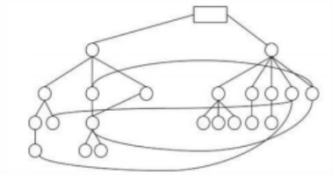
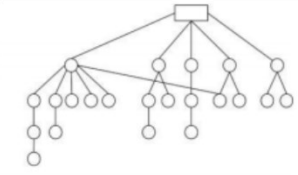
resulting in the correct assessment of cross-linkage, with in the case the spoke map is 0%, as all nodes are connected to the root concept without any cross-links.

Measured in this way, "cross-linkage," which is related to the degree sequences discussed above, speaks to the "interconnectivity" of the map, a variable which is positively correlated with expertise in concept-mapping literature (Watson & Barrella, 2017; Yin et al., 2005). Given the associations between degree sequence and levels of understanding, and between connectivity and expertise, as a very basic hypothesis we might expect stakeholder maps with higher values of degree-sequence and cross-linkage to be correlated with higher levels of client satisfaction in design outcomes.

2.2.3 Morphological Classification

The third stage of the framework involves characterizing maps within one of six classes based on their general structure: broad, deep, imbalanced, disconnected, interconnected, and normal. These categories are relatively self-explanatory and can be guessed based on simple observation of the normalized maps, but each is also loosely associated with specific quantitative parameters, summarized in Table 5.

Table 5 *Morphological classes of concept maps, and their "key indicators". Content duplicated from Buhmann & Kingsbury, 2015, arrangement in table by author.*

Morphology	***"Key-indicators"***
Broad 	• High degree of root concept • Small ex-radius
Deep 	• Small degree of root concept • Large ex-radius • High proportion of 2º concepts
Imbalanced 	• Small balance
Disconnected 	• Very low cross-linkage • Very low dimension • Concepts completely detached from root concept
Interconnected 	• High cross-linkage • High Dimension • Large proportion of 3º
Normal 	• Does not exhibit any of the indicators listed above

2.3 ANALYZING MAP AND REFLECTION CONTENT: BEGINNER VS. INFORMED BEHAVIOUR

Design Strategies	Beginning vs. Informed Designer Patterns	
	What Beginning Designers Do	What Informed Designers Do
Understand the Challenge	**Pattern A. Problem Solving vs. Problem Framing**	
	Treat design task as a well-defined, straightforward problem that they prematurely attempt to solve.	Delay making design decisions in order to explore, comprehend and frame the problem better.
Build Knowledge	**Pattern B. Skipping vs. Doing Research**	
	Skip doing research and instead pose or build solutions immediately.	Do investigations and research to learn about the problem, how the system works, relevant cases, and prior solutions.
Revise/Iterate	**Pattern H. Haphazard or Linear vs. Managed & Iterative Designing**	
	Design in haphazard ways where little learning gets done, or do design steps once in linear order.	Do design in a managed way, where ideas are improved iteratively via feedback, and strategies are used multiple times as needed, in any order.
Reflect on Process	**Pattern I. Tacit vs. Reflective Design Thinking**	
	Do tacit designing with little self-monitoring while working or reflecting on the process and product when done.	Practice reflective thinking by keeping tabs on design strategies and thinking while working and after finished.

Figure 14 Condensed "Informed Design Teaching and Learning Matrix," modified from Crismond & Adams, 2012.

I developed a simple scoring protocol for the content of student maps and reflections based largely on the range of student behaviours described in Crismond and Adams' 2012 "Informed Design Teaching and Learning Matrix." As discussed in the introduction, the matrix contrasts the behaviours of novice and "informed" designers in regards to "…nine observable design strategies that are fundamental to the performance dimensions of informed design," (Crismond & Adams, 2012). Although there are nine comparisons within the original matrix, for the purposes of this study I use four: "understand the challenge," "build knowledge," "revise/iterate," and "reflect on process." as these align best with the front-end problem scoping phase in which the stakeholder

mapping assignments are situated. Figure 14 is a condensed version of the matrix, showing the expected behaviours of beginner and informed designers in each of these four activities.

Each of the four design strategies included in Figure 14 correspond to sections of the scoring protocol I have created (Table 6). The scoring protocol for each assignment is based on the "breadth" of exploration and the "depth" of analysis evident in stakeholder maps and accompanying reflections. The parameters associated with "breadth" are broadly associated with the strategies "understand the challenge," and "build knowledge," from Crismond & Adams (2012) and those associated with "depth" are more closely related to "revise/iterate" and "reflect on process."

Within "breadth of exploration," the suggested protocol scores teams based on the diversity of stakeholders considered and the types of questions posed of these stakeholders. "Diversity" of stakeholders here refers to how closely the stakeholders identified are linked to the capstone client of a given project. "Questions" are described by two separate parameters, "topic" and "wording," where topics range from predominantly solution-focused to predominantly problem-focused, and wording ranges from closed/leading to open-ended. These parameters are designed to align both with the goal of stakeholder mapping itself, to gain a comprehensive understanding of a problem context before defining and solving a given problem, and with the beginner/informed behaviours associated with "understand[ing] the challenge" and "build[ing] knowledge" in the Informed Design teaching and Learning Matrix. Within these two observable design strategies, beginners are expected to "treat design task as a well-defined, straightforward problem…" to "…skip doing research..." and to "…prematurely attempt

to solve" a given problem, whereas informed designers are expected to "delay making design decisions in order to explore, comprehend and frame the problem better" (Crismond & Adams, 2012, p. 748) In this context, considering a very narrow range of stakeholders can be considered as a beginner behaviour in that it demonstrates a reduced scope of exploration/investigation in relation to problem context. Asking closed questions aimed at developing solutions can also be considered a beginner behaviour, whereas open-ended questions aimed at understanding the problem context can be considered informed. This distinction between question types also aligns with a recent examination of capstone student information gathering behaviours, in which the authors organized observed student behaviours as "more similar" and "less similar" to best practices. They found that students behaving "less similar" to best practices asked questions which "elicited shallow responses" from interviewees and those that behaved "more similar" to best practices "encouraged deep thinking" in their questions (Loweth et al., 2020).

"Depth" of exploration in this scoring protocol refers to how the students engaged with the information collected from stakeholders, as indicated by their answers to reflection prompts. Reflection prompt answers are to be scored on three parameters: "reflecting on decision-making," "integrating new information," and "responding to new information." The first, "reflecting on decision-making" applies to the demonstrated ability of students to make the reasoning behind the decisions made in their mapping assignments explicit. The second, "integrating new information," relates to whether students connected the information they gathered in the weeks preceding each assignment with their understanding of the greater problem context, or, if they found the information irrelevant to the problem context, whether they adequately described the reasoning

behind this. The third, "responding to new information," relates to whether a team's "next steps" are related to the insights and information gathered in preceding weeks. These three parameters align with the "revise and iterate" and "reflect on process" design strategies discussed of the Informed Design Teaching and Learning Matrix, in which beginners are expected to exhibit "haphazard" design, "…with little self-monitoring…" while informed designers are expected to "…practice reflective thinking…" and to develop " ideas…iteratively via feedback," implying an ability to respond to external information and new learning as they arise (Crismond & Adams, 2012, p. 749). Whereas in the original matrix these sections pertain specifically to active design phases, here they are being used for analyzing behaviour during the front-end of design, specifically during problem-framing, as it can be expected that the mindset necessary for managed iteration and reflective design in later stages should also be present in the initial stages of design.

As the content of the assignments varies, according to this scoring protocol "breadth" parameters are applied to assignments 1 through 4, and "depth" parameters are applied to assignments 2 through 5. For each of these assignments, teams are given a score from 0-2 for each of these parameters, which can then be averaged to generate a single score for each assignment. Teams can also be given an overall score by averaging their scores from all individual assignments. Changes in teams' scores between assignments can be analyzed for statistical significance, and teams' scores can also be compared with teams' conceptions of design and client satisfaction.

Table 6 *Scoring protocol for Fall 2020 Assignments 1-5. For assignment 1, only parameters related to "breadth of exploration" are applied, for assignments 2-4 all parameters are applied, and for assignment 5, only parameters associated with "depth of analysis" are applied.*

		Score		
Parameter		*0*	*1*	*2*
Breadth of Exploration (asgmt. 1-4)	Stakeholders	All stakeholders considered are closely related to the client.	Considers some stakeholders from outside the client's inner circle.	Considers a large range of stakeholders.
	Questions – Topic	Most questions are targeted at developing solutions.	Narrowly focused on the given problem; some questions may target solutions.	Targeted at understanding the broader problem context; few to no questions target solutions.
	Questions – Wording	Almost all questions are closed and/or leading.	Most questions are closed and/or leading.	Most questions are open-ended.
Depth of Analysis (asgmt. 2-5)	Reflecting on decision-making	Reasoning behind decisions (changes to map, grouping of stakeholders, next steps, etc.) is missing or incomplete.	Reasoning behind decisions is briefly outlined, with some gaps.	Reasoning behind decisions is clearly outlined.
	Integrating new information	No connection made between information gathered in the preceding two weeks and the group's understanding of the problem context.	Little/superficial connections made between information gathered in the preceding two weeks and the group's understanding of the problem context.	Clear connections made between information gathered in the preceding two weeks and the group's understanding of the problem context.

		Score		
Parameter		*0*	*1*	*2*
Continued - Depth of Analysis (asgmt. 2-5)	Responding to new information	"Next steps" do not respond to stakeholder information gathered in preceding weeks.	"Next steps" loosely consider stakeholder information gathered in preceding weeks.	"Next steps" directly respond to stakeholder information gathered in preceding weeks.

2.4 SCORING AND TRACKING STUDENTS' "CONCEPTIONS OF DESIGN"

The Conceptions of Design Survey was administered at three timepoints throughout the 2020-2021 schoolyear. In order to measure change in student responses between timepoints, I developed a scoring protocol similar to that used by Goldstein et al. 2019 (Table 7), which aimed to rank participants in terms of the similarity of their responses to those expected from experts.

Table 7 "Protocol for CDT Scoring," from Goldstein et al. 2019.

Score	Associated design terms
+1	Analysing data, conducting tests, evaluating, gathering information, generating alternatives, iterating, making decisions, making trade-offs, planning, reflecting, understanding the problem
0	Communicating, modelling, prototyping, setting goals, sketching
−1	Brainstorming, building, using creativity

As mentioned in the Introduction (Ch. 1), the scoring protocol used by Goldstein et al. 2019 awarded points for activities similar to those chosen by experts and revoked points for activities associated with "novices." The particular "novice" activities used by Goldstein et al. (those associated with a score of -1 in Table 7), are based on those picked by novice designers in a foundational study performed by Newstetter & McCracken 2001. This selection by Goldstein et al., however, injects contradictions into their protocol, as two of the activities chosen by beginners in Newstetter and McCracken 2001, "brainstorming" and "using creativity," were also chosen by experts in Mosborg et al.

2005. To avoid such internal contradictions, I have acted much more conservatively, basing the protocol on activities that were picked by at least 50% of expert respondents in the original Mosborg et al. study. There were eight such activities, four of which were chosen as "most important" by most experts and four as "least important". My scoring protocol (Table 8) is based on these eight activities; if students act in the same way as most experts in the original study, they receive a point, and if they act in the *opposite* fashion than the majority of experts, for instance if they rank an activity as "least important" that most experts rank as "most important," they are deducted a point. All other behaviour is cored as 0.

Table 8 Proposed scoring protocol for Conceptions of Design Survey responses.

	Design Activities and Associated Scores	
Category of Choice	(+1)	(-1)
"Most" Important	Understanding the problem	Building
	Identifying constraints	Abstracting
	Seeking information	Decomposing
	Communicating	Synthesizing
"Least" Important	Building	Understanding the problem
	Abstracting	Identifying constraints
	Decomposing	Seeking information
	Synthesizing	Communicating

This scoring protocol allows for scores to be measured at individual survey timepoints and for changes in score between timepoints to be calculated on an individual and team level. This in turn allows for comparisons to be made between COD scores, changes in COD scores, and team behaviours as measured by stakeholder mapping structure and content, reflection content, and client satisfaction.

2.5 CLIENT SATISFACTION QUESTIONNAIRE

As discussed in the introduction, Sobek & Jain's (2004) "Client Satisfaction Questionnaire" was designed in the interest of providing a quantified measure of design quality against which student design behaviour and specific design processes could be compared. While Sobek and Jain's original survey includes twenty multiple-choice and short-answer questions, for the purposes of this study, two of the original twenty questions were removed, due to redundancy and lack of pertinence to stakeholder mapping. The resulting questions and their categorization within the six parameters outlined by Sobek & Jain are displayed in Table 9. The full revised survey is included in Appendix C-2.

As is apparent in Table 9, most questions are arranged on a Likert scale, with four short-answer questions providing context to multiple-choice responses. Due to the categorization of questions within six parameters, with each implementation of the survey the researcher can test for reliability between responses to the Likert-scale questions associated with each parameter. If there is high inter-reliability, a single measure of the parameter in question can be formed by combining the Likert-scale answers associated with it, and this can be compared against elements of student behaviour. Researchers can also test for reliability between parameters, forming an aggregate measure of client satisfaction by combining parameters that are correlated with one another. Although this type of test was not possible in this research study due to low participation, in future iterations of the study it may prove very useful, as specific parameters, such as involvement and deliverables, can be compared individually against other measures of

student behaviour, such as Conceptions of Design survey responses and stakeholder mapping characteristics.

Table 9 "Client Satisfaction Questionnaire" questions, modified from Sobek & Jain, 2004.

Question		***Parameter***	***Question Type***
1	Name	----------	Short-Answer
2	What were the design objectives for this project? What did you expect the team to accomplish?	Quality	Short-Answer
3	On a scale of 1-5, how close was the final outcome to your initial expectations?	Quality	Likert
4	How much did your company benefit as a direct or indirect result of the design project outcomes?	Cost-Benefit	Likert
5	If you answered 1, 2, or 3 to question 4, how much potential do you think the design holds to benefit your company in the future?	Cost-Benefit	Likert
6	Approximately how often did you meet with the design team over the course of the year (face-to-face/virtually)?	Involvement	Likert
7	Approximately how often did you communicate with the students other than the above-mentioned meetings? (includes email, online messaging, etc.)	Involvement	Likert
8	How would you rate the quality of communication between the design team and you during the project?	Involvement	Likert
9	What was your role in these meetings/communications?	Involvement	Short-Answer
10	How would you rate the technical difficulty of the design problem assigned to the design team?	Complexity	Likert
11a	Did you view the final report?	Deliverables	Yes/No
11b	If yes, how accurate was the final report?	Deliverables	Liker
11c	If yes, how complete was the final report?	Deliverables	Likert
12a	Did you view the final presentation?	Deliverables	Yes/No
12b	If yes, how accurate was the final presentation?	Deliverables	Likert

Question		***Parameter***	***Question Type***
12c	If yes, how accurate was the final presentation?	Deliverables	Likert
13	Please comment on the accuracy, completeness and quality of the final prototype.	Deliverables	Short-Answer
14	How feasible is the design in its application and fabrication?	Overall	Likert
15	Are you going to implement this design?	Overall	Likert
16	If you had a chance, would you be interested in working on another project with this design team?	Overall	Yes/No
17	How would you rate your overall satisfaction with this design outcome?	Overall	Likert
18	What would you do differently if you work on another student project?	Overall	Short-Answer

CHAPTER 3 METHODS II – APPLICATION IN CAPSTONE SETTING

3.1 STUDY POPULATION & RECRUITMENT

3.1.1 Study Population

The study population consists of 93 senior mechanical engineering undergraduate students enrolled in a year-long capstone course, and the 24 clients associated with this course. Within the course, the student population is arranged within twenty-four teams, each undertaking a project for one of these external clients.

As I planned to use non-parametric tests for data analysis, it was unfeasible to perform a power analysis to determine necessary sample size for this study. However, my proposed cohort of 93 students was within the range of the sample sizes of similar studies upon which this study was based (n= 19-109) (Atman et al., 2008; Goldstein et al., 2019; Mosborg et al., 2005), and as such I did not presume the population size to be an issue at the outset of this study. Recruitment, however, did not go as planned, which greatly limited the data available and prevented statistical analysis.

3.1.2 Recruitment

Multiple recruitment attempts aimed at engaging capstone students were made throughout the 2020-2021 schoolyear. I first attempted to recruit student participants with a two-minute video presentation, in which I briefly introduced the study and what would be asked of participants. The video was posted to the "MECH 4015 Lectures" section, alongside lectures associated with the course, of the Microsoft Teams page organized for the capstone course in question (Appendix D-1). After the presentation had been posted to Microsoft Teams, one of the course instructors emailed PDF consent forms to

the students, who were asked to sign the consent forms virtually and to email them to me if they wished to participate in the study. The two-minute video remained posted on the course's Microsoft Teams page throughout the Fall 2020 semester. It received thirty-two views in total, and two participants were recruited to participate in the study.

Due to the lack of student uptake following the original recruitment video and consent form, I applied for and received ethics approval to deliver the consent form as an online survey, rather than an emailed PDF which students would have to download, sign, and email back to me. I also separated the "Conceptions of Design Survey" from the consent form, delivering it as a separate link. I created a new, shorter recruitment video, which was posted as an announcement in the course's Microsoft Teams page (Appendix D-2). This one-minute video directed students towards the original recruitment video, informing them that consent form links would be emailed to them soon. Prospective student participants were then sent two separate emails by a course instructor: one with the link to the Fall 2020 online survey, and one linking to the Opinio-based consent forms for stakeholder mapping and one-on-one interviews. Although this method was more successful than the first recruitment attempt, (three students completed the Fall 2020 Conceptions of Design Survey, three consented to participate in the one-on-one interviews, and five students gave me permission to use their teams' stakeholder maps in my analysis), participation remained far below what I had originally expected and desired.

In response to the continued lack of participation, I added compensation for student participation in the form of four separate draws for five $25 Amazon gift cards, with each draw corresponding to one of the four portions of the study still relevant in the

Winter 2021 semester: Conceptions of Design Surveys 2 and 3, one-on-one interviews, and release of stakeholder maps. This amendment to the consent process was approved by Dalhousie's Research Ethics Board. To introduce this new compensation measure, I created a third, two-minute recruitment presentation, which was posted as an announcement on the Brightspace page of the Winter 2021 mechanical engineering capstone course (MECH 4025). The recruitment script introduced the study and the new compensation measures for participation, while directing direct students towards the original recruitment video (which was also be posted on the course's Brightspace page) for a full description of the study (Appendix D-3). This announcement also contained direct links to the consent forms and the Conceptions of Design Surveys (which were also emailed to students) in order to make them as accessible and easy to find as possible. This new recruitment measure was more successful than the previous two: fourteen students consented to participate in the one-on-one interviews, out of which thirteen completed the interviews, thirteen completed the third instance of the COD Survey, and twenty-one consented to releasing their stakeholder mapping assignments for analysis. However, only two students completed the first Winter 2021 COD Survey, and I still did not have access to any of the stakeholder mapping assignments as no full teams consented to their release.

Client participants were recruited by email. All clients were sent an email by a course instructor containing the consent form (Appendix E-3), which detailed the study and their potential role in it. The email included a link to the "Client Satisfaction Questionnaire." By clicking the link and completing the questionnaire, the clients gave their consent to participate in the study.

3.2 DATA COLLECTION

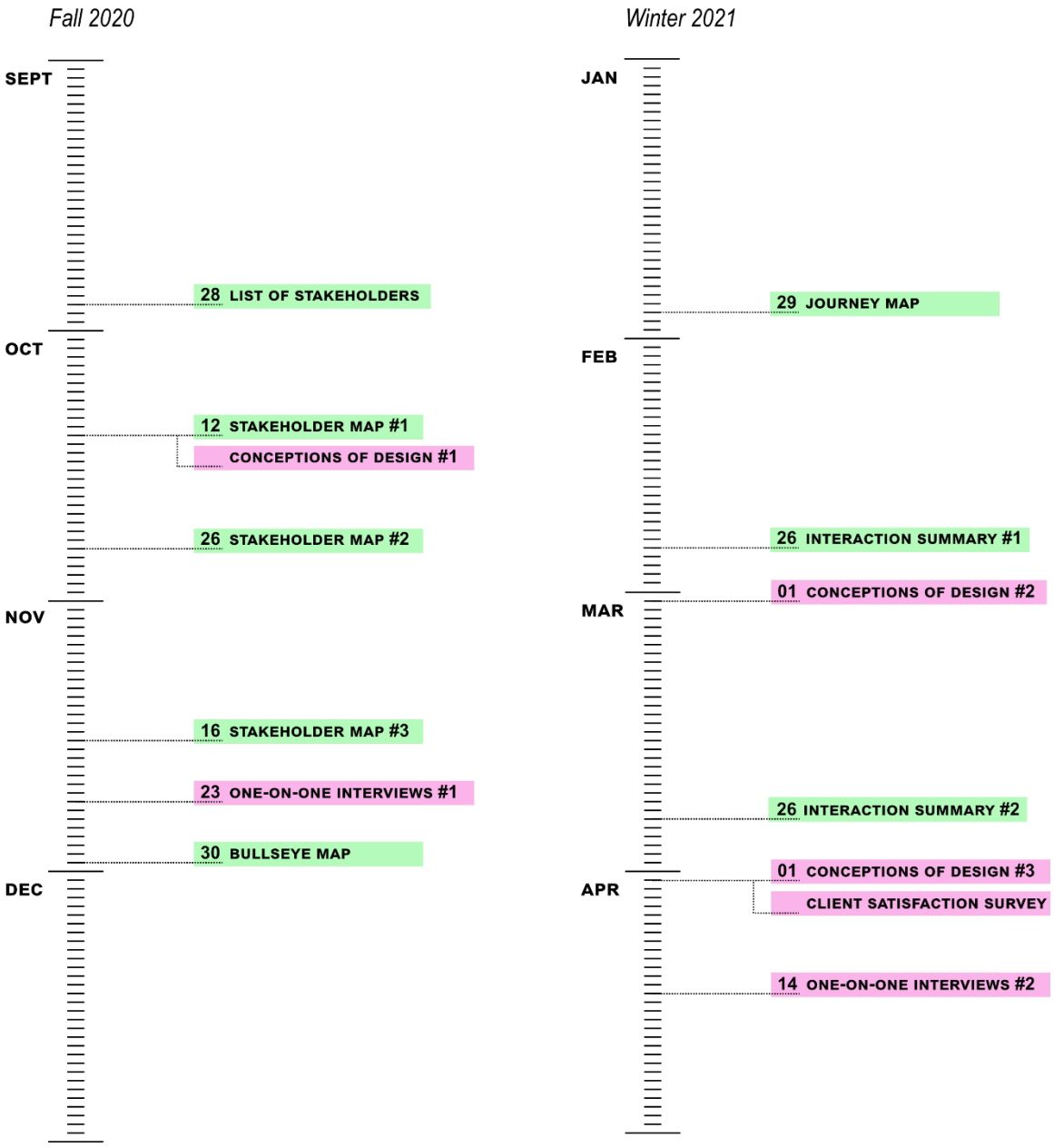


Figure 15 Project timeline; stakeholder assignments are highlighted in green, and other data collection tools in pink.

As discussed in previous sections, I used four sources of data in this study: stakeholder mapping assignments completed by students as part of their coursework, a "Conceptions of Design" survey administered to students at three timepoints throughout the 2020-2021 schoolyear, a "Client Satisfaction Questionnaire" administered at the end of the 2020-2021 schoolyear, and one-on-one interviews with students concerning their experiences with the stakeholder mapping assignments. Figure 15 shows the timeline at which these data collection tools were administered through the 2020-2021 schoolyear. Below is a description of how each tool was implemented.

3.2.1 Stakeholder Mapping Assignments

All student teams completed five stakeholder mapping assignments during the Fall 2020 semester and three during the Winter 2021 semester as part of their coursework. While the Fall assignments were designed with analysis in mind, the Winter assignments were created based on student feedback and were not intended for analysis. The Fall 2020 assignments were due on September 28th, October 12th and 26th, and November 16th and 30th. They were meant to coincide with the problem-definition phase of student design projects, in order to help student teams better acquaint themselves with the problems presented to them. The Winter 2021 assignments were due on February 29th, February 26th, and March 26th.

3.2.1.1 Introduction to Students

The first stakeholder mapping assignment (due September 28th) was preceded by a 13-minute video introducing stakeholder mapping to students (PowerPoint Slides and script are included in Appendix A-1). In this video, I explained what stakeholder mapping was, how it could potentially be useful to the engineering process, and how we were going to

be using it throughout the course. I walked through each of LUMA Institute's steps, in the order in which we would be using them in the stakeholder mapping assignments. I illustrated each of these steps with an example I developed using a capstone project from a previous year (see Ch. 2, Figure 9). The problem associated with the chosen project, "Design a machine to be used in an academic setting to break threaded fasteners" was chosen for use as an example because at first glance it could be perceived as a purely technical problem. I wanted to show how students could approach stakeholder mapping with such a project. I used this example project throughout the entire fall term, including it in assignment outlines and all instructive videos.

In addition to the "Introduction to Stakeholder Mapping" lecture, I also created a 20-minute video tutorial on creating stakeholder maps in PowerPoint/OneNote, a 3-minute introduction to the first stakeholder mapping assignment, and a 5-minute introduction to the second stakeholder mapping assignment. I did not include videos on assignments 3-5, as assignments 3 and 4 were very similar to assignment 2 and their content had been covered in the original introductory video, and assignment 5 was very simple and had also been covered in the introductory video. No video introductions were provided for the Winter 2021 assignments as these were considered simple enough to explain through assignment outlines alone.

As with all other lectures associated the course, these introductory videos were delivered asynchronously on the Microsoft Teams page associated with it. Students were not required to watch the videos, resulting in 62 views of "Introduction to Stakeholder Mapping," 31 views of the PowerPoint/OneNote tutorial, and 39 and 41 views of the introductions to assignments one and two respectively.

3.2.1.2 Marking

The assignments were marked by two teaching assistants (one for each term) who had no connection to the research project. They were asked to mark the assignments as a completion grade based on the outlines given to student teams. They were instructed to give a grade of 0 if nothing was handed in, 0.5 if some elements included in the assignment outline were not addressed in the assignment, and 1 if all elements of the assignment outline were addressed. Student groups received a phrase or two of feedback along with their grades.

3.2.2 Conceptions of Design Survey

The "Conceptions of Design" survey, presented in the Introduction (Ch. 1), was administered at three points throughout the 2020-2021 schoolyear: October 12th, March 1st, and April 1st. Ideally the first two instances would have been administered at the very beginning of the Fall 2020 and Winter 2021 semesters, however their implementation was delayed due to the timing of initial and supplementary ethics applications. The surveys were administered through Dalhousie University's Opinio license.

3.2.3 Client Satisfaction Questionnaire

The modified Client Satisfaction Questionnaire was administered throughout the month of April 2021. Potential client participants were emailed consent forms and a link to the Opinio-based survey at the beginning of the month.

3.2.4 Student Interviews

One-on-one interviews with students were completed at two timepoints throughout the 2020-2021 schoolyear: at the end of the Fall 2020 term (beginning on November 23rd) and at the end of the Winter 2021 term, (beginning on April 14th). Three students were

interviewed during the first round of interviews, and 13 in the second round. All interviews took place on Microsoft Teams video calls, which were audio-recorded and automatically transcribed using Microsoft Teams software.

Table 10 shows the questions which framed my conversations with students during the Fall 2020 and Winter 2021 interviews. As the interviews were semi-structured, these questions acted a loose guide, and were broadly aimed at assessing how students perceived of/experienced the assignments. Additional questions were inserted during the winter semester with the aim of building context around the interviewee's experience with the stakeholder assignments.

Table 10 Guiding questions for semi-structured interviews.

Round of Interviews	***Questions***
Fall & Winter	1. How has your team been using the stakeholder mapping exercise?
	a. Could you briefly describe how the workload is broken up between team members?
	b. Could you briefly describe any effect you think that exercises may have on your ability to communicate as a team?
	2. How does the stakeholder mapping exercise compare to other assignments you have done throughout your engineering education?
	3. Could you describe any aspects of the exercise that you find useful to your overall project?
	4. Could you describe any aspects of the exercise that you find frustrating?
Fall only	5. Do you think that the exercise will be useful to your team throughout the capstone course? Could you briefly describe why?
Winter only	6. Were there any specific obstacles that you faced as a team throughout the year, or anything that you wish had been different?
	7. Were there any areas of your project for which you feel like you could have used more support?

During interviews, I generally prompted students with a given question and let the student's response inform subsequent lines of questioning, adding new questions in response to new information. Depending on the conversation, some of the pre-scripted questions became obsolete throughout the course of the interview; for example, I did not use question five in any of my fall interviewees, as the students being interviewed had already spoken at length about the assignments' limited usefulness, and I did not want them to think that I hadn't heard them by pressing them to once again to consider their usefulness.

3.3 DATA ANALYSIS

3.3.1 Stakeholder Mapping Assignments

As previously mentioned, the stakeholder mapping assignments submitted by student teams could not be accessed for use in this study.

In the interest of illustrating the proposed method of stakeholder map structural analysis, I have applied Buhmann & Kingsbury's (2015) framework to five stakeholder maps gathered from existing literature. Four of these maps appear in academic literature in disciplines including management, engineering education, and veterinary medicine, and one appears in a "Systems Engineering Tool Box" published by a systems design consulting firm (Burge, 2011; Elias, Cavana, & Jackson, 2002; Hayes et al., 2021; Kans, 2021; Newcombe, 2003).

As my proposed protocol for scoring stakeholder map and reflection content, introduced in Methods I (Ch.2), is very specific to the assignments created as part of this study, it was not possible to test it on sample data collected from literature. Future application of this protocol is reviewed in the Discussion (Ch. 5).

3.3.2 Conceptions of Design

Student responses to the "Conceptions of Design" surveys are explored visually and described qualitatively. To maintain anonymity, the names of student respondents are replaced by alphanumeric codes, consisting of a letter followed by a number. The letter denotes the students' team, and the number is unique to each student. All letters and numbers were assigned randomly, both to teams and individuals. Survey responses from the Winter #2 timepoint are compared visually against an approximation of the "expert" and 1st and 4th year student responses presented in Atman et al. 2008. This approximation was obtained by analyzing a graph presented in Atman et al. 2008 using "WebPlotDigitizer," a "web based tool to extract data from plots, images, and maps" (Rohatgi, n.d.)

All capstone student responses were scored using the scoring protocol introduced in Methods I (Ch. 2), and these are explored graphically. As only three students responded to the first instance and two to the second, there were not enough responses to warrant statistical analysis of change between timepoints.

3.3.3 Client Satisfaction Questionnaire

To maintain anonymity, client names were replaced with letters assigned randomly to their student teams. Answers to all Likert-scale questions were rearranged so that all Likert scales point in the same direction (with 1 denoting lowest and 5 highest quality). As the sample size does not warrant statistical analysis, questionnaire responses are qualitatively described.

3.3.4 Student Interviews

I followed the coding method outlined by Leavy 2017, which consists of three steps: "immersion," "coding," and "categorizing and theming." All interviews were audio recorded and auto transcribed using software provided by Microsoft Teams. Student names were replaced by alphanumeric codes, described above. Many errors existed within the auto-transcriptions, and so I re-listened to each of the audio recordings while reading through and correcting the transcripts. This served as my initial "immersion" into the data.

All coding was done using NVivo software. I coded the transcripts using "in-vivo" coding. In this type of coding the interviewee's direct language is used to generate codes from the transcript (Leavy, 2017). I completed this "in-vivo" coding in two rounds; during my first read-through I coded entire phrases of interest, and on a second read-through I renamed these codes based on key words. I also coded all of the questions I had asked throughout the interviews, in order to have a record these questions. I then continued to the step of "categorizing and theming" which I completed by first binning all codes into one of nine folders based on whether they expressed positive, negative, or neutral opinions of either the Fall assignments, Winter assignments, or of the course in general. I considered this to be an appropriate way to sort codes, as I was aiming to assess how students perceived of/experienced the assignments, and sorting codes based on positive, negative, and neutral feelings would let me identify patterns in the likes and dislikes of students in relation to the assignments. Within each of these folders, I grouped codes which expressed similar opinions or spoke about similar topics and derived

overarching themes/categories from commonalities within these groupings. These themes are presented in Results (Ch. 4).

CHAPTER 4 RESULTS

4.1 ANALYSIS OF EXAMPLE STAKEHOLDER MAPS

Due to the lack of student participation, I have applied Buhmann & Kingsbury's (2015) analysis framework to five stakeholder maps collected from existing literature. I have done this in order to demonstrate the applicability of the framework, which was designed in the context of concept mapping, to stakeholder maps, and to identify any difficulties the framework may pose in this new context. This helps inform recommendations for future iterations of the study, which are considered in the Discussion (Ch.5).

4.1.1 Structural and Topological Normalization

As mentioned in previous chapters, Buhmann and Kingsbury's framework involves three steps: structural and topological normalization, quantitative analysis, and morphological classification. The results of the first step are displayed in Figure 16, where the maps as they originally appear in the literature are compared with the topologically normalized maps resulting from this analysis. As is apparent in the figure, the original maps differ greatly in terms of overall shape and drawing style. It can be expected that there would exist even more variation between student-created maps in the capstone course as students were encouraged to include hand-drawn elements in their maps. Although it would be possible to make some qualitative comparisons between maps based on their original formats, the normalized maps simplify comparison with their standardized format of node shape and organization, where the stylistic choices of the original authors are erased. The normalized maps clearly lay-out the hierarchies of nodes (how far each node is displaced from the root concept), and cross-links between nodes, which can both be hard to discern in the original maps. For instance, on first glance one might expect a

complicated looking map such as that published in Hayes et al. 2021 (map "d" in Figure 16) to have deeper branches than a less cluttered map, such as that in Newcombe 2003 (map "a"), when in fact the Newcombe map has two concepts which are three steps away from the root concept and the Hayes et al. map has no nodes at three steps away from the root, and only three at two steps away, with most nodes directly connected to the root concept.

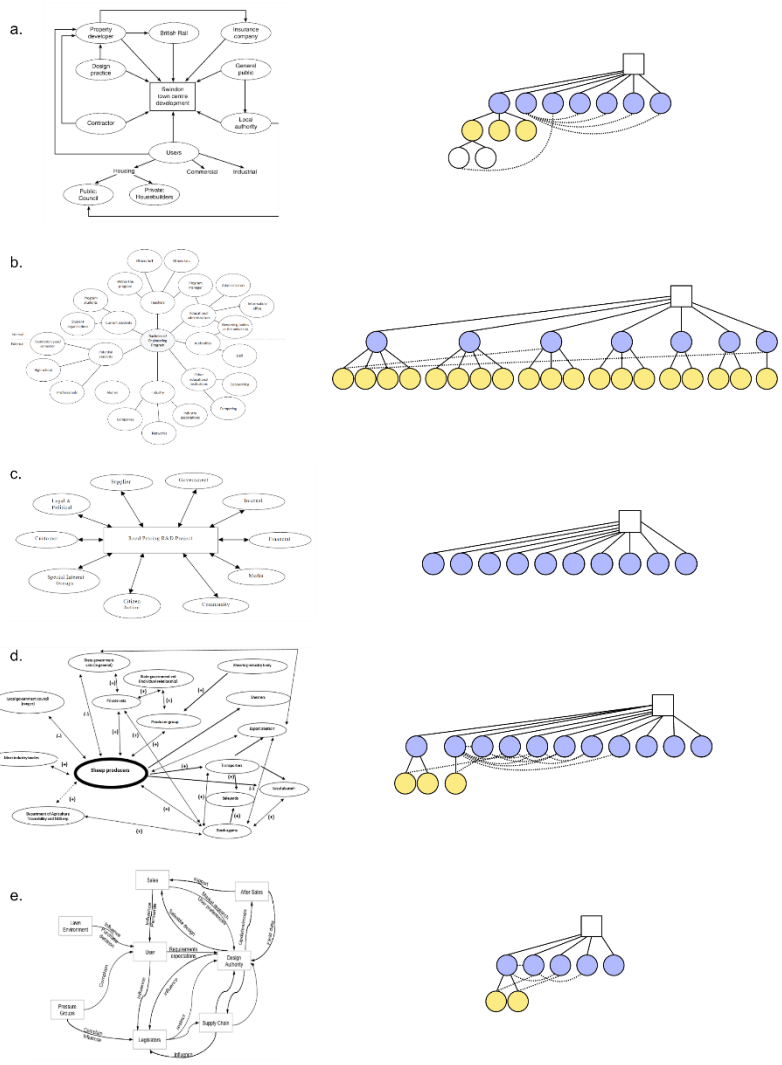


Figure 16 Structural/topological normalization of five stakeholder maps collected from literature, as per Buhmann and Kingsbury's "holistic framework" (a. Newcombe 2003, b. Kans 2021, c. Elias et al. 2002, d. Hayes et al. 2021, e. Burge 2011)

Buhmann & Kingsbury's normalization of maps also simplifies quantitative analysis, in that it is very easy to identify each of the parameters used to describe the maps when they are already in the standardized format. Although it would be possible to measure each of these parameters without first normalizing the maps, as the variables are not a function of the topological normalization but are inherent in the original maps themselves, it would likely be much more time consuming and prone to error than when applied to the normalized maps.

4.1.2 Quantitative Analysis

The results of quantitative analysis are displayed in Table 11. As is evident on first appraisal of this analysis, there is variation between maps in each of the nine parameters measured. This implies that Buhmann and Kingsbury's analysis framework is an effective way to differentiate between stakeholder maps, which is encouraging in terms of its application in future iterations of this study.

Table 11 Summary of quantitative analysis of five sample maps.

									Degree Sequence				
Map	**# Concepts**	**# Links**	**Diameter**	**In-Radius**	**Ex-Radius**	**Cross-Linkage (%)**	**Dimension**	**Balance (%)**	Root Degree	# 0º Nodes	# 1º Nodes	# 2º Nodes	# ≥3º Nodes
Newcombe 2003	14	19	4	1	3	31.58	1.64	33.33	8	0	3	6	5
Kans 2021	27	28	4	2	2	7.14	2.05	100.00	7	0	17	2	8
Elias et al. 2002	11	10	2	1	1	0.00	2.18	100.00	10	0	10	0	1
Hayes et al. 2021	15	25	4	1	2	44.00	1.68	50.00	11	0	4	3	8
Burge 2011	8	12	3	1	2	41.67	1.50	50.00	5	0	1	3	4

As discussed in the introduction of this thesis, parameters related to map complexity are of particular interest in map analysis, as they are expected to be important indicators of "meaningful learning" and of "expertise" among students (Watson & Barrella, 2017; Yin et al., 2005). Such parameters include "cross-linkage," "degree sequence," and "dimension."

4.1.2.1 Cross-Linkage

In the five example maps analyzed in this study, cross-linkage, which measures the proportion of total links not required to maintain map structure, ranges from 0% to 44%, with a mean of 24.88% and a median of 31.58%. This variation, although from a very small sample size, is encouraging in that it signals that cross-linkage may be useful to characterize and differentiate stakeholder maps in future iterations of this study.

4.1.2.2 Degree Sequence

"Degree sequence" measures how many nodes each node in a map is connected to. It is most useful in facilitating comparisons between maps once raw degree counts have been converted to show the frequency of nodes of degree 0, 1, 2, and 3+, due to the relation between specific degrees and the spoke, chain, and net structures discussed previously (Ch 2. Figure 13). In Figure 17, the proportion of total nodes of degrees 0, 1, 2, and ≥3 is compared between the five example maps.

Table 12 Degree sequence of five stakeholder maps, calculated as the proportion of total nodes bearing specific degrees.

	Proportion of Concepts of Each Degree (%)			
Map	*0º*	*1º*	*2º*	*≥3º*
a. Newcombe 2003	0.00	21.43	42.86	35.71
b. Kans 2021	0.00	62.96	7.41	29.63
c. Elias et al.2002	0.00	90.91	0.00	9.09
d. Hayes et al. 2021	0.00	26.67	20.00	53.33
e. Burge 2011	0.00	12.50	37.50	50.00

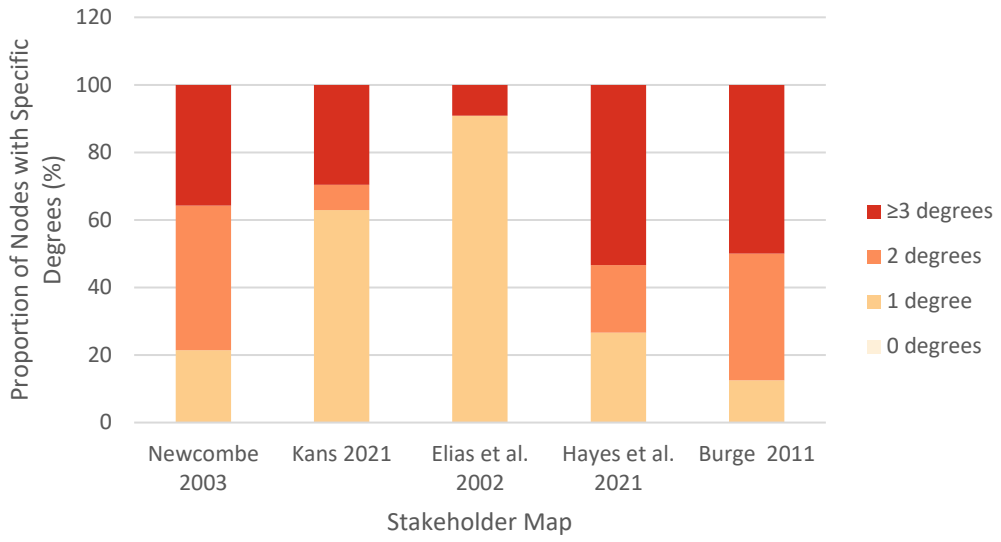


Figure 17 Degree sequences of example maps.

If we compare the degree sequences displayed in Table 12 and Figure 17 to the normalized maps in Figure 16, the proportional degree sequences describe the maps well in terms of spoke, chain, and net structures. The map appearing in Newcombe 2003 is characterized by almost equal levels of 2^o and $\geq 3^o$ nodes and low levels of 1^o in the analysis of degree sequence, which corresponds to its mixture of net and chain structures. The map appearing in Kans has a high frequency of 1^o nodes with a sizeable amount of $\geq 3^o$ nodes, reflecting the multiple spoke-structures connected to the map's root concept. The roots of each of the many spoke structures in this map are characterized by high-degrees, and the offshoots of these root concepts by degrees of 1. The map appearing in Elias et al. is also dominated by 1^o nodes, reflecting its classic spoke structure, and the maps appearing in Hayes et al. and Burge each have high frequencies of $\geq 3^o$ nodes, reflecting their high cross-linkage and net-like structures.

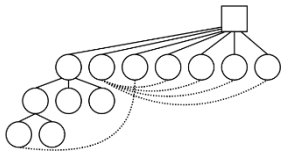
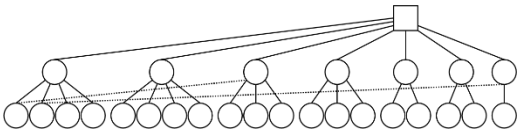
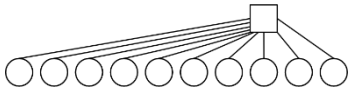
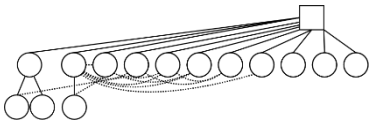
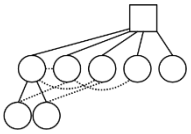
4.1.2.3 Dimension

Although "dimension" is proposed by Buhmann and Kingsbury as a measure of map interconnectivity, the converse appears to be true in the case of my sample data. The highest dimension is associated with the map appearing in Elias et al. 2002, which has a dimension of 2.18. This map also has the lowest cross-linkage of any of the maps analyzed and the lowest proportion of nodes of ≥3°. The map with the highest cross-linkage, implying highest interconnectivity, and highest proportion of nodes of ≥3° has a dimension of only 1.68. The implications of this disparity are discussed in the Discussion (Ch. 5).

4.1.3 Morphological Classification

The morphological classification of the five example maps is presented in Table 13. I found that the morphological classes provided by Buhmann and Kingsbury were not adequate in describing all five maps, as some exhibited characteristics of more than one class, and it was unclear how to decide which classification should take precedent over the other. In cases where classification was unclear, I included multiple classifications in tandem, such as "broad/interconnected" in the case of Hayes et al. I have also added a classification, "unconnected" in the case of Elias et al., as a defining feature of this map is its spoke-based structure, which is free from interconnections between nodes but also does not feature any completely detached nodes and thus seems unsuited to the "disconnected" morphological class defined by Buhmann and Kingsbury. These issues are emblematic of the subjective nature of Buhmann and Kingsbury's morphological classification, which I discuss further in the Discussion (Ch. 5).

Table 13 Morphological classification of example maps.

Map	***Normalized Map***	***Morphology***
a. Newcombe 2003		Interconnected
b. Kans 2021		Broad
c. Elias et al. 2002		Broad/Unconnected
d. Hayes et al. 2021		Broad/Interconnected
e. Burge 2011		Interconnected

4.2 CLIENT SATISFACTION QUESTIONNAIRE

As per my ethics approval, clients were only eligible to participate in the study if at least one member of the student team assigned to their project participated in one or more of the "Conceptions of Design" surveys and/or if all members of their student team consented to releasing their stakeholder mapping assignments for analysis. As consent for stakeholder map release was not acquired from all members of any team, only clients associated with participants of the Conceptions of Design surveys were eligible to

participate. Of nine eligible clients, four responded to the Client Satisfaction Questionnaire (CSQ).

Responses to multiple-choice questions are displayed in Table 14. Responses to all Likert scale questions have been normalized, with a response of 5 always denoting the "most" and/or "best" response possible, and 1 the "least" and/or "worst". For a complete list of questions and available answers, see the full survey in Appendix C-2. As the sample size is quite small, statistical analysis was not appropriate. However, it is encouraging to observe that there is variation between client responses, and that the sampling did not seem to select only those clients with very strong feelings, whether positive or negative, about their teams' performances.

Table 14 Responses to multiple-choice questions associated with the Client Satisfaction Questionnaire. Likert-scale questions have been normalized, with 5 representing the answers associated with "most/best" and 1 with "least/worst."

			Client's Student Team			
Parameter	***Question***		I	L	P	T
Quality	3	On a scale of 1-5, how close was the final outcome to your initial expectations?	5	2	3	5
Cost-Benefit	4	How much did your company benefit as a direct or indirect result of the design project outcomes?	5	2	3	5
	5	How much potential do you think the design holds to benefit your company in the future?	N/A	2	3	N/A
Involvement	6	Approximately how often did you meet with the design team over the course of the year? (face-to-face/virtually)	5	3	3	4
	7	Approximately how often did you communicate with the students other than the above-mentioned meetings (includes email, online messaging, etc.)?	3	1	2	2

			Client's Student Team			
Parameter	***Question***		I	L	P	T
	8	How would you rate the quality of communication between the design team and you during the project?	5	2	3	5
Complexity	10	How would you rate the technical difficulty of the design problem assigned to the design team?	4	3	2	3
Deliverables	11a	Did you view the final report?	Y	Y	Y	Y
	11b	How accurate was the final report?	5	3	3	5
	11c	How complete was the final report?	5	2	2	5
	12a	Did you view the final presentation?	Y	N	N	N
	12b	How accurate was the final presentation?	5	N/A	N/A	N/A
	12c	How complete was the final presentation?	5	N/A	N/A	N/A
Overall	14	How feasible is the design in its application and fabrication?	5	-	3	5
	15	1Are you going to implement this design?	4	-	4	5
	16	If you had a chance, would you be interested in working on another project with this design team?	Y	Y	Y	Y
	17	How would you rate your overall satisfaction with this design outcome?	5	2	3	5

Responses to short-answer questions are presented in Table 15. They have been redacted to obscure identifying information of respondents. Responses to question 2: "What were the design objectives for the project? What did you expect the team to accomplish?" have not been reported, as they are too clearly linked with each respondent. As in the case of the multiple-choice questions, it is difficult to make generalizations based on these responses. However, one interesting observation that can be made from this initial inquiry is that in multiple instances, the respondents' answers are more comprehensive than what was asked of them in the given questions. This is elaborated upon in the Discussion (Ch. 5).

Table 15 Short-answer responses to the Client Satisfaction Questionnaire. Reponses have been redacted to obscure identifying information. Redactions are represented by ellipses.

Client	***Short-Answer Questions/Responses***
	9. What was your role in these meetings/communications?
P	Primary contact and assisted with addressing technical questions related to the business.
T	Our roles were to provide feedback on what we are looking for, weigh in on design decisions as they were happening, and comment on product quality. The students always came very prepared – they had clear and concise information they needed from us, so our interactions went very smoothly. The students also received and implemented all important notes we had. This preparedness and consideration resulted in a fantastic final design.
L	Owner's representative
I	Project liaison/coordinator for [client company].
	13. Please comment on the accuracy, completeness and quality of the final prototype.
P	There were a couple of components that could have been designed with greater effectiveness. The team was rushed at the end, did not leave sufficient time for testing, this was primarily due to difficulties accessing materials and manufacturing services at Dal.
T	The prototype met all design requirements and expectations…
L	The project was challenging and there were challenges to overcome given the lack of availability of…and given the COVID-19 environment. The team could have spent more time and put more effort into the project.
I	Report and final presentation met or exceeded our expectations and provided us with the framework to construct new…when we require to do so….
	18. What would you do differently if you work on another student project?
P	Ensure the design and material acquisition phases were completed earlier in the term.
	18. What would you do differently if you work on another student project?
T	The only thing I would change is to give a more complicated design challenge – although this project has been impactful on the research here at…I know these students are capable of much larger, complicated projects. I do wish that we could have provided a more complicated project, however the students still approached the problem with the utmost importance and delivered a great product.
L	Prefer not to answer

Client	***Short-Answer Questions/Responses***
	18. What would you do differently if you work on another student project?
I	A more focused design problem may be in order in future projects. The project was large and mostly a paper project due to covid restrictions and the associated cost…However, the team stepped up and adapted during the project and produced a great result…

4.3 CONCEPTIONS OF DESIGN SURVEY

4.3.1 Description of Student Responses

A total of 14 students completed at least one "Conceptions of Design" survey. Three students completed the first instance of the survey ("F," held in Fall 2021), two completed the second instance ("W1," held in March 2021) and thirteen completed the third instance ("W2," held in April 2021). Two students (O35 and I23) completed more than one instance of the survey, with O35 completing all three instances and I23 completing F and W2.

Figure 18 shows each respondent's answers for each of the three survey timepoints, with activities chosen as "most important" coloured in blue, and "least important" in yellow. Because the number of participants was very low for surveys F and W1 (n=3, and n=2 respectively), the data cannot be assumed to be representative of capstone students in general, and generalizations that can be made about the data are therefore limited. However, it is interesting to note that "Understanding the problem" remains ubiquitous as a "most important" choice throughout all three surveys. It is also interesting to note that some activities, such as "prototyping," "iterating," and "testing," are considered by some students as "most important" and by others as "least important". This indicates that the students surveyed hold converse views of the importance of certain

activities, which is surprising in a class of upper-year students enrolled in the same program at the same institution.

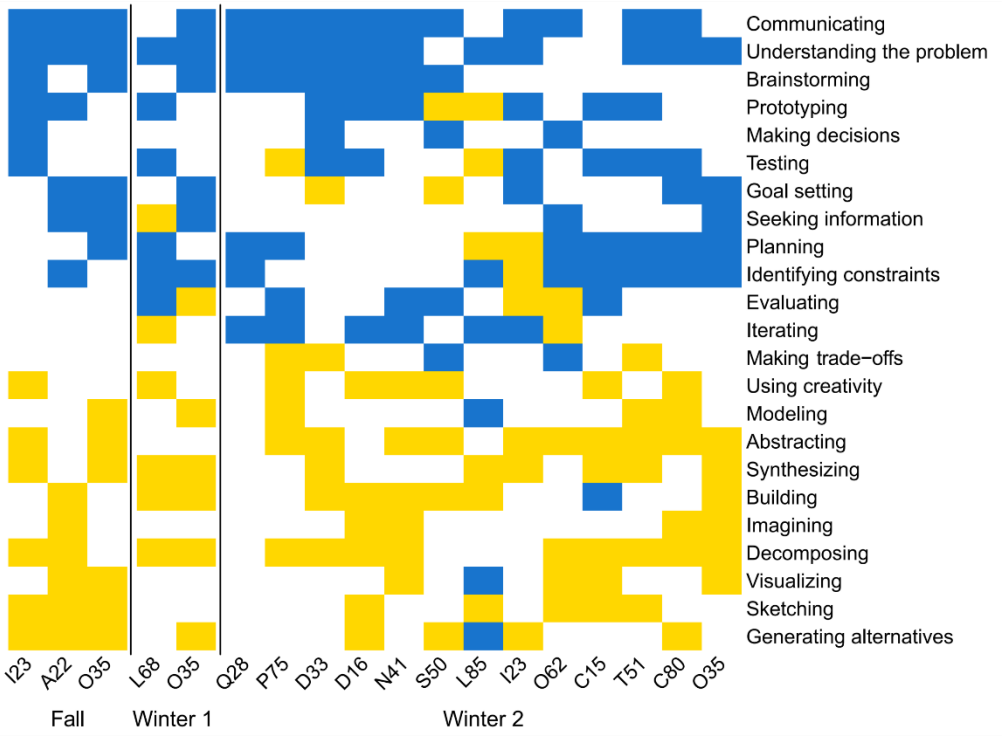


Figure 18 Student responses to "Conceptions of Design" survey, administered at three timepoints (Fall, Winter 1, and Winter 2). Design activities picked as "most important" are coloured in blue, those picked as "least important" are yellow, and those not picked by are white.

From the heatmap, we can also make qualitative observations of the responses given by the two students who responded to multiple instances of the survey, I23 and O35. Figure 19 is derived from the original heatmap, but instead of being organized primarily by survey timepoint with students as a subcategory, it arranges responses first by students and then by timepoint, allowing us to see changes in individual student perceptions over time. As only two students responded to more than one instance of the survey, only responses from these two students (I23 and O35) are included in this figure.

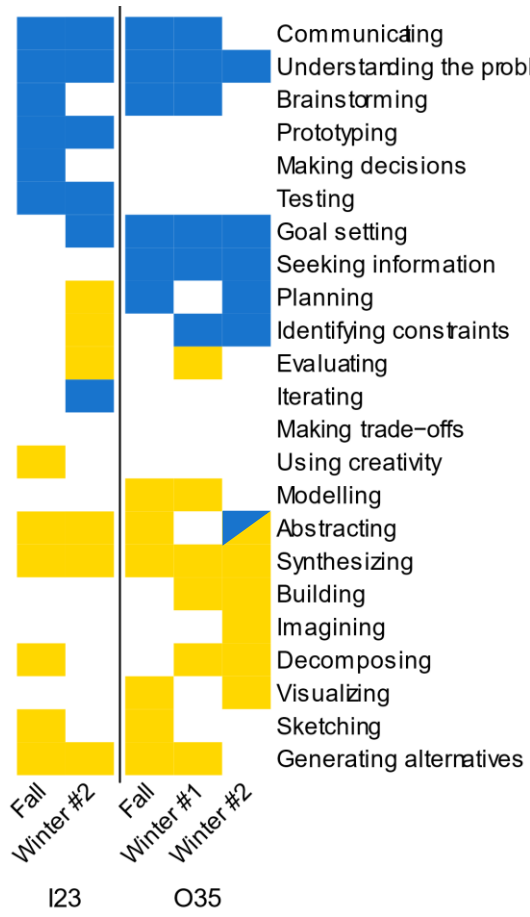


Figure 19 Responses of students I23 and O35 to the "Conceptions of Design," at different timepoints. Design activities picked as "most important" are coloured in blue, those picked as "least important" are yellow, and those not picked by are white.

From this heatmap, we can see that between the first and third instances of the survey, I23 dropped "brainstorming" and "making decisions" from their "most important" activities and replaced them with "goal setting" and "iterating." They also dropped "decomposing," "sketching," and "using creativity" from their "least important" activities, replacing them with "evaluating," "identifying constraints,", and "planning." O35, who completed all three instances of the survey, had slightly more stable responses. Between the first and second surveys (F and W1), they dropped "planning" and added "identifying constraints" in the "most important" category, and between the second and

third (W1 and W2) they dropped “brainstorming,” and “communicating,” reinstating “planning,” and adding “abstracting” (although this last choice may have been an error, as “abstracting” also appears of one of O35’s “least important” activities in this instance of the survey). In the “least important” category, they dropped “abstracting,” “sketching” and “visualizing” between F and W1, replacing them with “building”, “decomposing,” and “evaluating, and between W1 and W2, they dropped “evaluating,” “generating alternatives,” and “modelling,” replacing them with “abstracting,” “imagining,” and “visualizing.” In neither of these two subjects’ responses did they ever shift a design activity from “most” to “least important”. While generalizations are limited due to the very small sample, the responses of these two subjects certainly suggest that students’ conceptions of design as measured by the survey, are liable to change throughout the schoolyear, and that the degree and type of change may differ between individuals.

4.3.2 Comparing Student Reponses with Existing Literature

For the purposes of this comparison, I only use data collected from Winter #2 (W2), as this instance of the survey is associated with the highest number of participants. I chose not to combine data from different timepoints due to the repeat in participants and the demonstrated possibility for variability in student responses between timepoints. As such, all proceeding figures include data only from the W2 instance of the survey. Figure 20 shows the data collected from the W2 survey against an approximation of those presented in Atman et al. (2008).

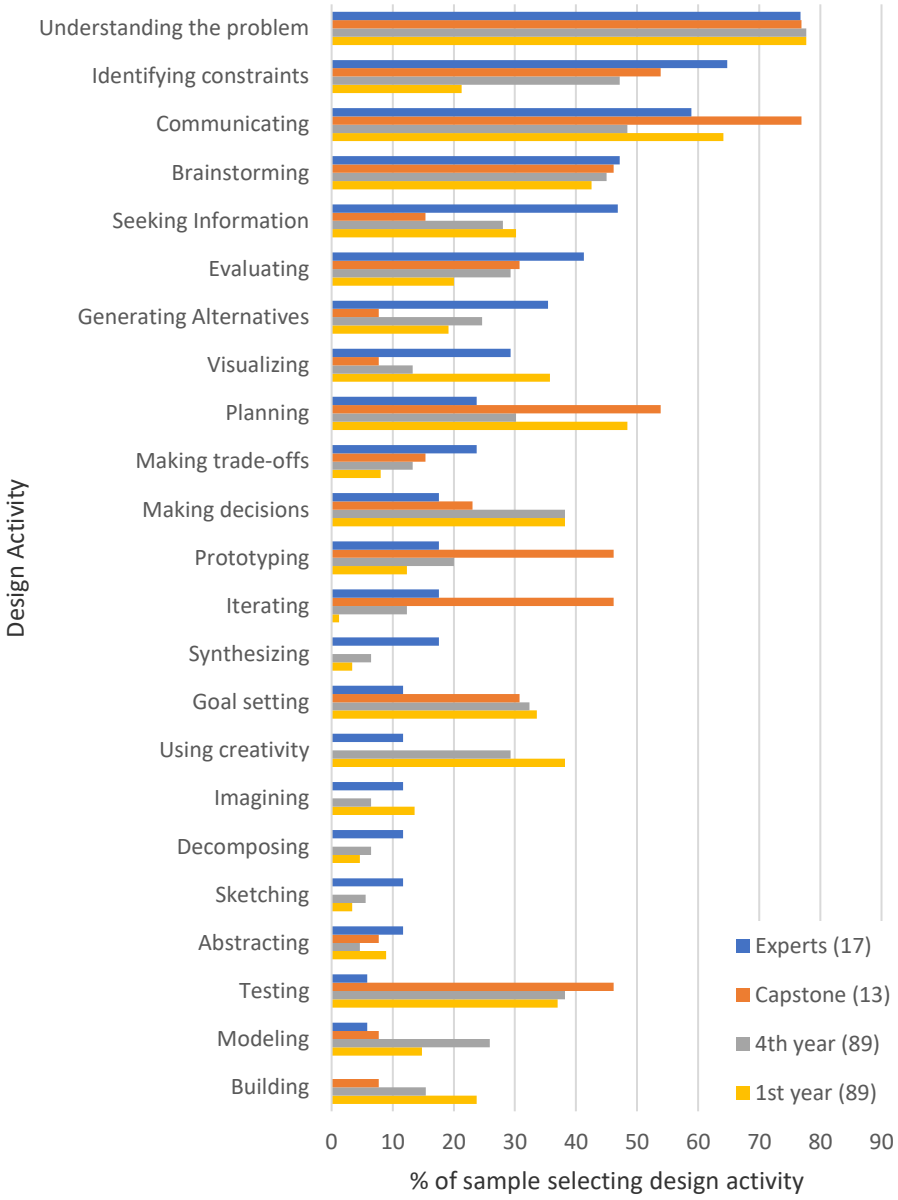


Figure 20 Comparison of frequency at which certain activities were picked as "most important" by capstone students, experts, first-year, and fourth-year students. Data corresponding to last three groups mentioned was obtained by analyzing a graph published in Atman et al. 2008.

As discussed in the introduction of this thesis, researchers associated with Atman et al. collected student responses to the Conceptions of Design survey in their 1st and 4th years of engineering study, compared student responses to those given by experts in

Mosberg et al. 2005, and identified statistical changes in student responses between timepoints. In Figure 20, responses given by capstone students in the W2 survey timepoint of my study are combined with those presented in Atman et al, with Capstone results coloured in orange, expert results in blue, and 1st and 4th year responses in yellow and grey.

An element that stands out in this figure is the consistent choice of "understanding the problem" as a "most" important activity, regardless of sampling group. There appears to be a fundamental understanding, even in first year students, that understanding the problem is integral to engineering design. The same can be said of "brainstorming," which presents a similar trend.

The results of my study appear to conform with those of Atman et al. 2008 in many areas in which student responses differ greatly from those of experts. This is especially evident in "goal setting," and "testing," which are picked much more frequently by each of the student groups than by experts.

Areas where capstone students differ from other student responses, especially from those of Atman et al.'s 4th year students, a cohort that we can assume has a similar amount of design experience as capstone students, include "communicating," "seeking information," "generating alternatives," "visualizing," "planning," "making decisions," "prototyping," "iterating," "modelling," and "building."

In the case of "making decisions," and "modeling," the capstone student responses more closely resemble those expected from experts than those given by 4th and 1st year students.

In the case of "communicating," and "planning," capstone responses are higher than experts and 4th year students and are most similar to responses expected from 1st year students.

"Prototyping," and "iterating," were complete outliers among the design activities, with capstone students picking them at a much higher frequency than all other groups.

"Seeking information," "generating alternatives," and "visualizing," also stand out, with capstone response frequencies much lower than all other groups. It is also interesting to note that five activities picked by experts, 1st years and 4th years in Atman et al., "synthesizing," "using creativity," "imagining," and "decomposing," were not picked by any capstone students.

As Atman et al. 2008 does not include an analysis of survey responses regarding the "least important" activities to design, here I present the results of the W2 survey against those collected from 19 experts by Mosborg et al. (2005). In Figure 21, we can see that capstone responses conform relatively well to those expressed by experts, except for in a few stand-out activities: "sketching," "making decisions," "using creativity," "generating alternatives," "making trade-offs," and "evaluating." It is interesting to note that three of these activities, "sketching," "generating alternatives," and "using creativity" are also major points of departure between capstone students and experts in the "most important" category, with capstone students choosing these at a much lower rate than all other groups sampled. The converse results in the "least" important category, with capstone students picking these activities at a much higher rate than experts, may be part of the same trend.

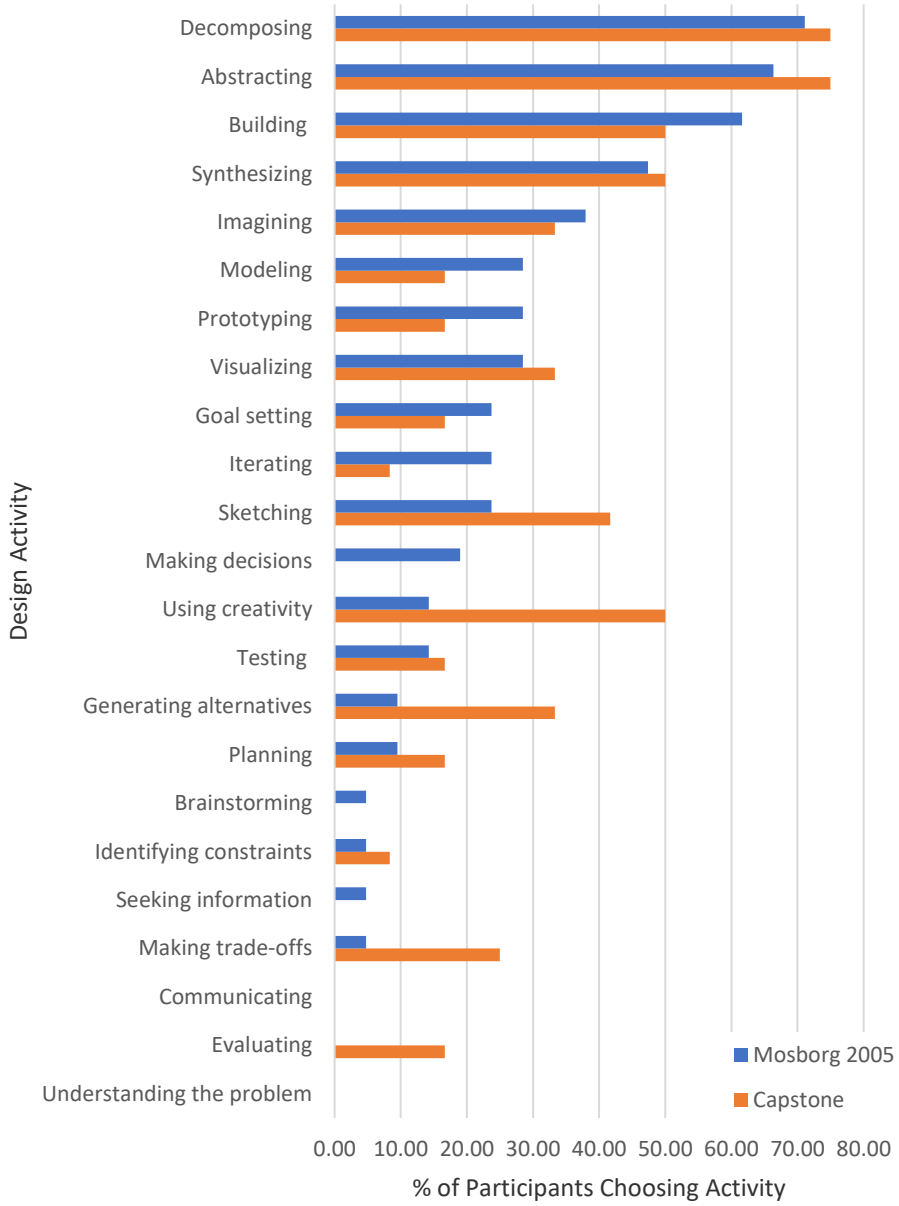


Figure 21 Comparison of frequency at which certain activities were picked as "least important" by capstone students and experts. Data corresponding to "experts" was obtained by analyzing a graph published in Mosborg et al. 2005.

4.3.3 Student Scores

Students' Conceptions of Design scores for each of the survey timepoints, as calculated by the scoring protocol discussed in the Methods I (Ch. 2), are displayed in Figure 22. Overall scores range from three to seven, out of a maximum score of eight. Within the "most important" subcategory, students' scores run from zero to four, and in the "least important" subcategory, scores run from one to four, out of a maximum of four. In the W2 instance of the survey, the only timepoint for which there are enough respondents to obtain a meaningful measure of central tendency, the mean overall score is 4.50, the median is 5.00, and the mode is 5.00 (the score associated with Q28 is omitted from central tendency calculations, as this student did not complete the "least important" portion of the survey, and therefore only has a score for their "most important" responses). Once again, from the viewpoint of future research it is encouraging to see variation between students in their COD scores as it suggests that the COD survey may be appropriate to differentiate between students within a capstone environment.

It is also encouraging to see changes in individuals' scores between timepoints. Although participation numbers exclude statistical analysis of change over time, it is interesting to take a qualitative look at the two participants who responded more than once to the survey. Figure 23 shows the COD scores of O35 and I23 across the three instances of the survey. There is obvious variation between both students and timepoints, with O35 moving from a score of 5, to 7, and then to 6, and I23 moving from a starting score of 5, to 3. As with the raw answers discussed earlier, the variation between timepoints of these two students is congruent with research plans, which hope to track change in student conceptions of design over time.

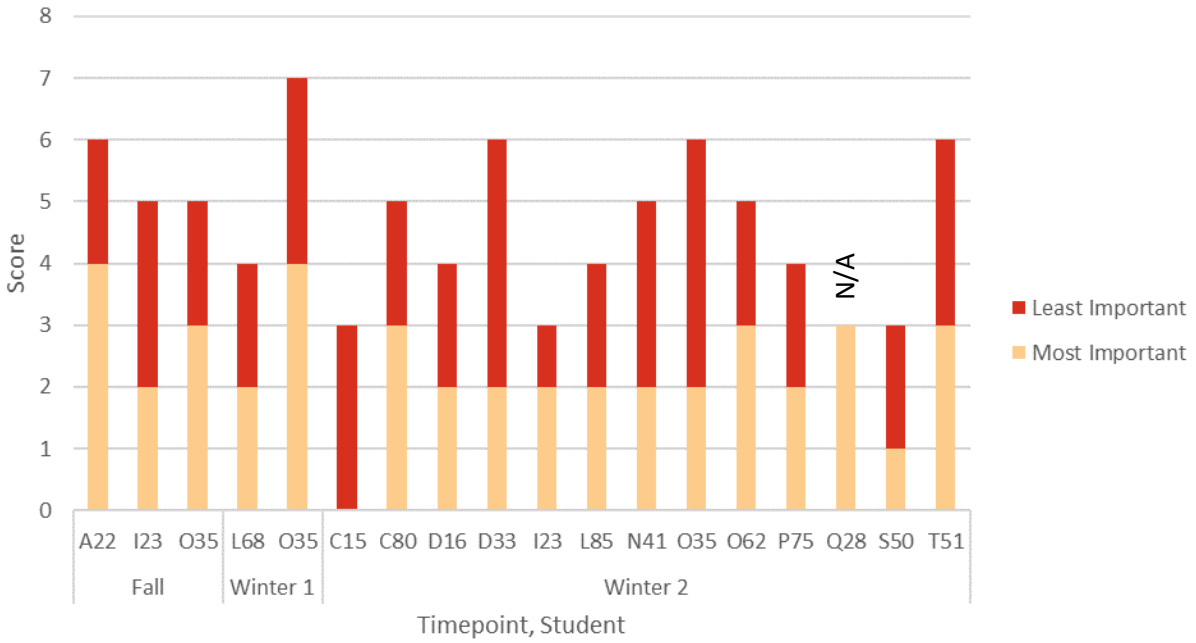


Figure 22 *COD scores as calculated with my proposed scoring protocol. Note, participant Q28 does not have a score of "0" for "least" important, but instead did not respond to this section of the survey. Due to the missing information at this data point, Q28's score is not included in calculations of central tendency in either the "least important" or "overall" categories.*

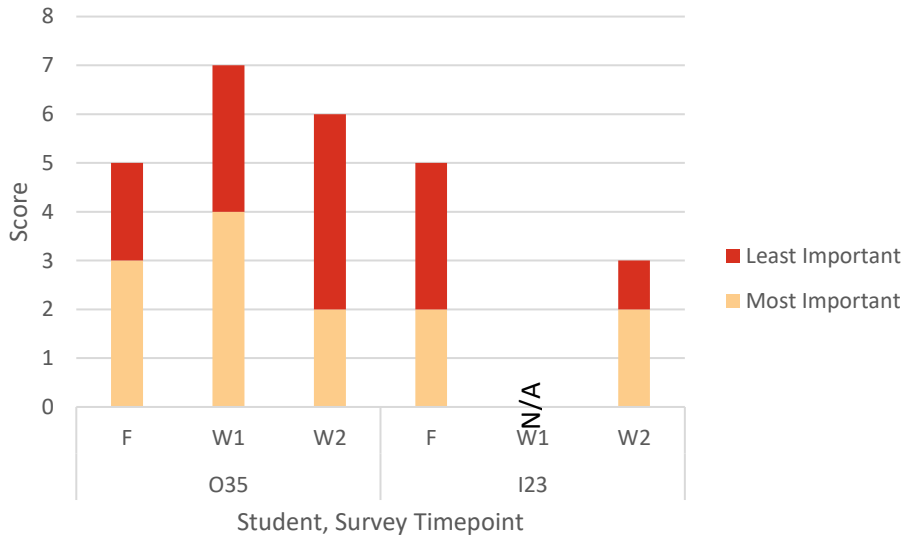


Figure 23 *COD scores of students O35 and I23 across three timepoints. Note, I23 did not complete the W1 instance of the COD survey, and thus does not have a score associated with this timepoint.*

4.4 STUDENT INTERVIEWS

Student opinions regarding the stakeholder mapping assignments ranged from the very negative, to the ambivalent, to the cautiously positive. Here I present themes arising in student comments regarding the fall and winter assignments and the course in general. Within each of these categories I present pertinent "neutral," "positive," and "negative" themes and comments. "Neutral" themes here refer to information which does not assign any type of value; for instance, in the case of the Fall 2020 assignments, I present whether each team completed the assignments as a group as a neutral theme, as this is simply a statement of fact. In general, only themes for which at least two or more students contributed comments are reported.

In all quotations of student comments, the word "like" has been removed without being replaced by ellipses. This is due to the overwhelming frequency of the use of the word "like" by interviewees; if ellipses were used in place of each instance of the word "like," the resulting phrasing would be extremely difficult to read in a fluid manner, and the meaning of the phrase could be obscured to the reader.

4.4.1 Fall 2020 Assignments

4.4.1.1 Neutral Themes

Of the nine teams from which I interviewed students, six completed the assignments together with their team, while three completed them by breaking up tasks among teammates who completed these individually (Table 16).

Table 16 Methods used by student teams to complete Fall 2020 Assignments.

Team	*Completed as team*	*Completed individually*
D		X
F		X
I	X	
J	X	
N	X	
O		X
P	X	
Q	X	
T	X	

Although the sample size is small, it is interesting to note that the three students who stood out as having the least favourable, bordering on hostile, opinions of the assignments, D16, D33, and F56, all belonged to groups who completed the assignments individually. This may be coincidence, but also suggests that student perceptions of the assignments may be correlated with how they complete them. It is however, also necessary to point out that F56's teammate, F31, did not share F56's negative views of the assignments.

4.4.1.2 Positive Themes

Comments expressing positive thoughts/feelings towards the Fall 2020 assignments fall into twelve themes, ten of which can be grouped into four overarching categories: planning, problem overview, ease, and external pressure. Table 17 shows the occurrence of comments by specific individuals within each of these thematic groups. Comments that did not fit into any of these twelve themes and which were mentioned only by one participant are not included in this table, however, comments made by one outlier, J59,

who had a very positive view of the fall assignments, are included in the Discussion (Ch. 5).

Table 17 *Distribution of student comments that express positive thoughts/feelings regarding the Fall 2020 stakeholder mapping assignments within twelve themes.*

	Planning			*Problem Overview*			*Ease*		*External Pressure*		
Student	Organizing information gathering	Forming questions	Planning next Steps	Problem Scope	Connectedness	Who to consider	Time/Effort	Applicability to other Assignments	Centrality of Client	Accountability	Connection to Industry
D16											
D33											
F31							X		X	X	X
F56											
I23		X			X	X			X	X	X
J59									X	X	
N41				X			X				
O35	X		X		X		X	X		X	
O62		X	X		X		X			X	
P38	X			X	X		X		X	X	X
P93	X					X		X	X	X	
Q28					X	X			X	X	X
T51				X							
Total	3	2	2	3	5	3	5	2	6	8	4

Planning

Comments grouped within the "planning" category revolve around three activities: organizing information gathering, forming questions, and preparing next steps. Five students spoke about planning activities in relation to the stakeholder mapping assignments. Three students referred to the first few stakeholder assignments as a

"starting point" for their information gathering stage, helping them decide what information they needed to gather and who they needed to talk to. Two students spoke about the usefulness of creating questions before going into stakeholder meetings, and two students spoke about how the assignments helped them prepare for their next steps. Quotations representative of each of these subsections are arranged in Table 18.

Table 18 Example student comments coded under "planning."

Student	*Subcodes and Example Comments*
	Planning for Information Gathering
P38:	"Ok, we have a list of stakeholders…now we have a starting point for our project, who do you want to interview to get more information and background stuff…"
O35:	"…the stakeholder mapping assignments in the fall were more helpful just because we were getting going. So, some of the information we were like… 'Ok, do we know this...do we have to find that out?'…"
	Forming Questions
O62:	"…the one where we had to come up with the questions, that was good in just planning questions for our interviews with the stakeholders, you know, going into an interview with the stakeholder you should have questions prepared anyway…"
I23:	"…one of the good questions was 'what are you gonna ask these people in the future?' …putting those…in question format can sometimes be something that [you] can go back to …if you don't have set deliverables, it's pretty easy to get lost in what you're talking about…"
	Organizing Next Steps
O62:	"…I found the fifth one was…more useful going forward than the previous four…just because that one was more planning ahead than kinda documenting what we'd already done…"
O35:	"…it definitely helps us layout what we've found out in the previous weeks or what we're looking forward to next."

Problem Overview

Eight of the thirteen students interviewed spoke about the fall assignments in terms of developing their understanding of the problem context, whether it was through

visualizing the scope of the problem, defining connections between stakeholders, or identifying who to consider when developing their design solutions. The frequency of comments related to these themes is not surprising, given that the stated goal of the assignments was to deepen students' understanding of their problem contexts by identifying and describing connections between stakeholders. Student views expressed here may be influenced by the language used in the assignment outlines and introductory materials. Typical phrases coded under these themes are presented in Table 19.

Table 19 Example student comments coded under "problem overview."

Student	*Subcodes and Example Comments*
	Scope
P38:	"…identifying stakeholder[s] is…key for project management…cause the first thing about any project is developing the scope…and to develop the scope you need to know the background and 90% of the background comes from talking to the stakeholders."
T51:	"…I found the first time was kind of fun and good to do because you just kind of see 'Ok, here's our whole project – what's happening?'…"
	Connections Between Stakeholders
O62:	"…the first couple stakeholder maps were good in terms of where we were at, like lining up with the project…it was good to make those connections and try to organize our stakeholders as to who interacted with who…"
I23:	"…to group people together…that was a way to see how people are interconnected. It was hard to do that, but sometimes that's a good way to build your design on who you're serving."
	Who to Consider
I23:	"…the exercise has been good to teach us about who to consider, who to keep in mind…"
	"It was good to consider who you're doing the design for."
P93:	"…in the beginning of the fall term, stakeholder map[ing] was…pretty useful because it did give you a good visual of the scene around you and who you need to consider when making this…design."

Ease

Six students spoke to the ease with which they completed the fall assignments. This ease related to two areas: the difficulty of the content and the time it took to complete each assignment, and the applicability of the assignments to other course requirements. Ease was seen as a positive aspect of the assignments, often given as a reason as to why they were not too much of a nuisance. Phrases typical of these themes are displayed in Table 20.

Table 20 Example student comments coded under "ease."

Student	*Subcodes and Example Comments*
	Time/effort
F31	"…it didn't really take a lot of extra effort…so maybe that's why we weren't bothered by it and found it useful in a way"
O35	"…I don't care, 'cause the assignments don't take like too, too long."
O62	"…even though we didn't find them the most valuable thing…it wasn't a ridiculous time commitment or anything like that."
	Applicability to other Assignments
O35:	"…complements the other assignments that we're doing, which is nice. So, I found…map four, we wrote a lot of stuff in there that was helpful to our conceptual design report."
P93:	"I guess it would also help with the requirements section, 'cause it's like: 'Who, who is this for?' You know, disposal – what does it need to be made of for it to be disposable and all that? So, I would say in the beginning it's pretty good for those types of things, you know?"

External Pressure

This was the most frequently occurring positive theme arising in relation to the fall assignments, with nine students describing the assignments as an external force that pushed them to think about stakeholders. Among these nine participants, six spoke specifically about the centrality of the client to the capstone process, and the lack of incentive to seek information from sources other than their client, a theme which arises

again in negative comments about the assignments. Eight students also talk about the assignments as enforcing accountability in that the assignments "force[d]" (O62) teams to speak with stakeholders, and kept teams "on track," (P38).

Table 21 Example student comments coded under "external pressure."

Student	*Subcodes and Example Comments*
	Centrality of Client
J59	"…I think the external pressure from the Department saying we had to go find these stakeholders. I think our client would've been completely happy with us just talking to him and…going over it with him because he's an expert."
Q28	"…I feel like when you're doing a capstone project it's kind of like 'Oh, we're dealing with the client and that's it.' But having to think a little bit more about who else is going to be affected down the line, I think was very useful… being able to visualize where each person comes into play."
	Accountability
J59	"...the stakeholder map stuff was useful for getting us to find people to talk to…I don't think we would have thought to necessarily seek out those stakeholders to talk to, get their opinions, if we hadn't been asked to do these assignments…"
P38	"If there's no…no governing bodies being like 'you need to talk to them' there could be teams that slack off and do not talk to a lot of stakeholders and miss opportunities and information on their project…"
O35	"…they forced you to be like 'OK, what are the connections between all these people?' and stuff like that…"
O62	"…you should have questions prepared anyway, so that forced us to do that."

Relevance to Industry

Four students linked the value of the fall stakeholder assignments to the relevance of stakeholder analysis within industry, either relating the assignments to their previous coop experiences or considering them as exposure to something they would be required to do in their careers. This theme also arises in negative comments about the winter

assignments, in which one student (P38) questions the usefulness of journey maps based on their absence within the student's previous coop experiences.

Table 22 Example student comments coded under "relevance to industry."

Student	*Themes and Example Comments*
	Relevance to Industry
F31	"…it's kind of exposure that we need going into real jobs, but we didn't really get anywhere else, so it's, even if people don't like it, it's kind of good that we had to at least learn that it was an important thing to do."
P38	"…the first identification was fine. That was great; like in industry they do that. I, as far as I've worked in my Coop, on all my projects we had to do that…"
Q28	"…stakeholder interaction is something that you would do a lot as an engineer in your future career, so I think it's better to do it now while you're still a student rather than being out in the field that they're like "Ok, go find the stakeholders"…"

4.4.1.3 Negative Themes

Comments expressing negative thoughts/feelings can be grouped into twelve themes, with three overarching categories, "pointlessness", "mismatch with capstone projects", and "timing," incorporating ten of these. Table 23 shows the occurrence of comments by specific individuals within each of these thematic groups. Comments that did not fit into any of these twelve themes and which were mentioned only by one participant are not included in this table.

Table 23 *Distribution of student comments that express negative thoughts/feelings regarding the Fall 2020 stakeholder mapping assignments within twelve themes.*

	Pointlessness				*Mismatch with Capstone Projects*			*Timing*				
Student	Already know/have information	Busy Work	Childish	Fabricated Information	No bearing on project	Projects too simple	Interacting with few people	Too many iterations	Pacing within course	Time Commitment	Messy	Online
D16		X	X	X	X		X	X				
D33				X	X		X					
F31								X	X	X		
F56		X	X		X			X	X	X		X
I23	X				X			X			X	
J59		X					X	X				
N41						X	X	X	X			
O35	X	X			X	X	X	X			X	X
O62	X	X			X		X	X	X		X	
P38	X	X				X	X	X	X		X	
P93								X				
Q28		X					X					X
T51						X	X	X				
Total	4	7	2	2	6	4	9	11	5	2	4	3

Pointlessness

Eight out of the thirteen students expressed doubt over the point of the assignments. Of these eight, four expressed the belief that they would have acquired all the necessary stakeholder information without being prompted by the stakeholder mapping assignments, seven considered the assignments as extra work irrelevant to their projects, two saw the assignments, especially the drawing portions, as "childish," and two (both

from the same group) expressed a refusal to engage with the assignments at all, having "fabricate[d]" stakeholders from the first assignment onward. This fabrication is distinct from that described by other students, many of whom explained the need to fabricate changes in the later iterations of the assignments due to lack of new information. Such comments are included in the "too many iterations" theme within the "timing" category. The comments made by D16 and D33, grouped here under "fabricated stakeholders," seem to express a much deeper antagonism to the assignments than do the comments given by students about later iterations.

Table 24 Example student comments coded under "pointlessness."

Student	*Themes and Example Comments*
	Already know Information
I23	"If we didn't do this exercise, I still think that those people would have told us the information that we would have had to consider anyway"
O35	"…we already knew all the stakeholders right up front. We knew all their connections just because we were told all that information by our client."
O62	"…we already knew what our client's main concerns were…we didn't necessarily need to show it on paper…we already know that…we already know what their concerns are"
	Busy Work
D16:	"…the general consensus of my team was that they were kind of busy-work feeling."
F56:	"…it took away from time that I wanted to be doing research and other stuff and it kind of felt like busywork…"
	"…I felt like the sub was in and the teacher had left worksheets…"
J59:	"…it's almost like we're trying to check the box rather than actually considering the stakeholder…"
	Childish
D16:	"…felt like, you know, when you made mind maps in grade 8 and…you're like 'All right, I mean, I think the teacher just didn't really have anything else for us to do.'"
F56:	"Having to draw them to see that they were 'real people' made me feel like I was a 5th grader with a psychopathy diagnosis….So that is not a great start…"

Student	*Themes and Example Comments*
	Fabricated Information (regardless of iterations)
D16:	"…'Ok, we almost have to fabricate these other stakeholders,'…there was no way we were ever going to actually find those people..."
D33:	"…most of it [writing] was just, you know, nonsense, because none of it was true and we were trying to fill the page…"

Mismatch with Capstone Projects

Eleven of the thirteen students spoke of a disconnection between the goals/outcomes of the assignments and the students' capstone projects. Six of these thirteen indicated that the assignments did not affect how they completed their projects, four suggested that their projects were too simple to benefit substantially from stakeholder mapping, and nine spoke to the small number of people they interacted with over the course of their projects. This last theme includes comments reflecting the client's centrality within capstone design (a subject which also appeared in the "positive" comments concerning the assignments), and barriers to accessing stakeholders, whether it be from their lack of interest in the project outcomes or administrative issues such as research ethics and non-disclosure agreements.

Table 25 Example student comments coded under "mismatch with capstone projects."

Student	*Themes and Example Comments*
	No Bearing on Project
D33:	"…we could think of the right number that they needed, but it wasn't useful to our project. It didn't affect how we did the project."
I23:	"…we don't really use it other than the fact that it's due every two weeks…the progress we've made hasn't been directly connected [to the assignments]"
O62:	"…as it's not directly contributing towards the progression of the project, it seems unnecessary."

Student	*Themes and Example Comments*
	Projects too Simple
N41:	"…this stakeholder mapping thing has the potential to be great for a *really* complex problem, and again, ours were not so complicated."
P38:	"Some other projects might be much more complex…which could make the stakeholder mapping process a lot more complicated and a lot more useful to them particularly…"
T51:	"…some projects may have a lot more options…or find it more useful because their scope is larger…"
	Interacting with Few People
D33:	"…we could get kind of all the information from a single stakeholder which was the CEO or founder…of our company…any questions that we had for the other stakeholders, he [the client] can answer himself."
	Interacting with Few People
J59:	"…we were kind of limited with the stakeholders we could actually talk to…he [the client] didn't want to have to deal with research ethics boards, so we couldn't directly interview some stakeholders."
N41:	"…we had *a* key stakeholder…who actually cared?...just one person..."
P38:	"Because our project is so client-based, all the requirements, definition and scope comes [sic] from the client. It doesn't change much when we talk to stakeholders 'cause it's not really like…most of the requirements come from the client themselves."

Timing

Eleven of the thirteen students interviewed commented on the timing of the assignments, whether it was the amount of time needed to complete the projects, the pacing of the assignments within the broader course and in relation to their projects, or the redundancy of the iterations required in the assignments. Within "pacing in relation to course," it is interesting to note that once again the centrality of the client is mentioned; one student, F31, expresses that if instructors want students to spend more time up front on stakeholder analysis, they should make that clear to clients, so that students are not disappointing them by delaying their development of solutions.

Table 26 Example student comments coded under "timing."

Student	*Themes and Example Comments*
	Time Commitment
F31:	"…at times [the assignments] felt like they took a long time...we felt like we were spending a lot of time on…class deliverables in general compared to like getting started on our actual project."
F56:	"…I'd be like 'time to do capstone,' and then I would spend all of my capstone time doing…the stakeholder mapping and wouldn't have time to do research…"
	Pacing in Relation to Course
F31:	"…if we're going to take more time at the beginning to be doing more stakeholder interviews and things like that, then we would have had to…[put] off our client…like 'No, we're not ready to decide yet. We still need to talk to these people.'"
P38:	"…we were moving faster than how the stakeholder mapping assignments were moving…by the time stakeholder assignment 2, for the first map we had to create, we [had] already interviewed 10 stakeholders."
O62:	"…what's the point of this?...we're past this stage…"
	Too Many Iterations
N41:	"…by the time you did an iteration or two you're probably at the solution, right? And, you know if you keep asking people they'll probably just start getting angry at you…so I think certainly it was the correct thing to do, but perhaps the number of iterations may have been…beyond what was required."
P38:	"We made our iteration one so well that in iteration two there only a little minor change and by the time it was iteration three we were like 'OK. What are we going to change?'"
F56:	"…you just start coming up with things to change…"

<u>Other</u>

Three students spoke about the difficulties posed by completing the assignments online, suggesting that this may have decreased the usefulness of the assignments. Four commented that the messiness of the maps themselves decreased their usefulness, as they were too complex to make sense of.

Table 27 Example student comments coded under "online" and "messiness."

Student	*Themes and Example Comments*
	Online
O35:	"…I feel like also if it were in person and…it was like 'Oh, OK, everyone has to go down to the design room…and everyone gets a white board and you get to like draw it out,'…I feel like [people] might start actually generating ideas and brainstorming. But yeah, for us we were like: 'Hey, this one person, go do it.' We're not making this a collaborative exercise..."
Q28:	"…if we wanted to set up interviews, you know it's going to be online and it might be kind of awkward like we haven't even met our clients in person…"
	Messiness
O62:	"…there was just so much...going on for it to be of any real use to us."
P38:	"…it was going crazy all over the map. So with like 45 stakeholders it will be disaster."

4.4.2 Winter 2021 Assignments

4.4.2.1 Neutral Themes

Of the nine teams from which I interviewed students, five spoke with stakeholders in order to complete both "interaction summary" assignments in the winter semester, and four completed the assignments only from information they had already collected (Table 28). All teams who reported speaking with stakeholders for these assignments did so during routine meetings; they did not set up specific "interview" sessions, but instead brought up questions similar to those asked in the assignment outlines in meetings they had already scheduled. These teams supplemented the data gathered during these conversations with information gathered previously when completing the interaction summary assignments.

Table 28 Methods used by student teams to complete the Winter 2021 "Interaction Summary" assignments.

Team	Spoke with Stakeholders	Completed only from Existing Data
D		X
F	X	
I	X	
J	X	
N		X
O		X
P		X
Q	X	
T	X	

4.4.2.2 Positive Themes

Positive comments concerning the Winter 2021 assignments were very limited. The only apparent recurring theme within these positive comments is that there were less assignments than in the Fall term, coded here as "timing". This was expressed by two students.

Table 29 Example student comments coded under "timing."

Student	*Themes and Example Comments*
	Timing
F56	"I think that the winter term, the spacing was a lot better….obviously time had passed, your project has developed, now let's talk about [it]."
I23	"…I like that there was less of them. It gave us more to think about in terms of talking to people…"

4.4.2.3 Negative Themes

Negative comments regarding the winter assignments can be grouped into four themes, three of which can be further grouped under the category of "timing within course." Four students spoke about the difficulties they had in maintaining contact with their client, and

how this limited their ability to interview subjects for the winter assignments. Nine students said that by the winter term they had already collected all relevant stakeholder information, and many therefore did not do the interviews but completed the assignments using information already collected. Seven students suggested that the timing of the assignments did not fit with their design progress; by the time the assignments arose it was too late in the schoolyear to integrate any potential insights into their designs. And two students spoke to the "crunch time" experienced by teams in the winter semester, relating this to their inability to focus on stakeholder mapping assignments.

Table 30 Distribution of student comments that express negative thoughts/feelings regarding the Winter stakeholder mapping assignments, arranged in four themes.

		Timing within course		
Student	Client too busy to interview	Already knew information	Too late to make design changes	Winter semester rushed
D16	X	X		
D33		X	X	
F31		X	X	
F56				
I23		X		
J59		X	X	
N41	X			
O35		X		
O62		X	X	X
P38		X		
P93	X	X	X	
Q28	X		X	X
T51			X	
Total	4	9	7	2

Table 31 Examples of negative comments made by students regarding Winter 2021 stakeholder assignments.

Student	*Themes and Example Comments*
	Client too Busy to Interview
D16	"…even getting him [the client] for a video call was sometimes a big planning process…the thought of actually planning a separate interview for this stakeholder assignment was off the table; like no one in our team was going to do that."
N41	"…I couldn't actually bring myself to ask any of those questions to any person that was busy in any way."
O35	"…we're like 'we can't even get ahold of our client,' so we're just like 'we already know the answers to all these questions, and they don't really have the time…'…"
	Already Know Information
D33:	"…I mean at that point, we would have already interviewed the people, like that happened a long time ago, so we didn't actually do it obviously."
J59:	"…the ones in the second semester, they were almost a little less useful because we'd almost been over that ground before."
P38:	"We just had so many interviews done…we already had the information…so it was basically reiterating…"
	Too Late to Make Design Changes
J59:	"…at that point nothing in our design was going to change anyways…we're already building it…there's not much we can do to change our design at that point."
P93:	"…I thought it was so funny because we're here at the end, we basically have our design finished; we're building it and we are doing the assignment…"
Q28:	"…the earlier you have this information, the better it's going to be because then it'll help guide your design…"
	Teams Rushed During Winter Semester
O62:	"…the winter term, it's kind of go-go-go anyway…you're really rushed in terms of designing and trying to figure stuff out…you just end up getting to a stage where you're just trying to get something put together regardless of any issues with it…it may not address every concern of every stakeholder, but you had to get *something* done..."
Q28:	"…at that point in the semester it was…kind of like crunch time for a lot of teams…"

4.4.3 General Capstone Course

4.4.3.1 Positive Themes

Table 32 Distribution of student comments that express positive thoughts/feelings regarding the capstone course in general, arranged in three themes.

	Themes		
Student	Group	Client	Project
D16	X		
D33			
F31		X	
F56	X	X	X
I23	X	X	
J59		X	
N41			X
O35	X		
O62	X		
P38			
P93	X		
Q28		X	
T51	X	X	X
Total	7	6	3

Seven students mentioned that they had an exceptional group, and six mentioned that they had an exceptional client. Some of these comments arose without any prompting from me, and some arose in response to me asking students what they liked about the course. Three students mentioned that they enjoyed the projects they had worked on. These were all in response to direct questioning from me regarding what they liked about the course. These results are summarized in Table 32.

4.4.3.2 Negative Themes

Negative comments commonly made by interviewees about the course can be grouped into six themes: machining/ordering delays, pacing of fall vs. winter semesters, variation

between projects, student priorities, availability of client, and course communication (Table 33). The first three of these can be further grouped under the category of "pacing."

Table 33 *Distribution of student comments that express negative thoughts/feelings regarding the capstone course in general, arranged in six themes.*

	Pacing					
Student	Machining/Ordering Delays	Fall vs Winter	Variation between projects	Priorities	Availability of Client	Course Communication
D16			X	X		
D33					X	
F31						
F56				X		
I23				X		
J59	X	X				X
N41	X		X		X	
O35	X	X		X	X	X
O62	X	X			X	X
P38	X			X		
P93						X
Q28		X		X		
T51	X	X	X			X
Total	6	5	2	6	4	5

Pacing

Eight students mentioned issues of pacing when speaking generally about the course. These involved delays in machining/ordering material, differences in pace and expectations between the Fall and Winter semesters, and difficulties conforming project progress to set course deliverables (Table 34).

Table 34 Example student comments coded under "pacing."

Student	*Themes and Example Comments*
	Machining/Ordering Delays
N41:	"…in ways [the course] could be improved, especially in terms of getting things early purchase-wise."
J59	"…the machining took a lot longer than I expected…we were waiting five weeks for it..."
	Fall vs Winter
J59:	"…you went to winter and suddenly you have to do all the calculations and all the finalizations within like 3 weeks and then submit all your drawings like you had no time. It was super rushed in the winter."
O62:	"…I think there should be more design progress in the fall…we didn't really get into the details…until February and it wasn't until we got to that point that we were like 'Oh my God, there's a lot of stuff to do.'"
Q28:	"…we were kind of like we like turned around we're like 'what just happened?'"
	Variation Between Projects
N41:	"…one of the things that caused sort of great dismay was needing to circle back or needing to artificially inflate parts of our project to satisfy the course objectives…"
T51:	"…we were ready to build way earlier than a lot of other groups…"

Other

"Priorities" were mentioned by six of the thirteen students. Some of these comments were overtly negative towards the capstone course, like that made by F56 in Table 35, while some were more general statements about how students act in relation to coursework. I have included them all within the "negative" section of this analysis, as most comments made regarding students' priorities implied that course deliverables for capstone design are a low priority. Four students mentioned the availability of their clients as a negative aspect of capstone. It is not surprising that none of these students belonged to groups with "exceptional" clients, as displayed in Table 32. Issues with communication within the course were mentioned by five students.

Table 35 Example student comments coded under "priorities," "availability of client," and "course communication."

Student	*Themes and Example Comments*
	Priorities
F56:	"…sometimes it feels like profs who do design courses…think that because it's design, it's so cool, everyone's going to brush off their other classes to do it. And I found that attitude to be kind of frustrating."
O35	"…they're [capstone team members] always backfilling their logbooks, which like, sucks to do, but obviously a lot of people do that 'cause they're lazy…"
Q28:	"…it was very easy to put this course on the backburner…it just seemed…kind of like background noise compared to some of my other courses."
I23:	"…other things get in the way, like, you prioritize…it's the nature of the student to do things that you're going to need."
	Availability of Client
O62:	"…our client kind of went off and did their own things. We didn't have a ton of communication so we…just had to figure something out on our own."
N41:	"…we didn't even know if they wanted our project in the end…"
	"…we needed to call this person seemingly every two days for two weeks to get a reply…"
	Course Communication
J59	"…the communication sometimes is a little up in the air, like we'd find out about things we have to do the week or three days before…"
O62:	"…I know at least four or five teams that kind of got screwed over by the technicians…in terms of what the technician said they could do, and then they couldn't actually do it."
T51:	"…there was some confusion with the machine shop…that was a big thing actually…there were some instances of miscommunication where they [the students] dropped something off to one person and he didn't pass on the message."

CHAPTER 5 DISCUSSION

5.1 ANALYSIS OF EXAMPLE MAPS

The variation observed between the five example maps is promising in that it signals that student-created maps may be equally or more diverse, which would provide fertile ground for comparing stakeholder mapping activity to project outcomes. Within Buhmann & Kingsbury's holistic framework, I expect specific quantitative parameters, namely degree sequence and cross-linkage, to be especially important in future assessment of student-created maps, as both describe the "interconnectivity" linked with expertise within concept mapping literature, and both show variability between the five example maps. Degree sequence may be especially useful, in that it is easy to visualize and compare graphically (as seen in Ch. 4 Figure 17) and provides sophisticated descriptions of overall map structure, namely the relative presence of spoke, chain, and network shapes, in a very simple way.

The usefulness of "dimension" is unclear to me at this time. Buhmann & Kingsbury's justification for the creation of this parameter is presented as such:

> The dimension is a parameter relating the number of concepts (i.e., volume) with the diameter of a concept map. This is based on the relation of diameter and volume in Euclidean space and inspired by the notion of fractal dimension. The formula that relates the diameter to the volume in this context is: (diameter + 1) dimension = number of concepts. (Buhmann & Kingsbury, 2015, p.28)

The authors claim that this "dimension" is positively correlated with interconnectivity between map nodes. However, as discussed in Results (Ch. 4), the converse appears to be true in the case of the five stakeholder maps analyzed as part of this study. The

mathematical foundations of this parameter, based in "fractal dimension" may be an area that future researchers can explore if they wish to continue using the Buhmann & Kingsbury framework in future iterations of this study.

While applying Buhmann and Kingsbury's framework to the five example maps, some ambiguities arose, especially during structural/topological normalization and morphological classification. Despite the detailed procedure for ordering nodes during structural normalization, some ambiguous instances did arise, and seemingly arbitrary decisions of ordering had to be made. However, these decisions are not expected to affect the map's scoring within the subsequent quantitative analysis, as the quantitative parameters are a function of the original map and are not specific to its normalized state. These choices also generally only resulted in small differences in overall map shape. As such, these uncertainties are not expected to pose a large threat to the validity of the analysis. Regardless, it may be useful to further develop Buhmann and Kingsbury's ordering rules in future studies, to prevent such uncertainties from arising. One slight addition which I have already made to the original framework, and which I found very useful when analyzing the five example maps included in this study, is adding colours to nodes to denote their distance from the root concept. These greatly decreased the complexity of performing topological normalization, as it helped differentiate branches in terms of branch length, which can be difficult to evaluate in complex maps. This colouring, introduced in Methods I (Ch. 2), is demonstrated in Figures 11 & 16.

Ambiguities also arose during morphological classification, as Buhmann and Kingsbury's classification is based on relative rather than absolute values of certain quantitative parameters (for instance, interconnected maps are associated with "*high*

cross-linkage," and broad maps with "*small* ex-radius"). There is no guideline for determining what constitutes small, large, low, or high within a cohort of maps. In the future, it would be useful to identify threshold values or percentiles at which maps pass between these categories. Maps also often did not conform specifically to one morphological group. In these instances, I created new morphologies by joining two existing ones, such as broad/unconnected, and broad/interconnected in Table 13. I believe that if many stakeholder maps are examined in the future, there may be a need to further subcategorize these groupings to create more meaningful distinctions between maps, however, appropriate subgroupings will only become apparent once maps have been collected and analyzed.

Unfortunately, no student maps were accessible to me through this research, due to low levels of student participation. This has limited my testing of the Buhmann & Kingsbury framework and has prevented me from testing the scoring protocol which I developed to analyze map and reflection content. Recommendations to increase student participation in future studies are discussed in section 5.5 – Implications for Future Research.

5.2 CLIENT SATISFACTION QUESTIONNAIRE

The "Client Satisfaction Questionnaire," succeeded in gathering data from clients with diverse levels of satisfaction, implying that it did not disproportionately select for clients with very strong feelings about their student teams, which is encouraging for future iterations of this project. The number of clients surveyed, however, is cause for concern; of the nine clients eligible to participate in the questionnaire, only four responded to it. This is discussed below in section 5.5 – Implications for Future Research.

The respondents' tendency to pontificate within the short-answer questions is also encouraging for future iterations of this research project. On multiple occasions, the respondents go beyond what was asked of them in the given questions (Ch. 4 Table 15). For instance, when asked about their personal role in meetings/communications, Client T elaborates on the preparedness of students and the resulting "fantastic final design." And when asked to comment on the accuracy, completeness, and quality of the final prototype, both clients P and L speak not only about the prototypes, but also about the possible reasons why the prototypes did not meet their expectations: "The team was rushed at the end…" (P) and "The team could have…put more effort into the project," (L). The fact that clients are willing to write so much without prompting bodes well for future iterations of this study; with a larger cohort of respondents these responses may be well suited to thematic analysis, which could be useful in a course-improvement context, as areas that are especially important to clients, whether positive or negative, are likely to arise in these semi-prompted responses.

5.3 CONCEPTIONS OF DESIGN SURVEY

As discussed in Results (Ch. 4), the "Conceptions of Design" (COD) survey results are promising in the variation displayed between student responses and between timepoints in the case of repeat responders. This bodes well for future iterations of this study, as it signals that COD results, and changes in COD results over time may be useful in differentiating between individuals and teams of individuals, which supports the feasibility of comparing mapping activity with changes in conceptions of design as asked in research question Q3d: "Is the structure and content of student stakeholder mapping exercises correlated with changes in students' conceptions of design activities?".

Some interesting trends also emerge in the comparison of capstone student, expert, and 1st/4th-year student responses (as measured by Atman et al, 2008), such as the high importance placed by capstone students on "communicating," "planning," "prototyping," and "iterating," and the low importance placed on "seeking information," "generating alternatives," and "visualizing."

The prevalence of "communicating" and "planning" within the "most important" category may reflect the timing of the Winter #2 (W2) survey; student respondents had just finished their year-long capstone projects, and their choices as such may be coloured by their recent experiences in wrapping up the year's work. For instance, it is possible that many teams experienced stress at the end of the Winter 2021 semester in terms of finishing their projects and other deliverables (this is supported by data collected during student interviews), and as such the consequences of failures in "planning" may have been fresh in students' minds when they filled out the W2 survey. In future iterations of this study, it will be interesting to test this theory by comparing survey results from the beginning and end of the schoolyear.

Differences between capstone students and other student groups (particularly the 4th year students surveyed by Atman et al.) may also be related to institutional differences between Dalhousie and the institutions included in the Atman et al study. Atman et al. found statistical differences in student responses between the four institutions sampled in their study and suggested that this may have been due to differences in how design is taught in each of these institutions. It may be that activities such as "prototyping" and "iterating," which arise at much higher frequencies within the "most important" category

in capstone responses than in all other groups' responses, are particularly stressed within Dalhousie University's design curriculum

It is also especially interesting that so few capstone students considered "seeking information" to be a "most important" design activity, with only two students, representing approximately 15% of those surveyed, choosing this activity in W2. At first glance, this seems at complete odds with the high frequency with which students picked "understanding the problem" as a "most important" activity; how is one to understand the problem without first seeking information? The explanation may lie in the structure of the capstone projects that students had just completed before taking the survey; as is evident in the interview results, capstone students tend to believe that all information necessary to complete these projects can be given to them by their clients. This may explain the lack of importance placed on specifically "seeking" information, in that students believe that this information is already supplied to them by their client. This dependance on the client, elaborated upon in my discussion of student interview results, emerges as an important reason for integrating assignments such as stakeholder mapping in capstone courses as a means to facilitate student information gathering beyond their project clients.

It is also important to contextualize student responses to the COD surveys within the conditions imposed by the COVID-19 pandemic. The 2020-2021 school-year was unlike all past iterations of the course. Half of the students' projects were completed virtually, without any build component. Students also had less interaction with course instructors than in past years, with all lectures being delivered online and asynchronously. This unique environment may have influenced which activities students considered most important to design and may be responsible for some of the variation seen between

capstone student responses and those collected by Mosborg et al. (2005) and Atman et al. (2008). The possible effects of this COVID-induced environment can be further examined in future iterations of the study, once COVID restrictions have relaxed and students have returned to in-person learning.

5.4 STUDENT INTERVIEWS

The student comments made during interviews show that some students found the assignments useful in the areas for which they were intended: organizing information gathering, generating questions, planning, and deepening one's understanding of the problem context. Although a proportion of these comments may be an artifact of students recalling the wording used in the assignment outlines, their presence is encouraging in that it signals that stakeholder mapping does have the potential to support students. This is especially evident in the comments made by one student, J59 who describes how the assignments pushed his team to seek information and perspectives beyond those of their client:

> …we learned a lot of good information that we wouldn't have learned otherwise …just different things we didn't consider from the start that really, I think, helped inform the design…
>
> …it was nice to have some other perspectives 'cause there was stuff that he [the client] didn't consider…like he had an idea of how it would be useful, but the [stakeholders had] like a different view of what a useful product would be, which kind of help[ed] [us] meet in the middle. (J59)

While J59 was an outlier among the interview participants in the connection he draws between the assignments and his team's resulting design (most interviewees, even those

who expressed positive views of the assignments, stressed their limited impact on the "progress" of their projects), his comments are a strong indication that in some instances stakeholder mapping can be perceived as extremely useful by students, which is very encouraging, and supports the case for this study to be repeated.

An important goal in adapting the original assignments for use in future studies will be to increase the probability that students find them genuinely useful. This will be done by reinforcing elements that students liked about the original assignments and trying to alleviate some of the negative experiences they had with the assignments. In planning for this, I discuss two major themes that arose during student interviews: timing, and the centrality of the client in capstone projects (Table 36).

Table 36 *Positive and negative themes arising from student interviews. Those connected to "timing" in some way, whether it be the efficient use of time, the pacing of the course, or the prioritization of time are coloured in yellow, and those related to capstone clients are coloured in blue.*

Topic	***Positive Themes***	***Negative Themes***
Fall Assignments	Organizing information gathering	Already know/have information
	Forming questions	Busy Work
	Planning next Steps	Childish
	Problem Scope	Fabricated Information
	Connectedness	No bearing on project
	Who to consider	Projects too simple
	Time/Effort	Interacting with few people
	Suitability to Project	Too many iterations
	Applicability to other Assignments	Pacing within course
	Assumption of Client Knowledge	Time Commitment
	Accountability	Messy
	Connection to Industry	Online
Winter Assignments	Timing	Client too busy to interview
		Already knew information
		Too late to make design changes
		Winter semester rushed

Topic	*Positive Themes*	*Negative Themes*
General Capstone	Good Group	Machining/Ordering Delays
	Good Client	Pacing of Fall vs Winter
	Good Project	Variation between projects
		Priorities
		Availability of Client
		Course Communication

5.4.1 Centrality of client

The assumption of the clients' knowledge is present throughout both positive and negative student comments related to the stakeholder assignments and the capstone course in general. Students cite client centrality both in positive descriptions of the assignments as an impetus to reach beyond the client:

> …I feel like when you're doing a capstone project it's kind of like 'Oh…we're dealing with the client and that's it.' But having to think a little bit more about who else if going to be affected down the line, I think was very useful… (Q28)

And in descriptions of a why they believe the assignments were not necessary:

"…any questions we had for the other stakeholders, he [the client] can answer himself." (D33)

The possible consequences of this reliance on client knowledge are evident in comments made by P93 who, when asked to speak about any major obstacles his team faced throughout the year, spoke about an incident involving the intended users of his team's design. Team P's project involved designing a product for use in a workplace. The team's client was in a management position at this workplace, and the student team interacted primarily with this client throughout the early stages of their design. When the team brought a prototype to the intended users to be tested, these users completely rejected the prototype, giving it a score of "0" in all possible parameters on the survey

provided to them by the students. Team P was very surprised by this, as their interactions with the client regarding the design had been largely positive. According to P93, the client explained this behaviour to the students as: "…they [the users] didn't want the new design, so they just gave it a zero," P93 described it as "…the [users] being babies." It is very interesting to think about this scenario in the context of stakeholder mapping, as it demonstrates a lack of understanding between the users, the client, and the student design team, and is an obvious example of a scenario where the client alone cannot be expected to give all the information necessary to create a workable design. Team P's reliance on the client was echoed in comments made by P93's teammate, P38:

> Because our project is so client-based, all the requirements, definition and scope comes [sic] from the client. It doesn't change much when we talk to stakeholders 'cause it's not really like…most of the requirements come from the client themselves. (P38)

This focus on the client likely partially explains why the student team did not find out until the Winter 2021 semester that the intended users of their design in fact *did not want* a new design. This is a huge piece of information that was missing from the team's perception of their problem context, which supports the notion that students need help in gathering meaningful information about and from stakeholders. It also suggests that perhaps clients should be advised that students are expected to reach out to stakeholders other than themselves throughout the capstone process.

In addition to being viewed as the main source of information needed to successfully complete students' capstone projects, clients were also central to students' positive and negative feelings towards the course in general, with a contrast between

teams who had “exceptional” (I23) clients who were engaged with the students and the outcomes of their projects, and teams who could not access their clients and doubted their level of interest in the end-product of their projects: "…we didn't even know if they wanted out project in the end…" (N41). This variability between clients in terms of availability and engagement must be taken into account in the iteration of stakeholder mapping assignments.

The centrality of client knowledge within student perceptions of their capstone projects supports the notion that students can benefit from being pushed to consider their problem contexts more broadly, which supports the use of stakeholder mapping within a capstone setting. However, in future iterations of this study researchers must be careful not to unduly disadvantage student teams whose clients are inaccessible. As such, in my proposed assignments for future iterations of this study, discussed in section 5.5 – Implications for Future Research, I limit questioning of stakeholders to the very beginning of the Fall semester. Based on the interviews completed as part of this study, this timing aligns with the time taken by many teams to interview stakeholders: “…by the time stakeholder assignment 2, for the first map we had to create, we [had] already interviewed 10 stakeholders," (P38). This timing also limits ongoing reliance on the client for input on stakeholder mapping assignments as the course progresses.

5.4.2 Timing

Students’ comments about the assignments and the course in general were overwhelmingly related to timing, especially the efficient use of time. Comments related to time arise both in the positive and negative themes listed in Table 36, and many are related to one another. For instance “time/effort” in the positive section is directly related

to “time commitment” in the negative section, with some students expressing positive attitudes towards the Fall assignments due to the small amount of effort and time required to complete them, and others explaining that the assignments took too long to complete and detracted from the time they could spend on more important activities: “…it took away from time that I wanted to be doing research and other stuff…” (F56).

Concerns and frustrations about wasting time are also prevalent in student comments, particularly in the negative themes, where “already know information,” “busy work,” “no bearing on project,” and “too many iterations,” all appear to stem from student doubts as to the applicability of the assignments to the progress of their projects: "…as it's not directly contributing towards the progression of the project, it seems unnecessary," (O62). This is contextualized by student comments relating to the prioritization of time, in which they describe how they are very busy, and that capstone is only one priority (and often not the top priority) among the many tasks demanded of them by their engineering coursework. Following this theme of time management and prioritization, students are also preoccupied about pacing within the course itself, especially within the winter semester, which many students found very stressful and rushed: "…it [the Fall semester] was a very big lull and then all of a sudden it's like ‘Oh my god, we need to get our sh*t together,’" (Q28). Within this balancing act of competing priorities, many students found the fall assignments helpful in that they forced them to complete stakeholder research that they otherwise would not have completed. In future iterations of this study, assignments should aim to spark this accountability while not overburdening students with what seems like “busy work”.

The original stakeholder mapping assignments were designed with limited consideration of their timing in relation to other course deliverables. This can be seen in Figure 24, which shows the pacing of stakeholder assignments and other data collection tools against capstone course deliverables. As is apparent, the pacing of the stakeholder mapping assignments does not generally correspond with the speed of capstone project progress presumed by the other course deliverables. For instance, "Stakeholder Map #1" was not due until after the requirements documents and review, which is counterintuitive for an assignment that is meant to facilitate exploration of the problem contexts surrounding capstone projects. This misalignment with the students' projects likely contributed to the "busy work" feeling described by many students: "…it's almost like we're trying to check the box rather than actually considering the stakeholder…" (J59). This mismatch is addressed in my recommendations for future assignments, discussed below.

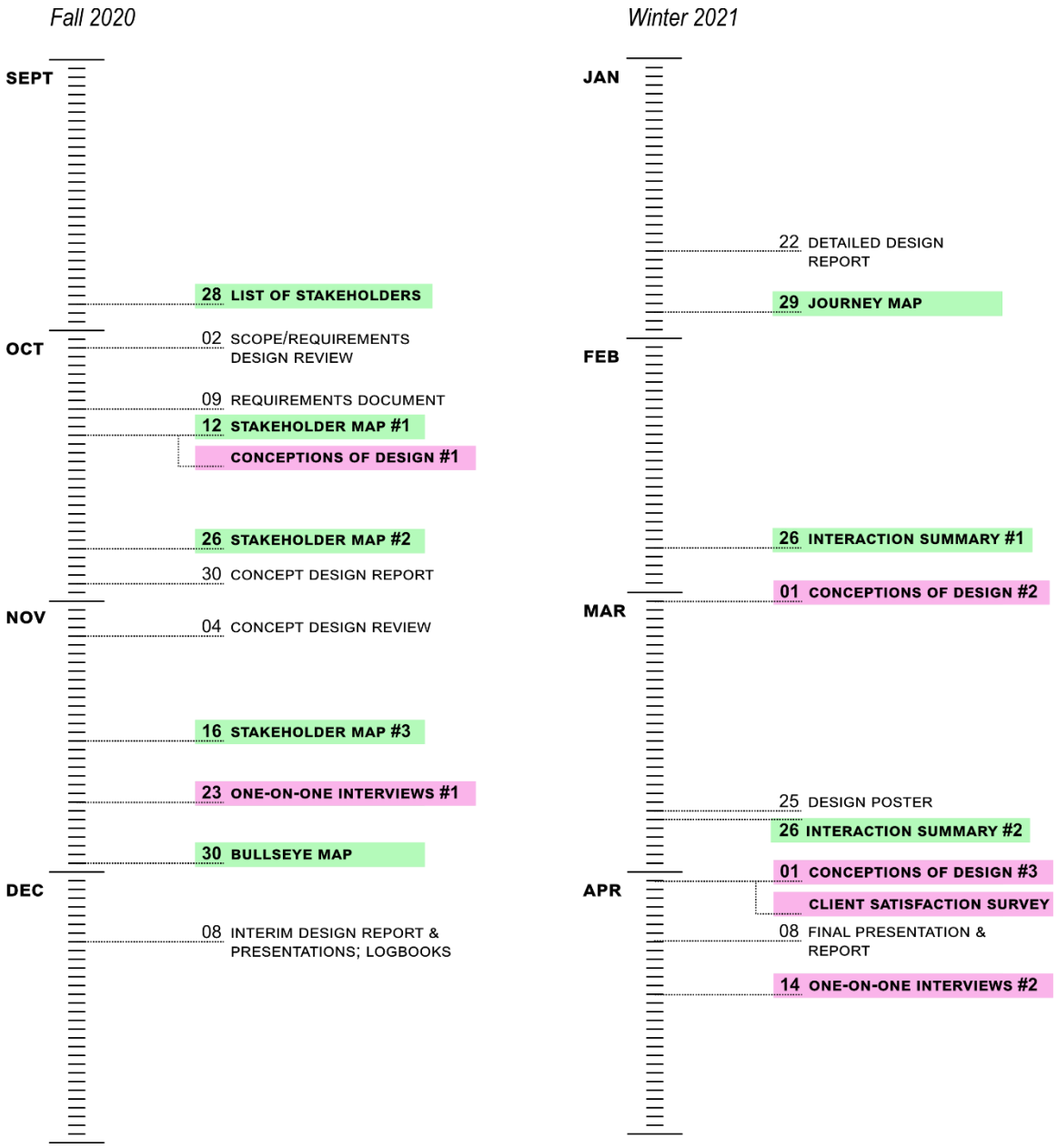


Figure 24 Research project and capstone course timelines. Stakeholder assignments are coloured in green, the administration of surveys and interviews in pink, and other assignments associated with the capstone course left uncoloured.

5.5 IMPLICATIONS FOR FUTURE RESEARCH

5.5.1 Recommendations for Future Assignments

In future iterations of this study, I suggest integrating stakeholder mapping assignments into the existing course deliverables and decreasing the amount of writing required in each of these assignments. I also suggest at this time not to repeat the "journey map" and "interaction summary" assignments, as they are not directly applicable to an evaluation of the impacts of stakeholder mapping to project outcomes and were not appreciated by the vast majority of students interviewed. However, if course instructors wish to implement assignments similar to the journey map and/or interaction summaries as elements of future courses, I suggest applying them in the fall semester rather than the winter, when students are still developing their conceptual design and are more likely to respond to information gathered from stakeholders.

Table 37 Proposed integration of Stakeholder Mapping assignments within capstone course structure.

Assignment	***Date***	***Description***
1 – Stakeholder Map #1	Early Fall – When student teams are first given their specific capstone projects.	- Create stakeholder map as per LUMA Institute's given steps - Write brief description of map - Draft questions to be asked of stakeholders
2 – Requirements Document	Early Fall	- Present refined stakeholder map (may be changed or unchanged from original) - Briefly describe how map represents teams' understanding of problem scope - Briefly describe which stakeholders relate to the stated requirements

Assignment	*Date*	*Description*
3 – Concept Document	Mid Fall	- When presenting design concepts, briefly describe how they affect key stakeholders - Describe how stakeholder needs will be considered as the project moves forward
5 – Interim Design Report	Late Fall	- Include consideration of stakeholders in "requirements" and "alternative design concepts" sections
6 – Mid-winter Check-in	February	- Write brief description of how key stakeholders will be impacted by the version of the design that teams are going forward with
7 – Final Report	April	- Include stakeholder map and briefly discuss problem context in relation to stakeholders in "project background" and "future considerations" - Briefly discuss impact on key stakeholders in descriptions of design concept alternatives

A brief outline of possible stakeholder mapping assignments is presented in Table 37. I suggest condensing what was administered as five separate assignments in the 2020-2021 schoolyear into one main stakeholder mapping assignment, which would be completed at the outset of the capstone projects and revisited with each major capstone course deliverable included in Table 37. Creating the stakeholder map in one sitting is in fact what is defined by the LUMA Institute's stakeholder mapping procedure; it was a conscious choice made by me and my supervisors to break these steps up between separate assignments for use in this study, as discussed in Methods I (Ch. 2). This was done in the hopes of supporting students' information gathering and integration of stakeholder needs into their understanding of the problem scopes associated with their projects, however, it has proven to be less than ideal for students as the resulting

assignments are out of step with other course deliverables and with the speed of progress that students believe their clients expect: "…if we're going to take more time at the beginning to be doing more stakeholder interviews…then we would have had to…[put] off our client…." (F31).

In this first assignment, students would create a stakeholder map based on LUMA Institute's six steps (Ch. 2 Table 2), would draft questions to ask key stakeholders targeted at deepening their understanding of the problem context, and write a brief report based on three of the reflection prompts described in the original assignment outlines (Ch. 2 Table 4):

1. Who are you planning to talk to?
2. What types of insights do you think they can provide with regards to your problem scope?
3. What questions will you ask in order to access these potential insights?

Here, the wording of question two has been altered slightly to make the goal of the stakeholder interviews clearer; students are asked to describe insights they expect certain stakeholder to hold in relation to the "problem scope" in particular. In the previous wording of this question, this specification was not included.

This first stakeholder map could then be revisited in each of the major course deliverables in the fall semester: the "Requirements Document," the "Concept Document," and the "Interim Design Report." The goal of this integration would be for students to continuously be reminded of their stakeholders as they developed their designs, and to avoid the stakeholder assignments as being viewed as "extra work" not connected to students' projects. Between each of these assignments, the students would

be encouraged to refine their maps, but this would not be required. Within each of the assignments mentioned above, the students would be asked to include their maps, explain any key changes made to them, and to relate the stakeholders in their map to the content of the given assignment.

In the "requirements document", students would be asked to describe how their understanding of stakeholder relationships play into their conception of the problem "scope," and to include stakeholder needs within their discussion of specific design requirements. Prompting questions for this could include:

1. How has information gathered form key stakeholders in the preceding weeks influenced your understanding of the problem originally handed to you by your client? Are the any differences between how your client views the problem and how other stakeholders view it?
2. What requirements must be met to satisfy the needs of your stakeholders? Are there any specific needs that stand out?
3. How do you plan to keep these needs in mind as you develop your conceptual designs?

In the "Concept Document", students would be asked to discuss how each of their alternative concepts meet/fail to meet specific stakeholder needs. Questions could include:

1. Explain how each of your design concepts meet/fail to meet to the needs of key stakeholders,
2. How will this accounting of met/unmet stakeholder needs factor into your decisions on which concept to move forward with?

The stakeholder map would be revisited once again in the "Interim Design Report," due at the end of the Fall 2020 term, in which students would be asked to include stakeholder considerations in the "requirements" and "alternative design concepts" sections of the report.

In the Winter semester, considering the stress described by many students and the preoccupation with "…get[ting] *something* done…" (N41) in terms of finalizing designs, I suggest implementing stakeholder mapping at only two points during the term, the first as a standalone assignment and the second integrated into the final report. The first assignment, a "mid-winter check-in," could occur in February, after students have submitted their detailed designs. In it, students would once again revisit their stakeholder maps, discussing how their planned designs would impact different stakeholders in the system described by their map. Prompting questions could include:

1. Explain how you expect your planned build/final product will meet/fail to meet to the needs of key stakeholders.
    a. Are there any stakeholders for which the proposed final product will not satisfy their needs? If so, discuss the reasoning behind the design choices and trade-offs made.
2. How will you continue to account for these needs stakeholders as you complete your design?

In the final report, consideration of the stakeholders would be included in discussions of "project background" and "alternative design concepts," in any evaluation of the final design, and in future recommendations regarding teams' designs. This could be done with a short paragraph in each of these sections of the report.

By integrating stakeholder mapping into the existing course structure, I hope to increase student buy-in by reducing the time commitment necessary to complete the assignments and by increasing their relevance to student projects and course deliverables.

5.5.2 Analyzing Map Structure

Based on the encouraging results collected in my analysis of five example maps, I recommend that Buhmann and Kingsbury's Holistic Framework be applied to the analysis of student maps in future iterations of this study. Special attention should be paid to ambiguities within structural and topological normalization, and morphological analysis; it is possible that future researchers could identify means by which to reduce these ambiguities. Caution should also be used when drawing conclusions based on analysis of the parameter "dimension," as the validity of this as a measure of interconnectivity is uncertain.

5.5.3 Scoring of Map and Reflection Content

Given the proposed integration of stakeholder mapping assignments within existing course deliverables, the scoring protocol for map and reflection content must be modified. The modified scoring protocol is presented in Tables 38 & 39. The parameters within this new scoring protocol are largely unchanged from those presented in the original protocol (Ch. 2 Table 6), however their application to specific assignments is slightly altered.

All of the newly proposed assignments will be scored based on "breadth of stakeholders" as it was worded in the original scoring protocol.

As the first assignment is the only newly proposed assignment in which students are explicitly asked to draft questions for stakeholders, its scoring is the only to include

the parameters "question topics," and "question wording" from the original scoring protocol (Table 38).

Table 38 Proposed scoring protocol for map and reflection content of "Stakeholder Map #1" from newly proposed assignments.

		Score		
Assignment(s)	***Parameter***	*0*	*1*	*2*
o Stakeholder Map #1	Breadth of Stakeholders	All stakeholders considered are closely related to the client.	Considers some stakeholders from outside the client's inner circle.	Considers a large range of stakeholders.
	Questions – Topic	Most questions are targeted at developing solutions.	Narrowly focused on the given problem; some questions may target solutions.	Targeted at understanding the broader problem context; few to no questions target solutions.
	Questions – Wording	Almost all questions are closed and/or leading.	Most questions are closed and/or leading.	Most questions are open-ended.

All other instances of stakeholder mapping activity will be scored based on the "depth of exploration" parameters of the original protocol. These are slightly re-worded to make them more relevant to the specific questions asked in the new assignments, resulting in: "reflecting on decision making," "integrating stakeholder information," and "responding to stakeholder needs." In this scoring protocol, "responding to stakeholder needs" will apply to answers to questions such as "How will this accounting of met/unmet stakeholder needs factor into your decisions on which concept to move forward with?" and in the case of the Final Report, will apply to future considerations proposed by student teams in relation to their designs.

Table 39 Proposed scoring protocol for reflection content of newly proposed assignments (excluding Stakeholder Map #1).

		Score		
Assignment(s)	***Parameter***	*0*	*1*	*2*
o Requirements Document o Concept Document o Interim Design Report o Mid-Winter Check-in o Final Report	Breadth of Stakeholders	All stakeholders considered are closely related to the client.	Considers some stakeholders from outside the client's inner circle.	Considers a large range of stakeholders.
	Reflecting on decision-making	Reasoning behind decisions (choice of conceptual design, trade-offs between stakeholder needs) is missing or incomplete.	Reasoning behind decisions (choice of conceptual design, trade-offs between stakeholder needs) is briefly outlined, with some gaps.	Reasoning behind decisions (choice of conceptual design, trade-offs between stakeholder needs) is clearly outlined.
	Integrating stakeholder information	No connection made between stakeholder needs and design artifacts (requirements, concepts, end-product).	Little/superficial connections made between stakeholders needs and design artifacts (requirements, concepts, end-product).	Clear connections made between stakeholder needs and design artifacts (requirements, concepts, end-product).
	Responding to stakeholder needs	Next steps do not respond to stakeholder needs discussed by team.	Next steps loosely consider stakeholder needs discussed by team	Next steps directly respond to stakeholder needs discussed by team

This revised scoring protocol retains its basis within the "informed" and "beginner" design behaviour described in Crismond & Adams' (2012) "Informed Design Teaching and Learning Matrix." While it should be used as the basis for the analysis of stakeholder map and reflection content in future studies, it may need to be refined further

as more is learned about how students are likely to complete the assignments and reflections.

5.5.5 Client Satisfaction Questionnaire

I suggest that the Client Satisfaction Questionnaire be applied in the same way it was in this study, however with slight modifications to recruitment, discussed below.

5.5.6 Conceptions of Design Survey

As student participation was a very large issue within this study, and students' aversion to wasting time is evident throughout student interviews, I suggest implementing the Conceptions of Design Survey at two timepoints instead of three in future iterations of this study, at the beginning and end of the schoolyear. This timing aligns with the newly formatted stakeholder mapping assignments, as the student groups will be referring to the stakeholder maps throughout the entire school year and as such, administering the COD surveys at the beginning and end of the year will bookend the stakeholder mapping well.

5.5.7 Recruitment

If this research project is to be repeated, some lessons can be applied from the issues I encountered while recruiting participants for the project described in this thesis.

First, monetary compensation, either in the form of a lottery or direct compensation, should be applied from the very outset of the study as an incentive for student participation. Considering the lack of participation even after monetary compensation was applied, a grades-based incentive should also be pursued from the outset of ethics applications in future studies.

Second, if the course is administered online, I suggest having more direct contact between students and the researcher during recruitment attempts; instead of posting

videos to the course's webpage, I suggest that recruitment videos be delivered synchronously wherever possible. I also suggest that all correspondence between the researcher and possible participants to be delivered directly, without mediation by an instructor. In this way, the potential participants will have a more direct connection with the researcher and may be more likely to respond to emails.

The online environment in which this study was run may be one of the main causes for low participation rates, in that it was difficult to connect and engage with students. If the course is delivered in-person during future studies, the recruitment issues may be largely diminished, but I believe it will still be important to offer incentives to participation or else risk a similar situation to that experienced in this study, where the researcher was not able to access a large amount of data.

To increase client participation in future iterations of this study, I suggest introducing the clients to the project/survey earlier in the schoolyear, rather than introducing it to them for the first time when they are sent the consent forms and survey links at the end of the schoolyear. If clients expect from the outset of their engagement with the capstone course that they will be asked to give feedback on their experience, they may be more likely to take part in the survey.

5.6 CONCLUSION

This preliminary application of the proposed stakeholder mapping assignments and accompanying data collection and analysis tools has been an important source of information for future iterations of the study. While low levels of participation precluded the analysis of student-created maps and limited the conclusions that could be drawn from available data, the basic efficacy of the selected tools in differentiating between

stakeholder maps, student's conceptions of design, and various levels of client satisfaction has been tentatively established, which supports the deployment of these same tools in future studies.

Important information has also been gleaned from interviews with students, such as the capacity of stakeholder mapping to, in some circumstances, meaningfully influence student designs: "…we learned a lot of good information that we wouldn't have learned otherwise…just different things we didn't consider from the start that really, I think, helped inform the design…" (J59). This positive feedback, which supports the application of stakeholder mapping in capstone design, was tempered by the large number of criticisms voiced by student interviewees. These criticisms have proven especially useful in designing future assignments to be better integrated with the course. In future iterations of this study, this integration should theoretically increase student engagement with stakeholder mapping and with the research study itself, by limiting perceptions of the mapping assignments as "extra work."

As student-created map data is collected in future iterations of the study, any meaningful relationships that exist between map characteristics, project outcomes, and students' ideas about design can be identified and validated. Once validated, these relationships could prove useful to instructors who wish to use stakeholder mapping within their own courses, in that they would be able to identify features in student maps that indicate deep or superficial understanding of problem contexts. On a broader level, this will also contribute to ongoing work on how best to prepare engineering students for success in industry, and to the evaluation of design thinking as a potential frame for

teaching skills necessary to this success, by explicitly evaluating the effect of a single design thinking tool, stakeholder mapping, on student outcomes.

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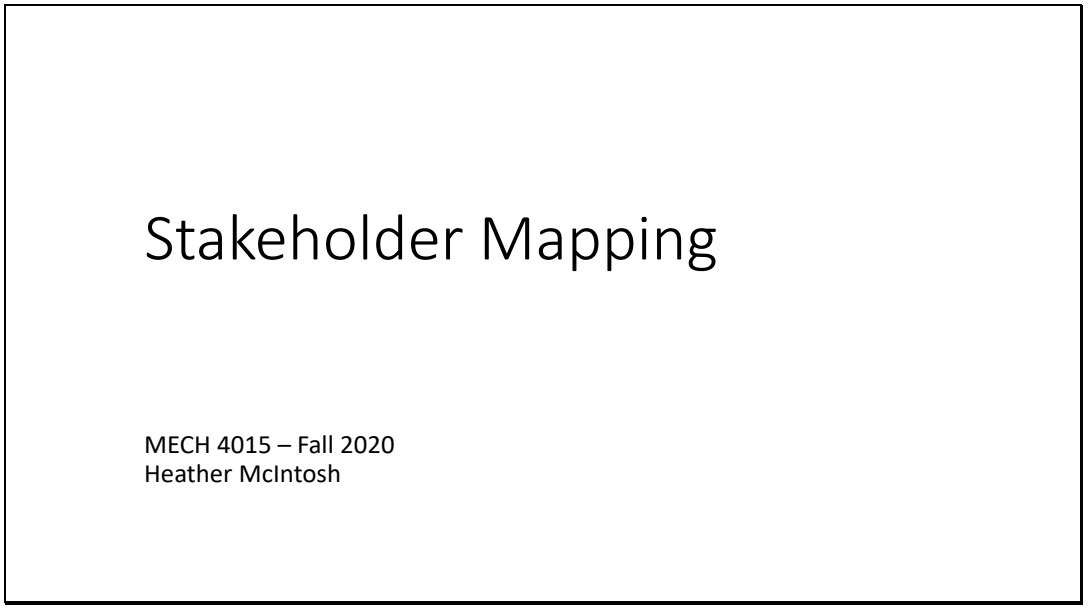
APPENDIX A FALL 2020 ASSIGNMENTS & INSTRUCTIONAL MATERIAL

APPENDIX A-1 "INTRODUCTION TO STAKEHOLDER MAPPING" PRESENTATION

Slide 1

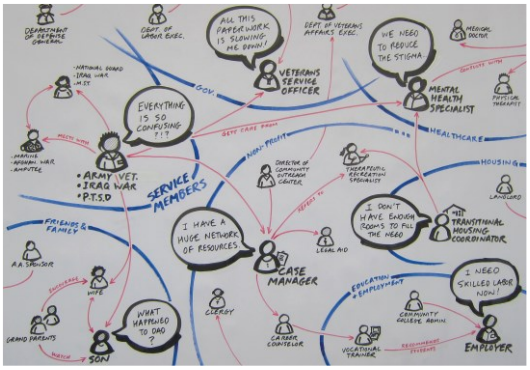


Hey everyone! Today I'm going to give you an introduction to stakeholder mapping – what it is, why it's useful, and how we're going to be using it in this course.

Slide 2

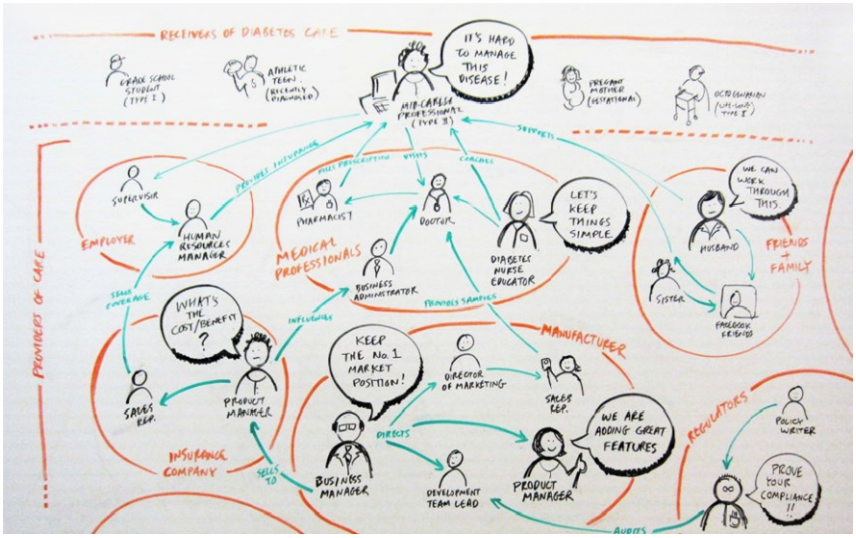
What is stakeholder mapping?

- Stakeholder mapping is a tool for understanding the context in which your project is situated
- Stakeholders include anyone who will have an impact on or will be impacted by your project
  - your client, members of your client's organization, end users, manufacturers, safety regulators, distributers, buyers, etc.
- Stakeholder mapping allows you to identify these individuals and to sort them based on their needs and their relations to one another



So, what is stakeholder mapping? It's a tool that helps us better acquaint ourselves with our problem context. In it, we identify potential stakeholders (anyone who will be affected by or have an effect on the outcome of our project), and we determine how these stakeholders relate to each other, and what their needs are in relation to the problem presented to us by our client. Stakeholders can include clients, end users, manufacturers, distributers, buyers, etc – pretty much anyone you can think of who has any connection to your project.

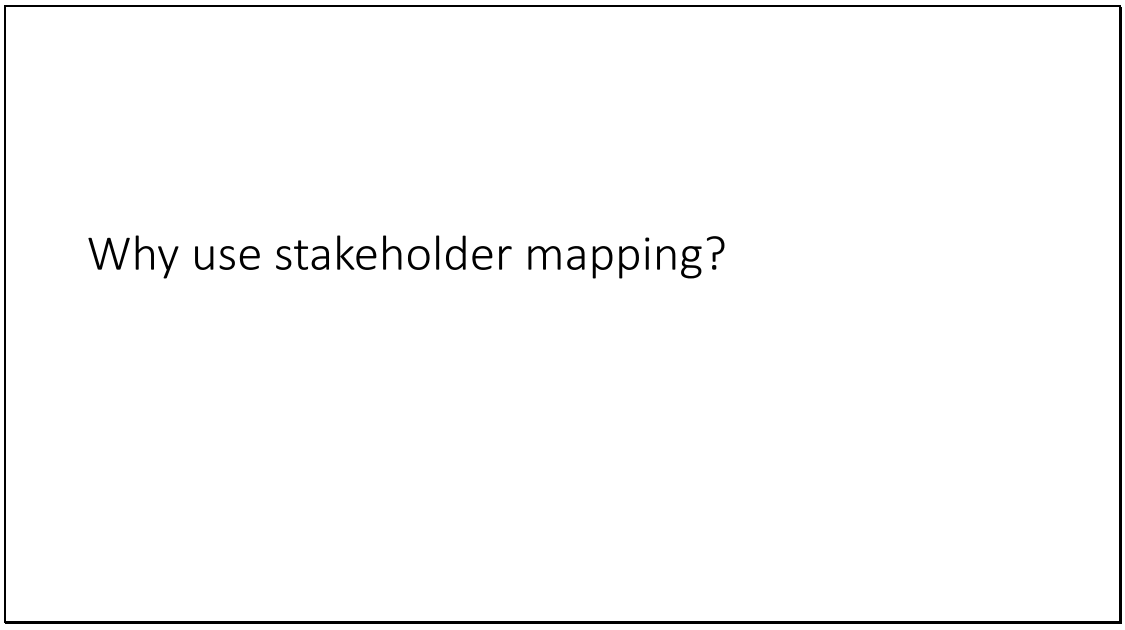
Slide 3



Let's look at an example of a stakeholder map. Here's one centered around diabetes care. The author has identified many stakeholders and grouped them into two broad categories: receivers and providers of care. They have further divided the "providers of care" into subgroups, such as manufacturers, friends and family, medical professionals, etc. Relationships between stakeholders are represented by arrows and sometimes verbs, and stakeholder needs are represented in speech bubbles.

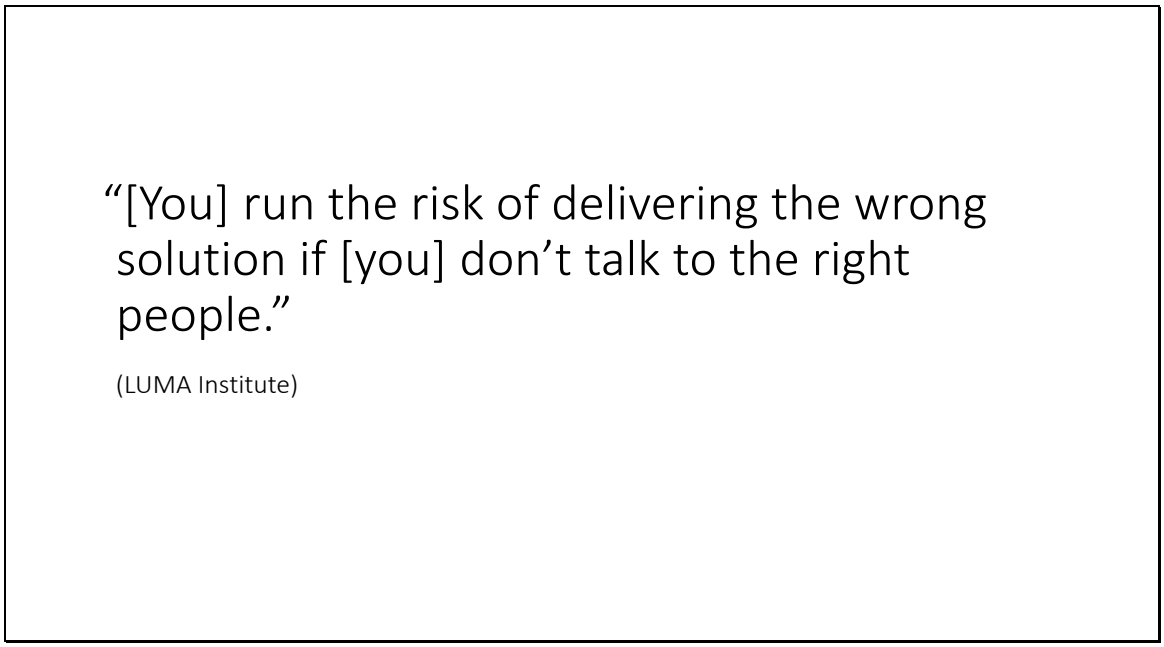
You can see how this map helps to make an abstract concept, such as "diabetes care," more concrete and manageable.

Slide 4



So, stakeholder mapping lets us identify stakeholders, and their needs and relationships, but how does this help us solve engineering problems? Well, the foremost benefit from conducting stakeholder mapping is that you ensure that your understanding of the problem context is correct before you move on to developing solutions. If you miss an important factor in your understanding of the original problem, you can end up delivering solutions that aren't relevant to your client's actual needs:

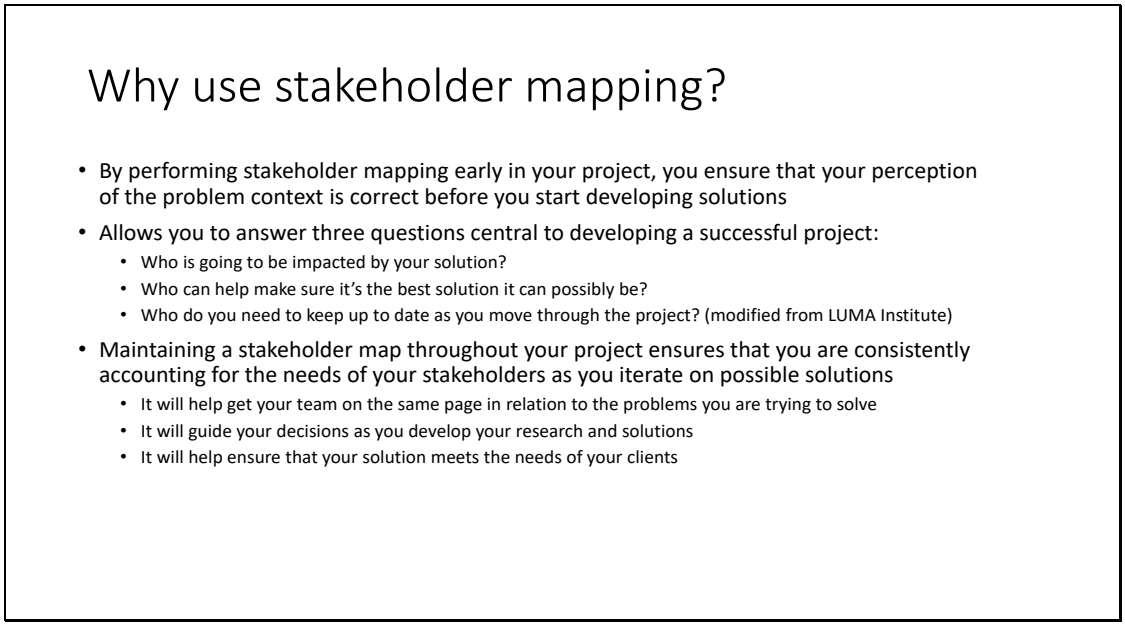
Slide 5



In essence, "You run the risk of delivering the wrong solution if you don't talk to the right people."

This isn't to say that your client is wrong in the initial problem statement they deliver to you, or that they are willfully withholding important information. But it's important to remember that your client may have a narrow understanding of the problem or may be accidentally omitting important information in their initial communications with you. Regardless of the reason, it is important to probe deeper to ensure you understand the problem from all viewpoints before diving into developing solutions.

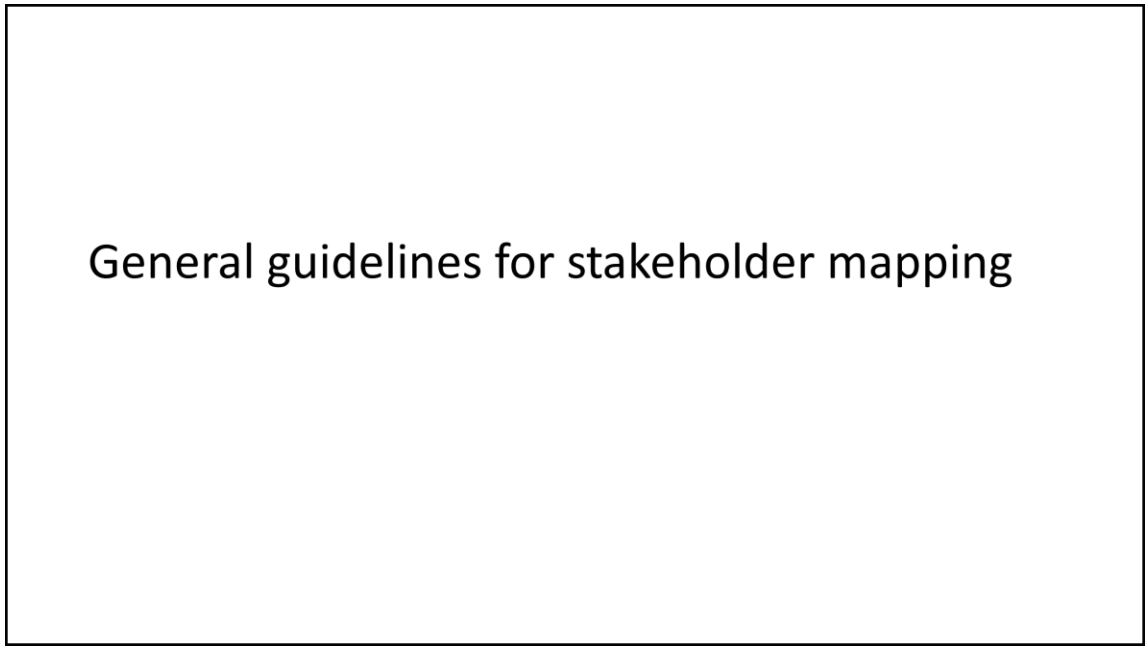
Slide 6



On top of helping you develop an understanding of the problem context, stakeholder mapping can also help you identify individuals who will be instrumental in helping you develop your end solutions, and who you will want to keep in contact with as you move through your project. It also helps to keep all members of your team on the same page regarding the problems you are trying to solve. And as you move on to developing your solutions, you can compare these solutions to the needs of stakeholders in your map, using the map to highlight areas that might need more work or research.

Stakeholder mapping can be tedious, especially if you're eager to get going on solving your client's problem. As you move along with your projects, try to remember that spending time on stakeholder mapping at the beginning of your project can help you avoid wrong paths and dead-end solutions later on. Stakeholder mapping is not something we do in place of developing technical solutions, it is something we do to ensure that those technical solutions are appropriate to the problem context.

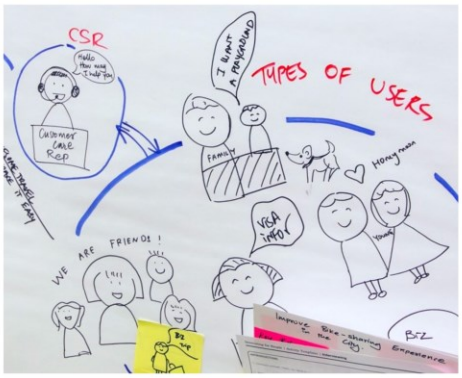
Slide 7



Ok, so let's go over the method of stakeholder mapping we'll be using in this course!

Slide 8

General guidelines to stakeholder mapping



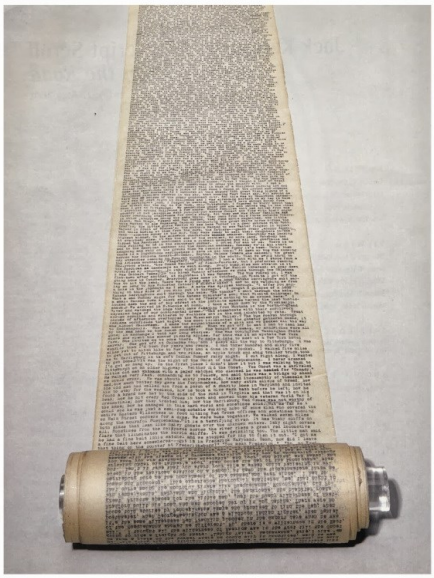
1. Identify stakeholders
2. Give your stakeholders a human face
3. Decide who to interview
4. Formulate questions
5. Conduct interviews
6. Map current understanding of stakeholder needs and relationships
7. Repeat steps 3-6 until you are no longer receiving any new information through interviews
8. Bull's eye diagram

In the fall semester of this course, we'll first develop a list of potential stakeholders, then go through three iterations of mapping their relationships based on data we retrieve from stakeholder interviews, and finally pinpoint key stakeholders in a bull's eye diagram.

Slide 9

1. Identify stakeholders – create a list

- Every stakeholder map begins with a list of stakeholders
  - When creating this list, it helps to think in very broad terms; it is better to start with a broad range of stakeholders and to narrow down than to start narrow and miss potentially important individuals



So, we'll start by making an exhaustive list of stakeholders. Try to think of anyone and everyone who may be affected by or may have an effect on the outcome of your project. At this point, it is important to go broad – it is better to start with a very broad list and narrow in as you gain a better understanding of the problem context, than to start with a narrow list based on your initial assumptions, only to find out later on that you've missed an important stakeholder who's input is essential to the success of your project.

Slide 10

Capstone Example – Bolted Connection Testing Machine

- "Design a machine to be used in an academic setting to break threaded fasteners"
- Possible stakeholders:
  - Client (professor/instructor)
  - Future professors/instructors
  - Other members of the faculty
  - Teaching assistants
  - Undergraduate engineering students
  - Parents (pay for students' education)
  - Custodial staff
  - Technicians
  - Funding agencies
  - Safety officer
  - Manufacturers
  - Future employers of students
  - Graduate students
  - ?????

Let's look at how this might play out in the context of a capstone project. Here's a project from a past year, where a Dalhousie engineering professor came to students with the following task: "Design a machine to be used in an academic setting to break threaded fasteners." At first glance, this may seem like a purely technical problem, but let's try to think about all the people who may interact with this machine, or who will have some stake in it's use. Off the top of my head, I came up with 13: the initial client, future profs/instructors, who may use the machine in their courses, other members of the faculty who may wish to have access to the machine, teaching assistants and undergraduate students who will use the machine in the professor's course, parents of students (who have a stake both in their children's safety and in the quality of the education they receive), custodial staff who may be cleaning the room where the machine is housed, technicians who may be responsible for maintaining the machine, etc., etc.

You may notice that this list of based completely on my assumptions; each of these stakeholders *may* have a link with out project, but we don't know for sure. And that's ok, we'll be able to validate our assumptions later on. The goal at this point is to identify as many people as possible who may be affected by or have an effect on your project.

Slide 11

2. Give your stakeholders a human face

- Once you have an exhaustive list of possible stakeholders, give them a human face
  - This will help you think concretely about their individual needs, rather than focusing on abstract groups of stakeholders
  - Doodles, pictures; whatever works for you
  - This will serve as an icon for the stakeholder throughout your project

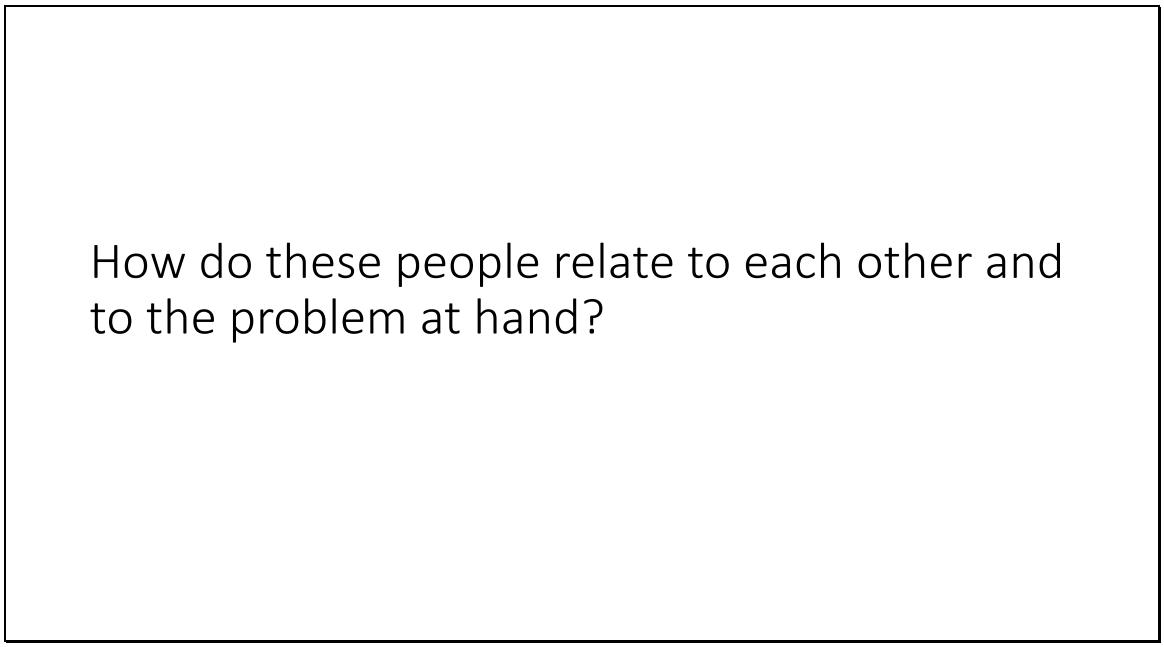
- Client (professor/ instructor)
- Future professors/ instructors
- Other members of the faculty
- Teaching assistants
- Undergraduate engineering students
- Parents (pay for students' education)
- Custodial staff
- Technicians

- Funding agencies
- Safety officer
- Manufacturers
- Future employers of students
- Graduate students
- ?????

Now that we have a list of potential stakeholders, let's give them each a human face. A human face, no matter how crudely it is drawn, will help us remember that the stakeholders in our list represent actual individuals, which will help us to think of their needs and relationships in concrete terms.

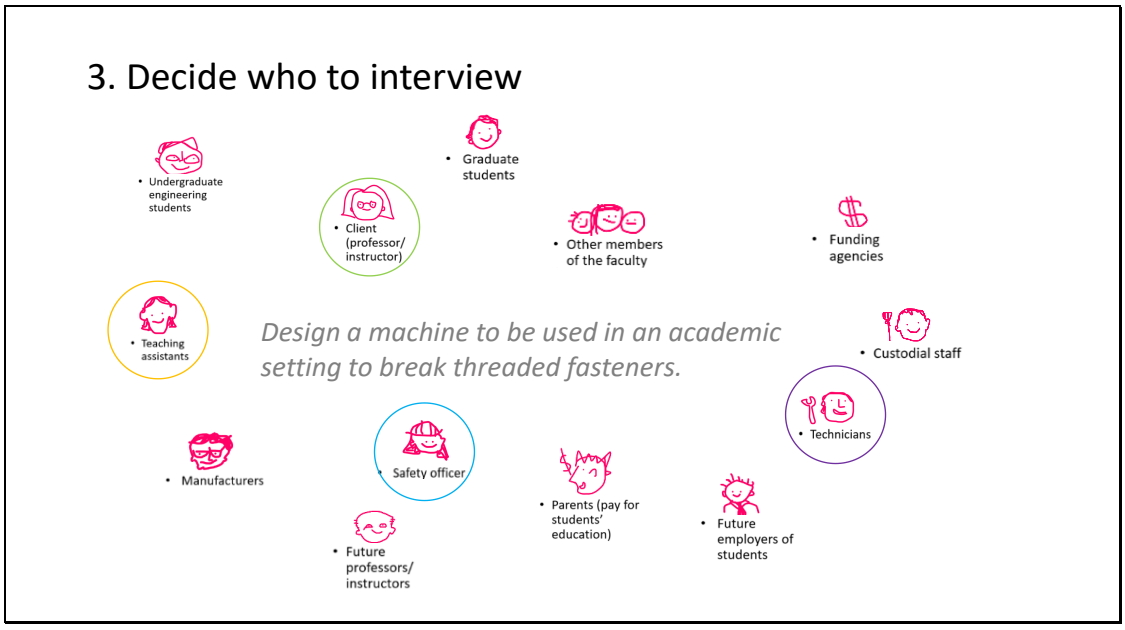
This human face will serve as an icon for your stakeholder group as you move forward.

Slide 12



Ok, so we've got our list and our doodles, now let's come back to why we're doing this in the first place. Remember, our goal is to get a better understanding of the problem context, and in order to do this need to determine how these stakeholders relate to each other and to the problem at hand.

Slide 13

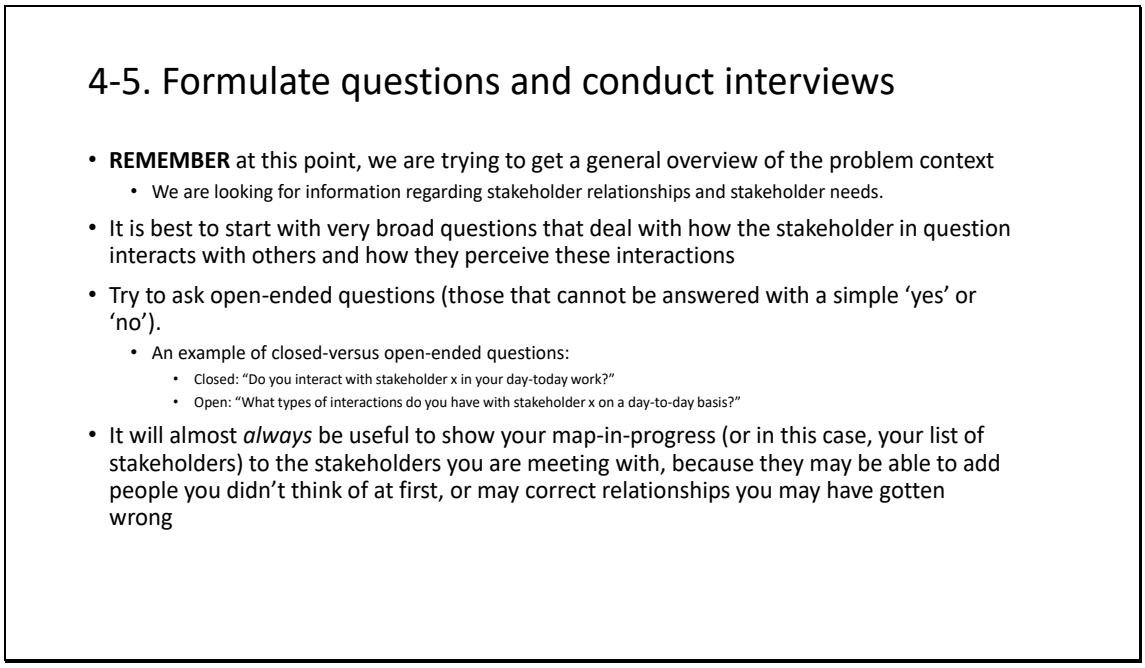


In order to get more data about our problem context, we'll have to talk to some of our stakeholders. Since we're at the very beginning of our project, let's try to pick stakeholders who we think will have a strong connection to our project, and who we expect will be able to provide the most information on the problem context.

The decisions we make here are not going to be perfect, and will ultimately be based at least partially on our group's assumptions about which of the stakeholders is most important. And at this stage, that's ok – as we gain a better understanding of the problem context through our interviews, we will be able to make more informed decisions. At this stage, let's just pick some people we *think* will be useful to talk to, and start gathering information.

My first pick here is my client, because they will clearly have insight into the use situation of the machine, and may help me identify stakeholders I may have missed in my original list. I think I'll also talk to the safety officer, because I feel pretty safe in assuming that this machine will have to meet Dalhousie's safety standards, and so the safety officer is bound to be involved at some point in the project. I think the technicians will probably be interacting with the machine quite a bit, so I'll talk to them. And teaching assistants will probably be operating the machine pretty frequently. I'll talk to them and ask them a bit about what it's like to be a TA.

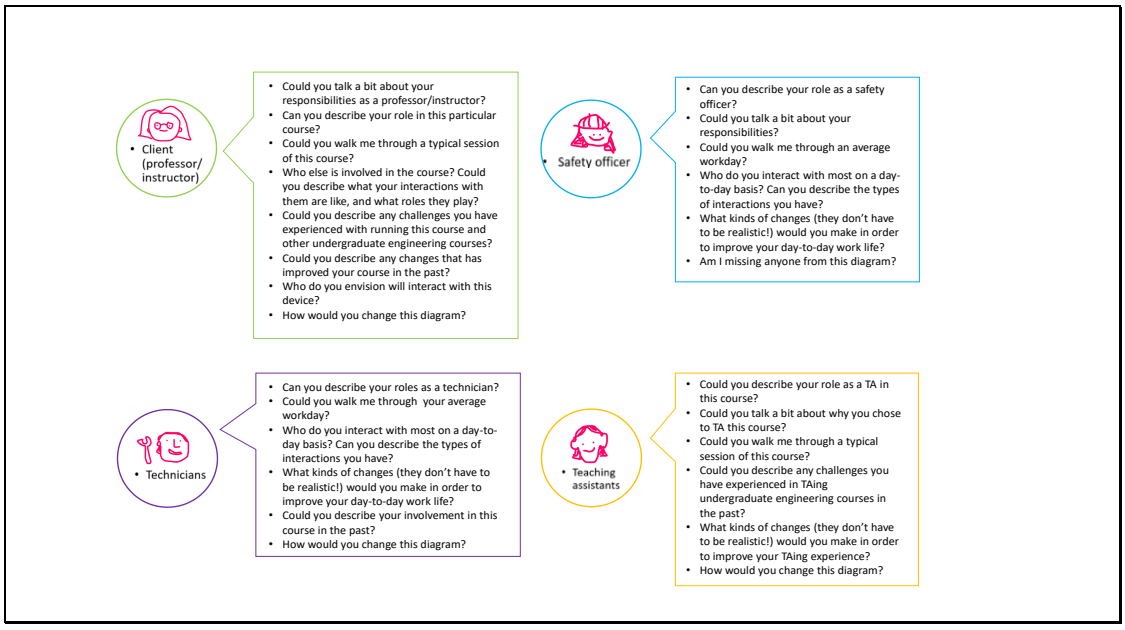
Slide 14



Ok, now let's try to think of questions to ask. REMEMBER, at this point, we are trying to get a general overview of the problem context. We want to ask questions that will give us information on stakeholder relationships and stakeholder needs. These most useful questions at this stage are likely to be very broad and very open-ended. We are looking to collect a wealth of information, not just receive confirmation of our preconceived ideas about the project. If we ask questions that are too specific, or that don't give the interviewee space to elaborate and expand on their answers, we run the risk of missing out on important information.

It is also very useful to show your list of stakeholders or stakeholders maps to your interviewees, and to ask them if they would make any changes to it. You could even send them an electronic copy of your list or map, and have them mark it up. This will help validate the decisions you make in your stakeholder map, and can add useful information that would otherwise have missed.

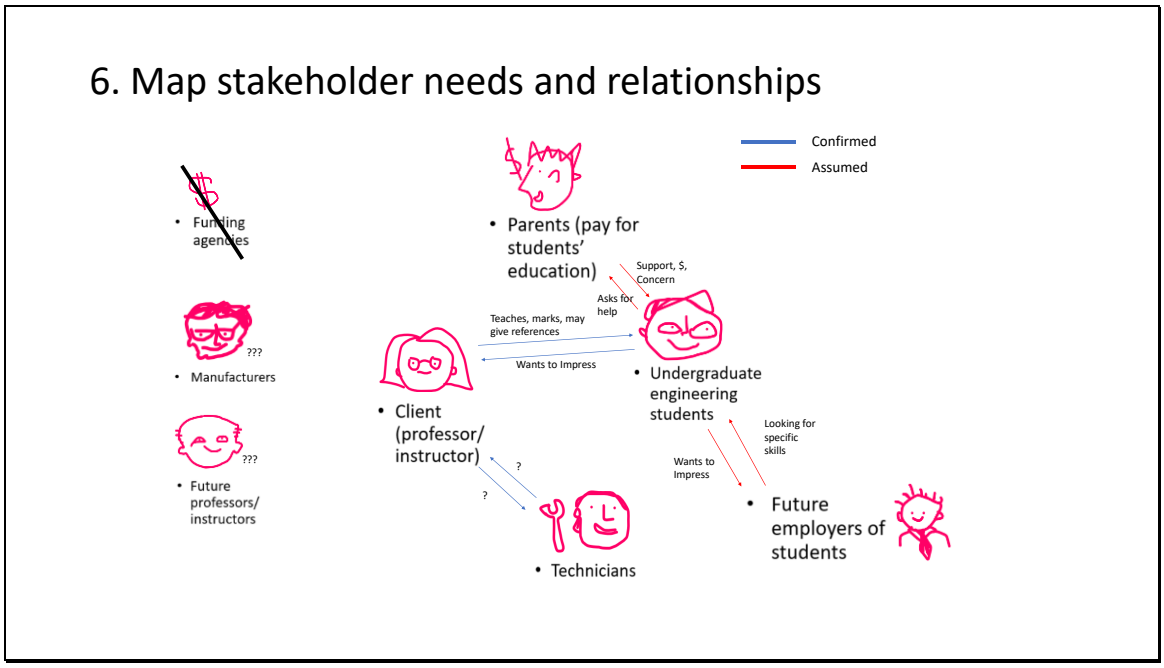
Slide 15



Ok, so I've written out some VERY broad questions to ask my four stakeholders, each aimed at collecting information on what kinds of relationships exist between them and the problem at hand. I'm asking questions about how each stakeholder experiences their day-to-day work, what kinds of interactions they have with others, what challenges they face, etc. Since I don't know much about any of these stakeholders, I am starting very broad with the questions. As I learn more about the problem context and about the stakeholders, I can create more specific questions.

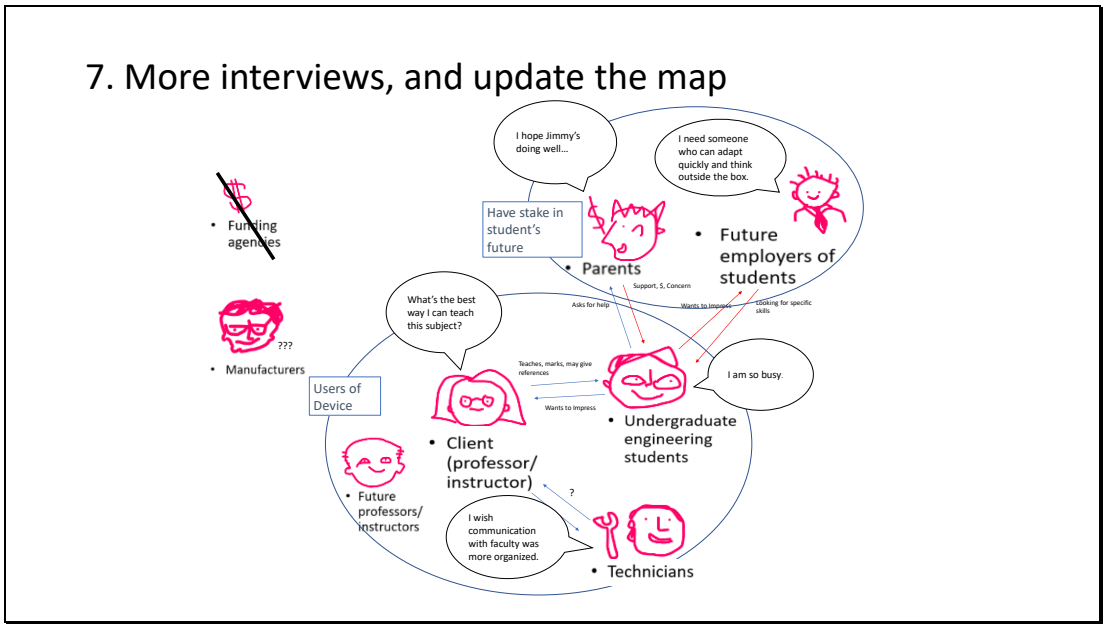
As you go into your interviews with the stakeholders, use the questions you develop at this stage as a general guide for the interview, and do not feel tied to these questions alone. New information may arise during the interview and spark new questions previously not considered. Interviewing is tough, because you want to strike a balance between rigid adherence to pre-scripted questions, and loosing control of the interview to an overly talkative interviewee. Try to use your judgment as much as possible when deciding whether a line of inquiry is worth pursuing during any of your interviews.

Slide 16



Once we've done some initial interviews we'll hopefully have a slightly better idea about how these stakeholders are linked, and we can start mapping out these relationships. I've just picked some stakeholders randomly to map from the original list, but you will be including all of your stakeholders from your original list in your maps. If you have some stakeholders who you have ruled out from being connected to your project, you can represent them with a line drawn through them.

Slide 17

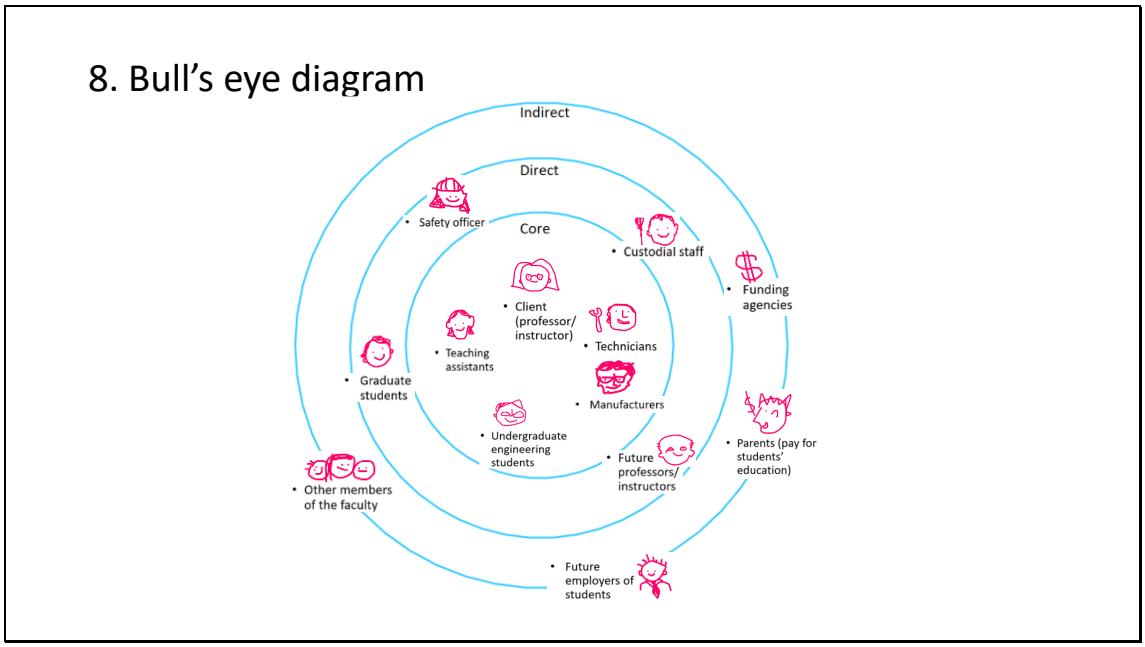


In the fall semester, we'll do three iterations of our stakeholder map. Between each iteration, you'll be talking to stakeholders and gathering information. You'll use this information to update your map every two weeks. You can start grouping stakeholders and also reporting their main needs in the form of speech bubbles.

As you move through these iterations, you may even end up making changes to the problem statement originally given to you by your client, based on your new understanding of the problem context. This change could be anything from a slight-rewording, to a complete reframing of the problem. Of course you don't want to completely reframe the problem behind your client's back, but if you think a reframing is warranted, that is something you can highlight in your stakeholder mapping assignments, which will highlight it to the instructors of the course and can open up discussion.

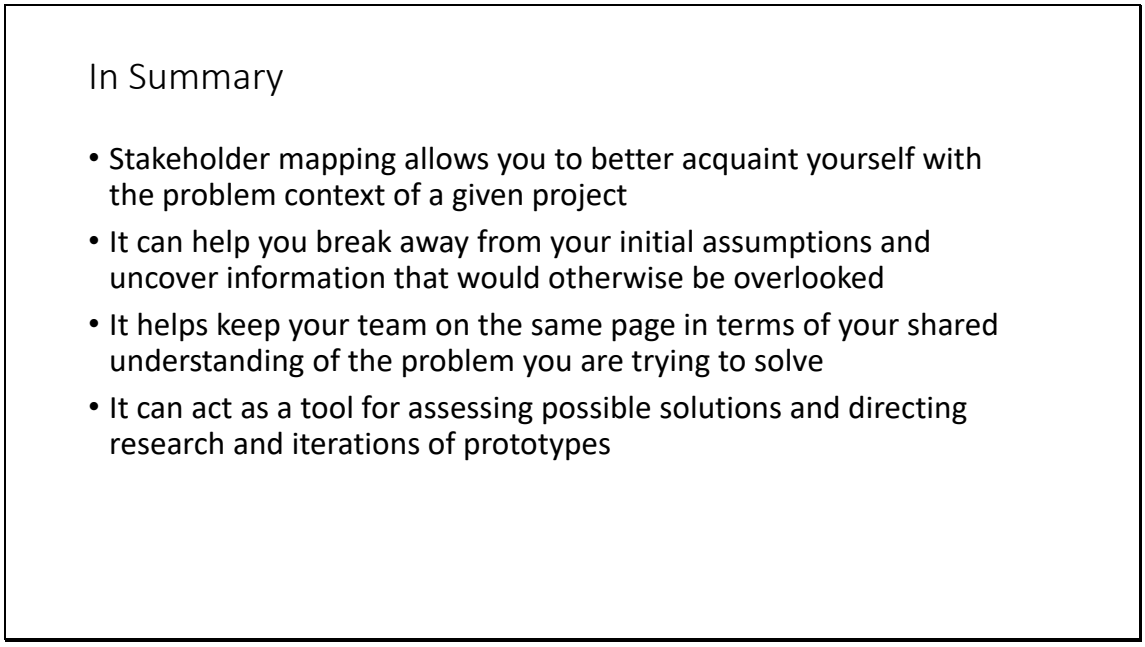
By the time you finish your third iteration of the stakeholder map, you should have a pretty good understanding of the needs of your stakeholders, and how they are connected to each other. This will help you develop solutions that respond to these needs, and will give you a template by which to assess how well different solutions fit the problem context.

Slide 18



Once we have a good understanding of the general problem context, we can narrow in on some key stakeholders who will be useful to keep in mind as you develop solutions and prototypes. At this stage in the process, sort the stakeholders in terms of importance to your project, with those most directly linked to it in the "core" circle, and those will looser links in the "direct" and "indirect" sections of the bullseye. The "core" group will be those who you keep in touch with most as you develop your solution.

Slide 19



And that's all the stakeholder mapping we'll be doing in the Fall semester. In summary, stakeholder mapping is just another tool to add to our arsenal when tackling engineering problems. It can help us better understand the context in which our engineering problems lie, allowing us to look for information beyond our preconceived notions of a given situation. And it can help us stay in tune as a team, both in our understanding of the problem at hand and in our assessment of possible solution. Although it is unliked other skills central to engineering, if used properly it can greatly increase the usability and adoptability of your end solutions. I hope you enjoyed this lesson! I'll be posting videos on particular assignments as we move along with the course. Talk to you soon!

APPENDIX A-2 ASSIGNMENT 1 – LIST OF STAKEHOLDERS (DUE SEPTEMBER 28, 2020)

- State the problem given to you, as worded by your client.
- Create an exhaustive list of stakeholders associated with this problem.
    - Include everyone who may be impacted by, or who may have an impact on the outcome of your project (no matter how indirect!)
    - Include at least 12-15 stakeholders.
- Create a visual icon for each stakeholder. Doodles are encouraged!
- Explain why each stakeholder is relevant to the given problem.
- Pick 3-4 stakeholders who you think will be able to give you the most information in terms of filing in relationships between stakeholders. These will generally include you client, and those stakeholders who you think will be most impacted by or will have the most impact on your end solution.
    - Develop some questions to ask each of these stakeholders in the next two weeks
        - **REMEMBER** at this point, we are trying to get a general overview of the problem context. We are looking for information regarding stakeholder relationships and stakeholder needs.
        - It is best to start with very broad questions that deal with how the stakeholder in question interacts with others and how they perceive these interactions
        - Try to ask open-ended questions (those that cannot be answered with a simple 'yes' or 'no').
            - This will help ensure that you aren't limiting the information you receive. Remember, we are trying to go *broad* at this point.
            - An example of closed-versus open-ended questions:
                - Closed: "Do you interact with stakeholder x in your day-today work?"
                - Open: "What types of interactions do you have with stakeholder x on a day-to-day basis?"
        - It will almost *always* be useful to show your map-in-progress (or in this case, your list of stakeholders) to the stakeholders you are meeting with, because they may be able to add people you didn't think of at first, or may correct relationships you may have gotten wrong
- Organize your list of stakeholders in a table, as illustrated in the example on the following page. Include all stakeholders from your list. You only need to include "Questions to Ask" for the 3-4 stakeholders that you intend to interview in the coming weeks.
- For assignment 2, you will be required to draw an initial stakeholder map, based on information gathered over the next two weeks.

Stakeholder	Relevance	Questions to ask
 Client (a Dalhousie professor)	○ Brought the problem forward – is very invested in the outcome ○ Will use the device in their course	• Could you talk a bit about your responsibilities as a professor/instructor? • Can you describe your role in this particular course? • Could you walk me through a typical session of this course? • Who else is involved in the course? Could you describe what your interactions with them are like, and what roles they play? • Could you describe any challenges you have experienced with running this course and other undergraduate engineering courses? • Could you describe any changes that have improved your course in the past? • What kinds of changes (realistic or not) would you make to improve your experience with teaching this course? • Who do you envision will interact with this device? How will they interact with the device? • Am I missing anyone from this list?
 Technicians	○ Will likely be involved in the device's maintenance and use	○ Can you describe your roles as a technician? ○ Could you walk me through your average workday? ○ Who do you interact with most on a day-to-day basis? Can you describe the types of interactions you have? ○ What kinds of changes (realistic or not) would you make in order to improve your day-to-day work life? ○ Could you describe your involvement in this course in the past? ○ If a device like this were to be made, what do you think your relationship with it would look like? ○ Am I missing anyone from this list?

 Safety Officer	○ Is responsible for the safety of students and staff ○ Will likely be involved in assessing whether the device is safe for classroom use	○ Can you describe your role as a safety officer? ○ Could you talk a bit about your responsibilities? ○ Could you walk me through an average workday? ○ Who do you interact with most on a day-to-day basis? Can you describe the types of interactions you have? ○ What kinds of changes (realistic or not) would you make in order to improve your day-to-day work life? ○ If a device like this were to be made, what do you think your relationship with it would look like? ○ Am I missing anyone from this list?
 Teaching assistant	○ Will likely be interacting with the device during class or lab hours.	○ Could you describe your role as a TA in this course? ○ Could you talk a bit about why you chose to TA this course? ○ Could you walk me through a typical session of this course? ○ Could you describe any challenges you have experienced in TAing undergraduate engineering courses in the past? ○ What kinds of changes (they don't have to be realistic!) would you make in order to improve your TAing experience? ○ Am I missing anyone from this diagram?

APPENDIX A-3 ASSIGNMENT 2 – STAKEHOLDER MAP #1 (DUE OCTOBER 12, 2020)

- Part 1: Stakeholder Map
    - Organize you stakeholders from assignment 1 into a map, linking stakeholders to each other and describing their relationships
    - Base this first iteration of your map on information you have gleaned from talking to stakeholders over the past two weeks, and from your own assumptions (you can test these assumptions in the coming weeks)
    - What to include:
        - All stakeholders from assignment 1
            - If you have decided to remove a stakeholder from your original list, please include it in this map with a line through it
        - Any new stakeholders you have identified in the past two weeks
        - Known links between stakeholders (those validated through your previous discussions with stakeholders)
            - Draw known links in the colour blue
        - Assumed links between stakeholders (those that you think may be true, but have not validated yet)
            - Draw these in the colour red
- Part 2: Explanation of changes made
    - Write a brief report (approx. 2 pages) describing the new information you have acquired over the past two weeks, and how it has affected your stakeholder map
    - For each new aspect of the map (be it a new stakeholder, a new relationship, or a discarded stakeholder), answer the following questions
        - What is the reasoning behind this change?
        - What information prompted this change? How was that information obtained?
        - Has this change influenced your understanding of the given problem? If so, how?
        - How will this change influence your next steps?
- Part 3: Next Steps
    - Address the following questions in a brief report (maximum 1 page)
        - Based on you work so far, what will be your next steps in expanding on your existing map?
            - Who are you are planning to talk to?
            - Why do you want to talk to them? What type of insights do you think they can provide?
            - What questions will you ask in order to access these potential insights?

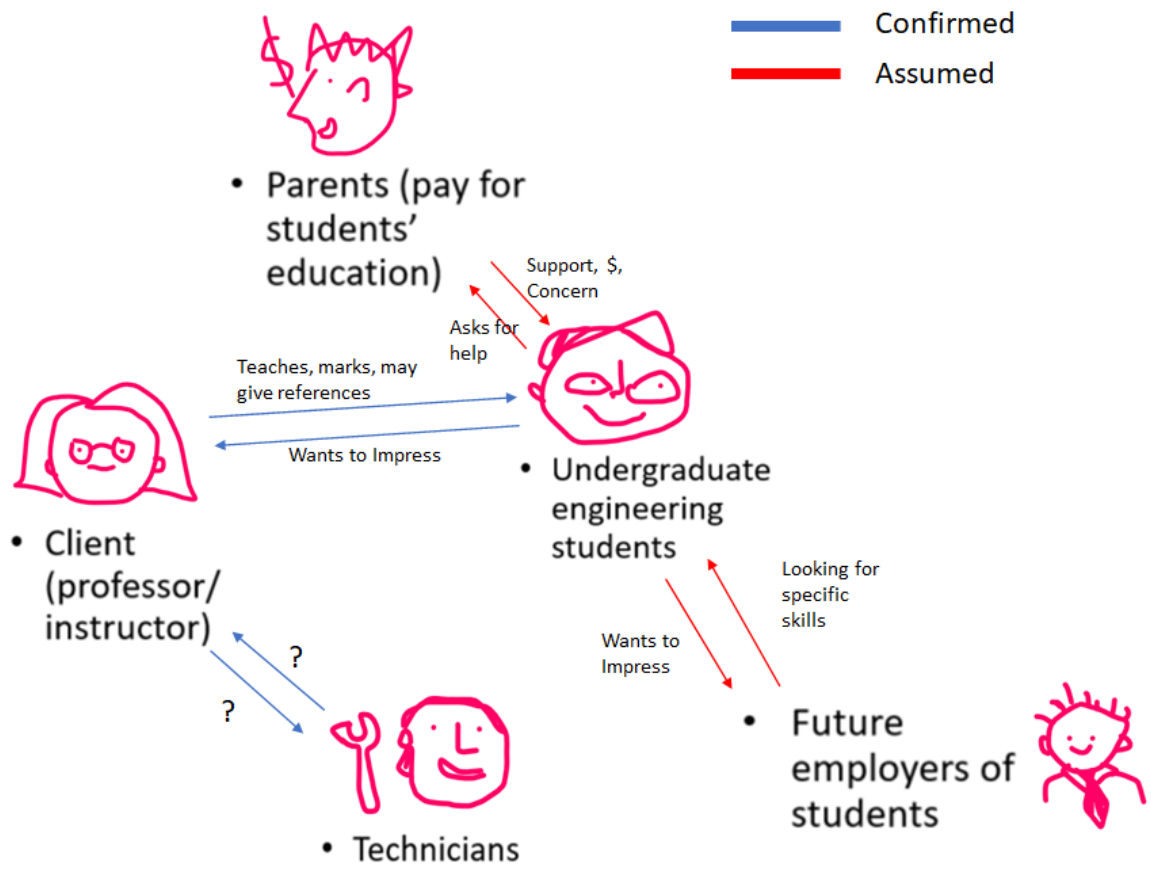
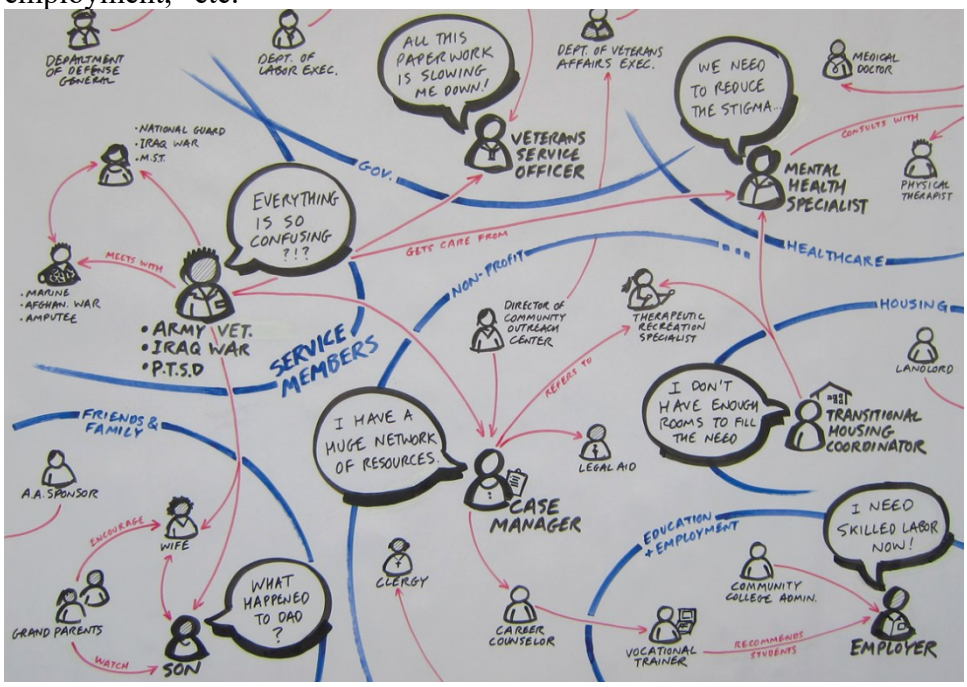


Figure 1. Example of how you might start mapping your stakeholders.

APPENDIX A-4 ASSIGNMENT 3 – STAKEHOLDER MAP #2 (DUE OCTOBER 26, 2020)

- Part 1: Stakeholder Map
  - Make changes/add new information to your first stakeholder map, based on information you have accumulated in the past two weeks
  - Add a speech bubble beside each stakeholder, and fill it with what you think is their most important need or opinion regarding your project (see image below)
  - Group your stakeholders in terms of they relate to your project. You can do this by drawing outlines around stakeholders in each group, as picture below in the groups "service members," "healthcare," "education and employment," etc.



- Part 2: Explanation of changes made
  - Write a brief report (approx. 2 pages) describing the new information you have acquired over the past two weeks, and how that affected your stakeholder map
  - For each new aspect of the map (be it a new stakeholder, a new relationship, or a discarded stakeholder), answer the following questions
    - What is the reasoning behind the change?
    - What information prompted this change? How was that information obtained?
    - When and how were stakeholders involved in making this change?
    - How has this change influenced your understanding of the given problem?
    - How has this change influenced your next steps?
- Part 3: Next Steps

- Address the following questions in a brief report (maximum 1 page)
    - Based on you work so far, what will be your next steps in expanding on your existing map?
        - Who are you are planning to talk to?
        - Why do you want to talk to them? What types of insights do you think they can provide?
        - What questions will you ask in order to access these potential insights?

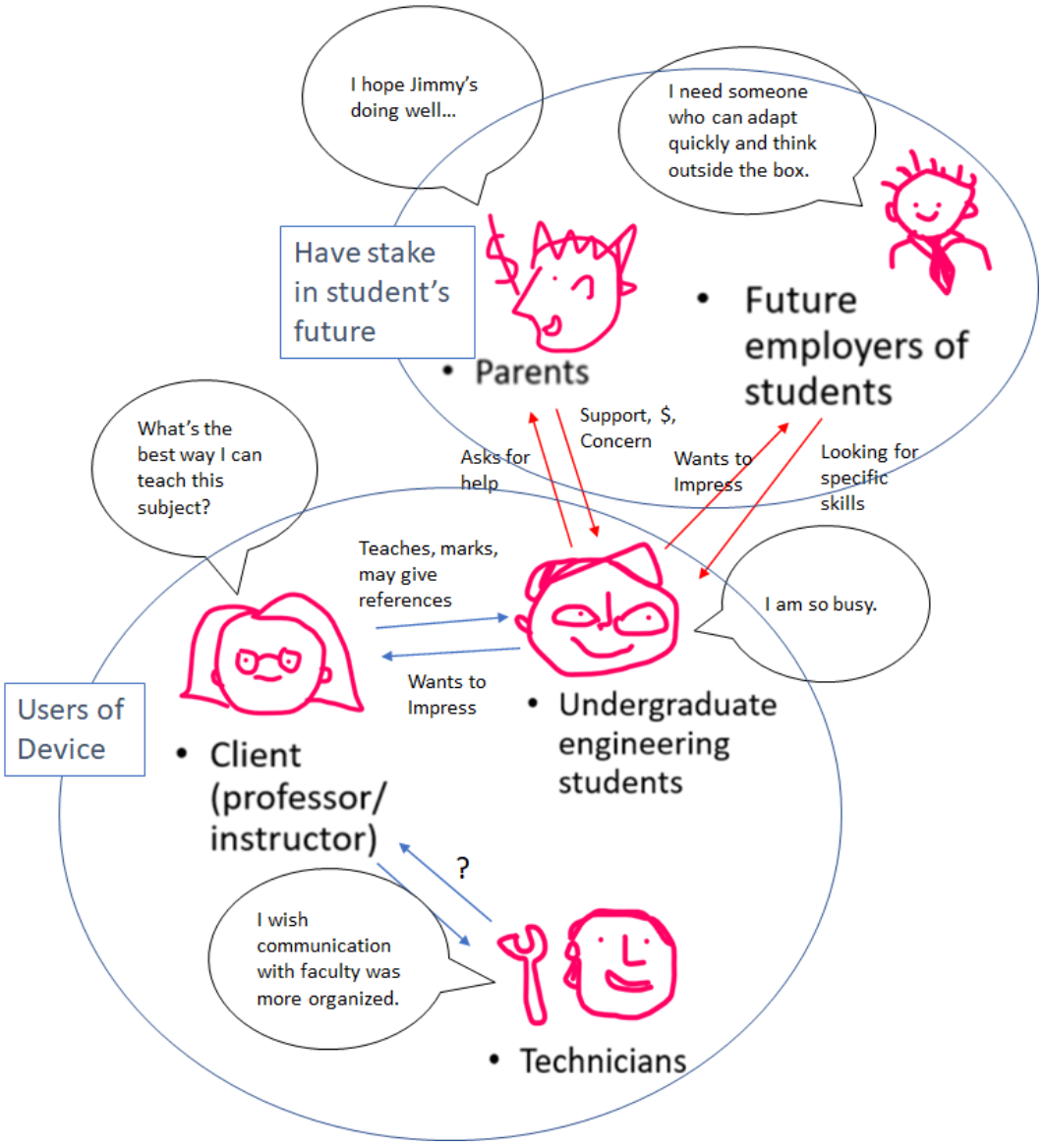


Figure 1. An example of how you might organize stakeholders into groups and represent their main needs through speech bubbles

APPENDIX A-5 ASIGNMENT 4 – STAKEHOLDER MAP #3 (DUE NOVEMBER 16, 2020)

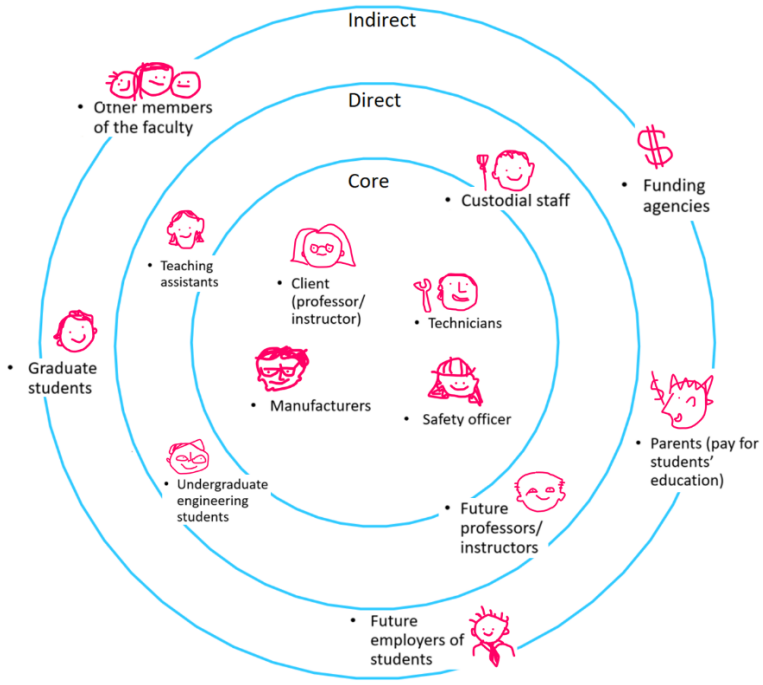
- Part 1: Stakeholder Map
  - This will be your final iteration of this map for the Fall 2020 semester.
  - Make changes/add new information to your second stakeholder map, based on information you have accumulated in the past two weeks

- Part 2: Explanation of changes made
  - Write a brief report (approx. 2 pages) describing the new information you have acquired over the past two weeks, and how it has affected your stakeholder map
  - For each new aspect of the map (be it a new stakeholder, a new relationship, or a discarded stakeholder), answer the following questions
    - What is the reasoning behind this change?
    - What information prompted this change? How was that information obtained?
    - Has this change influenced your understanding of the given problem? If so, how?
    - How will this change influence your next steps?

- Part 3: Overview of problem context
  - Write a brief report describing the problem context as you currently understand it (approx. 1 page)
  - It may be useful to think of the following questions as you develop your report:
    - How will the different stakeholders be affected by the outcome of your project?
    - How will you take stakeholder needs into account as you develop your solution?
    - How has your understanding of the original given problem changed over the past six weeks?

APPENDIX A-6 ASSIGNMENT 5 – BULLSEYE MAP (DUE NOVEMBER 30, 2020)

- Part 1: Bullseye Map
  - Now that you have a good understanding of the general problem context, it is time to narrow in on some key stakeholders who will be useful to keep in mind as you develop your prototypes.
  - For this assignment, organize the stakeholders from your most recent map onto a bullseye diagram (pictured below), consisting of three concentric circles.
    - Sort the stakeholders in terms of importance to your project, with those most directly linked to it in the "core" circle, and those will looser links in the "direct" and "indirect" sections of the bullseye
    - The "core" group will be those who you keep in touch with most as you develop your solution
  - **HINT** students frequently underestimate the importance of *manufacturers* and *distributors* at this phase in their projects; if any of your proposed solutions require material or hardware, make sure you will be able to source them in an economical and timely way. Communicating with manufacturers and distributors early can save you a lot of time.



- Part 2: Report (approx. 2 pages)
  - Explain the reasoning behind the choices you made in the bullseye map
  - Explain what role each stakeholder group will play as your project moves forward
    - How will you keep in touch with them?

        - What information do you plan to share with them?
        - What types of insight/information do you expect them to provide?
    - Explain how you plan to address the needs of these stakeholders in your prototypes/solutions

APPENDIX B WINTER 2021 ASSIGNMENTS

APPENDIX B-1 ASSIGNMENT 1 – JOURNEY MAP (DUE JANUARY 29, 2021)

- In this assignment, you will create a "journey map," charting the life of your design in terms of who interacts with it
- Using the template below as a guide (you may either fill in the given template or draw your own journey map based on the template), identify every instance in which a person will interact with any aspect of your design throughout its life-cycle
    - For each point on the journey map where an interaction is expected to occur, write in a stakeholder group to represent the person who will be interacting with your design
        - This may be one of the stakeholder groups you identified in the Fall semester, or may be a completely new stakeholder group
- Save your journey map as a pdf and submit

****If your team's project does not involve a design, please email me at heather.mcintosh@dal.ca, and we can figure out how to better tailor the assignment to your team's needs****

Future Assignments:

- In assignments two and three (due February 26th and March 26th), you will be asked to interview one stakeholder per assignment, and then complete a one-page report answering the following questions about their interaction with your design:
    - Who is the stakeholder?
    - What are they doing?
    - Where are they doing it?
    - When are they doing it?
    - Why are they doing it?
    - How are they doing it?
- More details on assignments two and three will be released in the coming weeks, but you may want to start thinking about which two stakeholders you would like to interview now – it may be useful to pick someone who is involved in an area for which you are lacking information

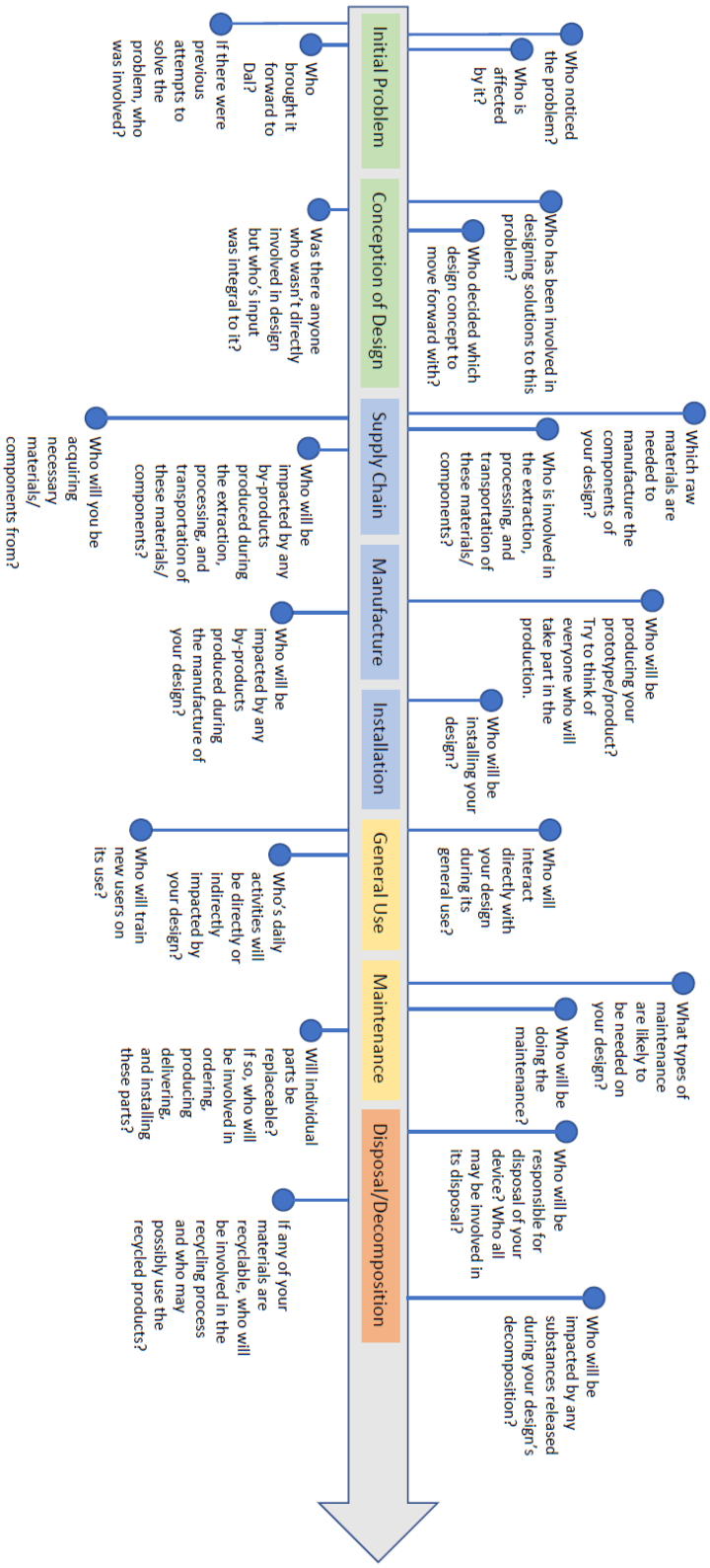


Figure 1. Template for journey map. This is also attached as a PowerPoint file. Replace the text in each textbox with the stakeholder(s) that correspond to the question posed in the textbox. Save as a pdf to hand in. You can make your own journey map if you wish, just make sure to include the key points seen in the template (Initial Problem, Conception of Design, Supply Chain, etc.)

APPENDIX B-2 ASSIGNMENTS 2&3 – INTERACTION SUMMARIES 1&2 (DUE FEBRUARY 26 AND MARCH 26, 2021)

- In this assignment you will interview one stakeholder from the journey map you created in assignment 1, in order to better understand how they will interact with your design.
    - Choose a stakeholder who you either know very little about or who you think could affect your design decisions moving forward.
    - If the stakeholder you have chosen interacts with your design at multiple points on your journey map, pick one of those interactions to focus on for this assignment.
- The goal of your interview is to gain a better understanding of how the stakeholder in question will interact with your design. As such, structure your interview with the following questions about the interaction in mind:
    - Who is the stakeholder?
    - What part do they play in the design/its use?
    - What specific tasks do they do and what knowledge/tools do they need to do it?
    - Where are they going to be interacting with your design? What does the environment in which the design is situated look like?
    - When in the lifespan of your design does this person interact with it? How often do they interact with the design?
    - Why is this person important in the lifespan of the design? Why are they interacting with your design?
    - How does this person interact with other stakeholders? How does their interaction with your design affect other stakeholders?
    - How does this person interact with the design?
- ***NOTE:*** Interviewing often feels awkward, especially when you are trying to both interview someone and keep notes. Instead of trying to do both, try to have the questions you would like to ask in mind before going into the interview so that you can keep it conversational, and have another person there to keep notes, or (even better), record (with permission) the audio of your conversation so you can go back later and make notes.
- After interviewing your stakeholder, create a one-page report summarizing that stakeholder's interaction with your design. You may use the template included below if you like (the sections of the template loosely correspond to the questions listed above). Save as a pdf and submit.

****If you are unsure of which stakeholder to interview, you can contact the instructors or Heather McIntosh (heather.mcintosh@dal.ca) to help clarify.****

Interaction Summary #1

Who is the stakeholder?

What are they doing?

Where are they doing it?

When are they doing it?

Why are they doing it/why are they important to your design?

How are they doing it/how does their interaction affect others?

APPENDIX C DATA COLLECTION TOOLS

APPENDIX C-1 CONCEPTIONS OF DESIGN SURVEY (ADAMS & FRALICK, 2010)

1. Name (first and last) _____

2. Of the twenty-three design activities listed below, put a check mark next to the six *most* important.

❑ Abstracting	❑ Identifying constraints	❑ Seeking information
❑ Brainstorming	❑ Imagining	❑ Sketching
❑ Building	❑ Iterating	❑ Synthesizing
❑ Communicating	❑ Making decisions	❑ Testing
❑ Decomposing	❑ Making trade-offs	❑ Understanding the problem
❑ Evaluating	❑ Modeling	❑ Using creativity
❑ Generating alternatives	❑ Planning	❑ Visualizing
❑ Goal Setting	❑ Prototyping	

❑ Prefer not to answer

For one of the six activities you marked as most important, explain why you believe it is important.

❑ Prefer not to answer

3. Of the twenty-three design activities listed below, put a check mark next to the six *least* important.

❑ Abstracting	❑ Identifying constraints	❑ Seeking information
❑ Brainstorming	❑ Imagining	❑ Sketching
❑ Building	❑ Iterating	❑ Synthesizing
❑ Communicating	❑ Making decisions	❑ Testing
❑ Decomposing	❑ Making trade-offs	
❑ Evaluating		

❑ Generating alternatives ❑ Goal Setting	❑ Modeling ❑ Planning ❑ Prototyping	❑ Understanding the problem ❑ Using creativity ❑ Visualizing

❑ Prefer not to answer

For one of the six activities you marked as least important, explain why you believe it is not important.

❑ Prefer not to answer

APPENDIX C-2 CLIENT SATISFACTION QUESTIONNAIRE (MODIFIED FROM SOBEK & JAIN, 2004)

1. Name (first and last) _____

2. What were the design objectives for the project? What did you expect the team to accomplish?

3. On a scale of 1-5, how close was the final outcome to your initial expectations?

- ❑ 1 (significantly below expectations)
- ❑ 2
- ❑ 3 (met expectations)
- ❑ 4
- ❑ 5 (significantly above expectations)
- ❑ Prefer not to answer

4. How much did your company benefit as a direct or indirect result of the design project outcomes?

- ❑ 1 (no benefit)
- ❑ 2
- ❑ 3 (benefited somewhat)
- ❑ 4
- ❑ 5 (benefited a great deal)
- ❑ Prefer not to answer

5. If you answered 1,2, or 3 to questions 4, how much potential do you think the design holds to benefit your company in the future?

- ❑ 1 (little, if any)
- ❑ 2
- ❑ 3 (moderate potential)
- ❑ 4
- ❑ 5 (excellent potential)
- ❑ Prefer not to answer

6. Approximately how often did you meet with the design team over the course of the year (face-to-face/virtually)?

- ❑ 0 times
- ❑ 1-2 times
- ❑ 3-6 times

- ❑ 7-12 times
- ❑ >12 times
- ❑ Prefer not to answer

7. Approximately how often did you communicate with the students other than the above-mentioned meetings? (includes email, online messaging, etc.)

- ❑ Multiple times daily
- ❑ Daily
- ❑ 1-2 times/week
- ❑ 1-2 times/month
- ❑ <1 time/month
- ❑ Prefer not to answer

8. How would you rate the quality of communication between the design team and you during the project?

- ❑ 1 (highly productive)
- ❑ 2
- ❑ 3 (moderately productive)
- ❑ 4
- ❑ 5 (waste of time)
- ❑ Prefer not to answer

9. What was your role in these meetings/communications?

- ❑ Prefer not to answer

10. How would you rate the technical difficulty of the design problem assigned to the design team?

- ❑ 1 (extremely easy)
- ❑ 2
- ❑ 3 (moderately difficult)
- ❑ 4
- ❑ 5 (very difficult)
- ❑ Prefer not to answer

11. Did you view the final report?

- ❑ Yes
- ❑ No
- ❑ Prefer not to answer

If yes, how accurate was the final report?

- ❑ Very Accurate
- ❑ Mostly accurate but with some minor errors
- ❑ Fairly accurate with no major errors
- ❑ 1-2 major errors
- ❑ Numerous major errors
- ❑ Prefer not to answer

If yes, how complete was the final report?

- ❑ Very complete
- ❑ Complete but some key issues not fully addressed
- ❑ Multiple key issues not fully addressed
- ❑ 1-2 key issues missing
- ❑ Several key issues missing
- ❑ Prefer not to answer

12. Did you view the final presentation?

- ❑ Yes
- ❑ No
- ❑ Prefer not to answer

If yes, how accurate was the final report?

- ❑ Very Accurate
- ❑ Mostly accurate but with some minor errors
- ❑ Fairly accurate with no major errors
- ❑ 1-2 major errors
- ❑ Numerous major errors
- ❑ Prefer not to answer

If yes, how complete was the final report?

- ❑ Very complete
- ❑ Complete but some key issues not fully addressed
- ❑ Multiple key issues not fully addressed
- ❑ 1-2 key issues missing
- ❑ Several key issues missing
- ❑ Prefer not to answer

13. Please comment on the accuracy, completeness and quality of the final prototype.

- ❑ Prefer not to answer

14. How feasible is the design in its application and fabrication?

- ❑ 1 (not feasible)
- ❑ 2
- ❑ 3 (fairly feasible)
- ❑ 4
- ❑ 5 (demonstrated feasibility)
- ❑ Prefer not to answer

15. Are you going to implement this design?

- ❑ Implement as-is
- ❑ Implement with slight modifications
- ❑ Implement with major modifications
- ❑ Implement with complete redesign
- ❑ Will probably not implement
- ❑ Prefer not to answer

16. If you had a chance, would you be interested in working on another project with this design team?

- ❑ Yes
- ❑ No
- ❑ Prefer not to answer

17. How would you rate your overall satisfaction with this design outcome?

- ❑ 1 (very satisfied)
- ❑ 2
- ❑ 3 (somewhat satisfied)
- ❑ 4
- ❑ 5 (very dissatisfied)
- ❑ Prefer not to answer

18. What would you do differently if you work on another student project?

- ❑ Prefer not to answer

APPENDIX D RECRUITMENT MATERIALS

APPENDIX D-1 RECRUITMENT SCRIPT FOR FIRST RECRUITMENT PRESENTATION.

Hi everyone!

My names is Heather and I'm a graduate student with Dr. Johnston, working towards a Master of Applied Science in Mechanical Engineering. I'm here today to invite you to participate in a research study I am running this year. The purpose of the study is to explore whether stakeholder mapping is a useful tool to support students in identifying and addressing stakeholder needs in their engineering projects.

There are three parts to this study: an online survey, release of stakeholder mapping assignments, and one-on-one interviews. If you wish to participate, you can choose to participate in a single section, or any combination of the three.

If you decide to participate in the online survey section of this research, you will be asked to complete a 4-question online survey at the beginning of the Fall 2020 and Winter 2021 semesters, and at the end of the Winter 2021 semester. The survey will ask two multiple choice and two short answer questions relating to which activities you think are most and least important to engineering design projects. The survey is expected to take approximately 10 minutes to complete on each occasion.

If you decide to participate in the stakeholder mapping portion of this research, you will be asked to give consent for releasing your team's stakeholder mapping assignments to the lead researcher for analysis. The lead research, (me), will only have access to the stakeholder maps if all members of the team agree to consent in this research, and whether an individual has consented or not will only be known to me. Whether you choose to participate or not in this portion of the research will have no bearing on how your stakeholder maps are marked or on the general evaluation of your team.

If you decide to participate in the interview portion of this research, you will be asked to participate in two one-on-one interviews with me. I'll ask you a few questions regarding your use of stakeholder mapping in your project, and you will have the opportunity to raise your own points and ideas about stakeholder mapping. The interviews are each expected to last approximately 30 minutes. They will be conducted over Microsoft Teams, and will be audio recorded and later transcribed.

In my data analysis I will be making comparisons between teams in terms of how thorough they were in completing their stakeholder mapping exercises, and how their

combined perceptions of design changed throughout the course. I will also make comparisons between the thoroughness of stakeholder mapping assignments, conceptions of design, and capstone client satisfaction. These comparisons will help us understand how to best support students in addressing stakeholder needs in their engineering projects and will contribute to the broader discussion around fostering "professional skills" in engineering students.

Choosing whether or not to take part in this research is entirely your choice. There will be no impact on your studies, future job or research opportunities, or performance evaluations if you decide not to participate in the research. All data will be withheld Dr. Johnston until grades have been submitted for the semester.

I will be emailing everyone a consent form with more information about the study. My email and phone number are included on the forms, so please don't hesitate to contact me with any questions you may have. If you wish to participate in the study, please email the completed consent forms (signed either electronically or by hand) to me within the next two weeks.

Thanks!

APPENDIX D-2 RECRUITMENT SCRIPT FOR ONE-MINUTE SUPPLEMENTARY RECRUITMENT VIDEO.

Hello everyone!

I hope you term is going well. I am Heather McIntosh, a graduate student with Dr. Clifton Johnston.

I'm just checking-in to let you know that I am still looking for students to participate in the study I'm running as part of my MASc. If you would like more info on the project, please take a look at the "Invitation to participate in MASc research study" video in the MECH 4015 Lectures section of this team.

I'll be emailing out two separate consent forms for this study in the next couple of days. Choosing whether you participate or not is entirely your choice and will have no bearing on your evaluations for this course. If you have any questions about the study, please do not hesitate to contact me at heather.mcintosh@dal.ca

Good luck with the rest of your term.

Thanks,

Heather

APPENDIX D-3 RECUITMENT SCRIPT FOR TWO-MINUTE SUPPLEMENTARY RECRUITMENT VIDEO.

Hello everyone!

If some of you do not remember me, I am Heather McIntosh, a graduate student working with Dr. Clifton Johnston. I am here today to invite you to participate in a research study I have been running throughout this school year. The purpose of the study is to explore whether stakeholder mapping is a useful tool to support students in identifying and addressing stakeholder needs in their engineering projects.

There are four parts of this study that I will be running in the Winter 2021 semester: two instances of an online survey, release of stakeholder mapping assignments, and one-on-one interviews. If you wish to participate, you can choose to participate in a single section, or any combination of the four. For each section that you choose to participate in, you will automatically be entered in a draw for one of five $25 Amazon.ca gift cards. There will be four draws in total (one for each of the parts mentioned above). You can be entered in multiple draws and can win multiple gift cards but can only win one gift card per draw. Students who have already submitted signed consent forms for stakeholder mapping and one-on-one interviews will automatically be entered in the corresponding draws.

Each draw will occur when the data collection for the portion of the study in question ends. For instance, the first Winter 2021 instance of the "Conceptions of Design" survey will be open to students until the end of February 2021. At the time when the survey is closed, the draw will take place and the gift cards will be sent to the winning students.

Withdrawal of participation will have no effect on your inclusion in the gift-card draws. If you choose to withdraw from the study after being awarded a gift card you will be allowed to keep the gift card. If you withdraw your participation before a draw has occurred, your name will remain in the draw and you will remain eligible to win a gift card in that draw.

If you would like more info on the project, please take a look at my "Invitation to participate in MASc research study" video, which I presented at the beginning of the Fall 2020 semester, and which I've posted in the content section of this course's Brightspace page.

Below you will find a link to the two Winter 2021 instances of the online survey, and to the consent forms for the stakeholder mapping and one-on-one interview portions of this

study. I will also be emailing you all of these links. The first instance of the online survey will be open from now until the end of February, and the second instance will be open from April 1st-30th, 2021. The consent forms for the stakeholder mapping and one-on-one interviews will be open from now until March 26th (when the last stakeholder mapping assignment is due).

Choosing whether you participate or not is entirely your choice and will have no bearing on your evaluations for this course. If you have any questions about the study, please do not hesitate to contact me at heather.mcintosh@dal.ca
Good luck with the rest of your term.

Thanks,

Heather

APPENDIX E CONSENT DOCUMENTS

APPENDIX E-1 CONSENT FORM FOR STUDENT PARTICIPANTS – STAKEHOLDER MAPPING AND ONE-ON-ONE INTERVIEWS.

DALHOUSIE UNIVERSITY

CONSENT FORM

Project title: Exploring stakeholder mapping as a tool to support student incorporation of stakeholder needs in a senior undergraduate mechanical engineering capstone course

Lead researcher: Heather McIntosh
Department of Mechanical Engineering, Dalhousie University
902-802-3970
heather.mcintosh@dal.ca

Other researchers
Dr. Clifton Johnston
Department of Mechanical Engineering, Dalhousie University
902 494-8985
clifton.johnston@dal.ca

Prof. Glen Hougan
Design Division, NSCAD University
ghougan@nscad.ca
Funding provided by: NSERC

Introduction
We invite you to take part in a research study being conducted by Heather McIntosh, who is a graduate student at Dalhousie University. Choosing whether or not to take part in this research is entirely your choice. There will be no impact on your studies, future job or research opportunities, or performance evaluations if you decide not to participate in the research. The information below tells you about what is involved in the research, what you will be asked to do and about any benefit, risk, inconvenience, or discomfort that you might experience.
You should discuss any questions you have about this study with Heather McIntosh. Please ask as many questions as you like. If you have questions later, please contact Heather McIntosh at 902-802-3970 or heather.mcintosh@dal.ca.

Purpose and Outline of the Research Study

The purpose of this study is to explore stakeholder mapping as a tool to support students in identifying and addressing stakeholder needs in their engineering projects. This research responds to increased calls for engineering educators to better prepare students for success in real-world projects, which involve interactions with many stakeholders (clients, manufacturers, users, etc.) each with their own unique and complex needs.

The study population will consist of senior-level mechanical engineering students enrolled in a year-long capstone course, and the clients associated with the capstone projects. Student teams will complete regular "stakeholder mapping" exercises as part of their coursework. These exercises will take the form of an ever-evolving concept map, in which students will explore the many stakeholders connected to their project, and the needs/desires of each of these stakeholders.

The study will include four sources of data: student responses to a "Conceptions of Design" survey, which will be administered three times - at the beginning, middle and end of the course; student reflections completed as part of regular stakeholder mapping exercises; semi-structured interviews with students regarding their experience of completing the stakeholder mapping assignments; and a "Client Satisfaction Survey" completed by capstone clients at the end of the course.

The "Conceptions of Design" survey has been used with students and design professionals by numerous researchers. It asks participants to choose the six "most" and six "least" important design activities from a list of twenty-three. The results of the survey will be analyzed to determine how student perceptions of the relative importance of design activities change over the course of the capstone course.

Comparisons will be made between teams in terms of how thorough they were in completing their stakeholder mapping exercises, and how their combined perceptions of design changed throughout the course. Comparisons will also be made between the thoroughness of stakeholder mapping assignments, conceptions of design, and client satisfaction.

This study will help us understand how to best support students in addressing stakeholder needs in their engineering projects and will contribute to the broader discussion around fostering "professional skills" in engineering students.

You will be given additional information about the study after your participation is complete. This will be delivered by email.

Who Can Take Part in the Research Study

Any student enrolled in MECH 4015 and MECH 4025 (the mechanical engineering capstone courses) during the 2020/2021 schoolyear may participate in this study. Clients associated with student projects in these courses may also participate if at least one member of the student team assigned to their project has consented to participate in the "Conceptions of Design" surveys and/or if all of the members of their student team have consented to releasing their stakeholder mapping assignments for analysis.

What You Will Be Asked to Do

There are three parts to this study: stakeholder mapping, surveys, and one-on-one interviews. If you wish to participate, you can choose to participate in a single section, or any combination of the three. Consent for the survey portion of this study will be addressed in a separate form.

If you decide to participate in the stakeholder mapping portion of this research, you will be asked to consent to the release of your team's stakeholder mapping assignments to the lead researcher for analysis. The lead research will have no affiliations with the course in terms of evaluating students. Your team's stakeholder map assignments will only be released to the lead researcher if all members of your team consent to their release. Whether you consent to this portion of the study or not (or whether you withdraw your participation from this portion of the study at any point) will only be known to the lead researcher, and this information will not be shared with your teammates. Whether you choose to participate or not in this portion of the research will have no bearing on how your stakeholder maps are marked or on the general evaluation of your team.

If you decide to participate in the interview portion of this research, you will be asked to participate in a one-on-one interview with the lead researcher. The lead researcher will ask you a few questions regarding your use of stakeholder mapping in your project, and you will have the opportunity to raise your own points and ideas throughout the meeting. The interviews are expected to last approximately thirty minutes. They will be conducted over Microsoft Teams, and will be audio recorded and later transcribed.

Possible Benefits, Risks and Discomforts

Participating in this study may help us better understand how to best support students and instructors in future capstone courses, although this is not expected to benefit you directly.

There is a small risk of stress associated with the time commitment needed to participate in the interview section of this study. For students participating in the interview section of the research, interviews will be planned around their schedules, and they may reschedule or cancel interviews at any time without repercussion.

There is a small risk that you may feel pressured to participate in the "stakeholder mapping" portion of the study, because all team members must consent in order for their team's stakeholder maps to be included in the study. This risk will be mitigated by the fact that whether you consent to this portion of the study or not (or whether you withdraw your participation from this portion of the study at any point) will only be known to the lead researcher, and this information will not be shared with your teammates. Whether you choose to participate or not in this portion of the research will also have no bearing on how your stakeholder maps are marked or on the general evaluation of your team.

Compensation / Reimbursement

For each portion of the study that you choose to participate in (either of the two Winter 2021 instances of the "Conceptions of Design" survey, stakeholder mapping, or one-on-on interviews), you will immediately be entered into a draw for one of five $25 Amazon.ca gift cards. There will be a separate draw for each portion of the study mentioned above (for a total of twenty $25 gift cards). You can be entered in multiple

draws and may win multiple gift cards but are only eligible to win one gift card per draw.
Each draw will occur when the data collection for the portion of the study in question ends. For example, the last stakeholder mapping assignment will be collected on March 26th. At that time, the draw will take place and the gift cards will be sent to the winning students.
Withdrawal of participation will have no effect on your inclusion in the gift-card draws. If you choose to withdraw from the study after being awarded a gift card you will be allowed to keep the gift card. If you withdraw your participation before a draw has occurred, your name will remain in the draw and you will remain eligible to win a gift card in that draw.

How your information will be protected:
Your participation in this research will be known only to the lead researcher, Heather McIntosh. She will have no role in the MECH 4015 and MECH 4025 courses and will have no influence on student evaluations in these courses. Only Heather McIntosh will have knowledge of which teams are participating in the stakeholder mapping portion of the study, and only she will have knowledge of which students have consented to the release of their team's stakeholder maps.
The information that you provide to us will be kept confidential. Only Heather McIntosh and Professor Glen Hougan will have access to this information. Heather and Prof. Hougan have an obligation to keep all research information confidential. All of your identifying information (such as your name and contact information) will be securely stored separately from your research information. We will use an alphanumeric participant number (not your name) in our written and computer records so that the research information we have about you contains no names. Only Heather McIntosh will have access to the key-code that links your name with your assigned alpha-numeric code. During the study, all electronic records will be kept secure on a Dalhousie University server. All paper records will be kept secure in a locked box located in the lead researcher's personal residence.

We will describe and share our findings in a master's thesis, conference presentations, journal articles, and on the Dalhousie design website (http://design.engineering.dal.ca). For quantitative data, we will only report group results and not individual results. For qualitative data (such as interview data) we may quote individuals but will not identify them by name.
Data will be retained on Dalhousie-owned equipment and servers until six months after the study has been completed, at which time the original data will be deleted.

If You Decide to Stop Participating
You are free to leave any portion of the study at any time. If you decide to stop participating during the study, you can decide whether you want any of the information that you have provided up to that point to be removed or if you will allow us to use that information. To withdraw from the stakeholder mapping or interviews sections of the study, email the lead researcher, Heather McIntosh.

If you decide to stop participating in the stakeholder mapping portion of the study, your team's stakeholder maps will be removed from the study. Your teammates will not be given any information regarding your withdrawal or the removal of the stakeholder maps from the study.
After participating in the study, you can decide for up to 6 months if you want us to remove your data. After that time, it will become impossible for use to remove it because the key-code and data will have already been destroyed.

Withdrawal of participation will have no effect on your inclusion in the gift-card draws. If you choose to withdraw from the study after being awarded a gift card you will be allowed to keep the gift card. If you withdraw your participation before a draw has occurred, your name will remain in the draw and you will remain eligible to win a gift card in that draw.

How to Obtain Results
Study results will be posted on the design website: http://design.engineering.dal.ca/. An email will be sent to all participants once the results have been posted. For quantitative data, we will only report group results and not individual results. For qualitative data (such as interview data) we may quote individuals but will not identify them by name.

Questions
We are happy to talk with you about any questions or concerns you may have about your participation in this research study. Please contact Heather McIntosh (at 902 802-3970, heather.mcintosh@dal.ca) [or Dr. Clifton Johnston (at 902 494-8985, clifton.johnston@dal.ca)] at any time with questions, comments, or concerns about the research study (if you are calling long distance, please call collect).

Throughout the project, you will be provided with any new information which might affect your decision to participate in the study.

If you have any ethical concerns about your participation in this research, you may also contact Research Ethics, Dalhousie University at (902) 494-3423, or
email: ethics@dal.ca (and reference REB file # 2020-5269).

Signature Page

Project title: Exploring stakeholder mapping as a tool to support student incorporation of stakeholder needs in a senior undergraduate mechanical engineering capstone course.

Lead researcher: Heather McIntosh
Department of Mechanical Engineering, Dalhousie University
902-802-3970
heather.mcintosh@dal.ca

1. Stakeholder Mapping Participation (Optional)

I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that I have been asked to release my stakeholder mapping assignments, completed as part of MECH 4015 and MECH 4025, to the researcher for analysis. I understand direct quotes of excerpts from my stakeholder mapping assignments may be used without identifying me. I agree to take part in this study. My participation is voluntary, and I understand that I am free to withdraw from the study at any time, until 6 months after my team's final stakeholder map is submitted.

_____ _____ _____
Name Signature Date

2. Interview Participation (Optional)

I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that I have been asked to take part in an interview that will occur over a Microsoft Teams video call. I agree to take part in this study. I realize that my participation is voluntary and that I am free to withdraw from the study at any time, until 6 months after my second interview is complete.

Options (you can still participate in the research if you select no):

I agree that my interview may be audio-recorded □ Yes □ No
I agree that direct quotes from my interview may be used without identifying me □ Yes □ No

_____ _____ _____
Name Signature Date

APPENDIX E-2 ONLINE SURVEY CONSENT FORM FOR STUDENT PARTICIPANTS.

CONSENT FORM

EXPLORING STAKEHOLDER MAPPING AS A TOOL TO SUPPORT STUDENT INCORPORATION OF STAKEHOLDER NEEDS IN A SENIOR UNDERGRADUATE MECHNICAL ENGINEERING CAPSTONE COURSE

You are invited to take part in a research study being conducted by Heather McIntosh, a graduate student in the Department of Mechanical Engineering at Dalhousie University. The purpose of this research is to evaluate whether stakeholder mapping exercises help students identify and respond to stakeholder needs in their capstone engineering projects. Participating student teams will complete regular stakeholder mapping exercises throughout the 2020-2021 schoolyear, and comparisons will be made between the thoroughness of teams' maps, team members' perceptions of which design activities are most important to engineering projects, and how satisfied their clients are with their projects. This study is open to students enrolled in Dalhousie's senior mechanical engineering courses during the 2020-2021 schoolyear, and the clients associated with the projects in this course. The study is funded by NSERC.

There are three parts of this study in which students can participate: online surveys, stakeholder mapping, and one-on-one interviews. If you wish to participate, you can choose to participate in a single section, or any combination of the three. This consent form deals only with the online survey portion of this study. Consent for the stakeholder mapping and one-on-one interviews is addressed in a separate form.
The online survey will be administered three times throughout the 2020-2021 schoolyear; once in the Fall 2020 semester, and at the beginning and end of the Winter 2021 semester. This form deals specifically with participation in the first of the two Winter 2021 surveys.*

If you decide to participate in this online survey, you will be asked to complete a 4-question "Conceptions of Design" survey. The survey will ask two multiple choice and two short answer questions relating to which activities you think are most and least important to engineering design projects. The survey is expected to take approximately 10 minutes to complete.

Your participation in this research is entirely your choice. You do not have to answer questions that you do not want to answer (by selecting prefer not to answer), and you are welcome to stop the survey at any time if you no longer want to participate. All you need to do is close your browser. I will not include any incomplete surveys in my analyses. If you decide to withdraw your participation after completing and submitting the

"Conceptions of Design" survey, you can do so by emailing the lead researcher. After participating in the study, you can decide for up to 6 months if you want us to remove your data. After that time, it will become impossible for us to remove it because the key-code and data will have already been destroyed.

You will be asked to include your name on the survey. This is the only identifying detail that the survey will ask for. Your name will only be used to link your survey results with any other contributions you make to this research, and with any contributions made by your capstone team members. This will allow for survey results to be analyzed longitudinally and for comparisons to be made between teams. Once all your results have been linked together and with those of your team, your name will be replaced by an alphanumeric code. Only Heather McIntosh will have access to the key-code and to the survey results.

I will describe and share general findings of this research in my Master's thesis, conference presentations, in academic journals, and on the Dalhousie design website (http://design.engineering.dal.ca). For quantitative data, I will only report group results and not individual results. For qualitative data (such as short-answer responses in the online survey) I may quote individuals but will not identify them by name. I will destroy all the collected information 6 months after completing/reporting the results.

The risks associated with this study are no greater than those you encounter in your everyday life. There is a chance that you may experience slight boredom while completing the survey.

Participation in the "Conceptions of Design" survey may directly benefit you, as it will prompt you to reflect on what activities are important in you design processes. No other direct benefits to student participants are expected, but you may experience indirect benefits in knowing that your participation may help us learn things that will benefit future students and instructors. If you would like to see how your information is used, please feel free to visit my website: http://design.engineering.dal.ca/ after September 30th, 2021.

For each portion of the study that you choose to participate in (either of the two Winter 2021 instances of the "Conceptions of Design" survey, stakeholder mapping, or one-on-on interviews), you will immediately be entered into a draw for one of five $25 Amazon.ca gift cards. There will be a separate draw for each portion of the study mentioned above (for a total of twenty $25 gift cards). You can be entered in multiple draws and may win multiple gift cards but are only eligible to win one gift card per draw.

Each draw will occur when the data collection for the portion of the study in question ends. For example, the first Winter 2021 instance of the "Conceptions of Design" survey will be open until 11:59pm, February 28th, 2021.** When the survey closes, the draw will take place and the gift cards will be sent to the winning students.

Withdrawal of participation will have no effect on your inclusion in the gift-card draws. If you choose to withdraw from the study after being awarded a gift card you will be allowed to keep the gift card. If you withdraw your participation before a draw has occurred, your name will remain in the draw and you will remain eligible to win a gift card in that draw.
You should discuss any questions you have about this study with Heather McIntosh and Dr. Clifton Johnston. Please ask as many questions as you like before or after participating. My contact information is heather.mcintosh@dal.ca, and Dr. Johnston's is clifton.johnston@dal.ca.

If you have any ethical concerns about your participation in this research, you may contact Research Ethics, Dalhousie University at (902) 494-3423, or email ethics@dal.ca (and reference REB file # 2020-5269)."

If you agree to complete this instance of the "Conceptions of Design" survey, please click "start" to begin the survey. If you would like to complete the survey at a later date, you can return through the link provided on Brightspace at any time before 11:59pm, February 28th, 2021.***

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*This text read: "This form deals specifically with participation in the second of the two Winter 2021 surveys" in the consent forms for the second Winter 2021 instance of the survey.
**This text read "For example, the second Winter 2021 instance of the "Conceptions of Design" survey will be open until 11:59pm, April 30th, 2021" In the consent form for the second Winter 2021 instance of the survey.

*** This text read "before 11:59pm, April 30th, 2021" in the consent form for the second winter 2021 instance of the survey.

APPENDIX E-3 CONSENT FORM FOR CLIENT PARTICIPANTS.

DALHOUSIE UNIVERSITY

CONSENT FORM

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If you choose to participate in this research, you will be asked to answer 18 questions (13 multiple choice and 5 short-answer) as part of an online survey concerning your satisfaction with the work students have completed on your project. The survey should take approximately 30 minutes. The results of the survey will have no bearing on students' grades, and the course instructor and teaching assistants will not have access to the results of the survey.

Your participation in this research is entirely your choice. You do not have to answer questions that you do not want to answer (by selecting prefer not to answer), and you are welcome to stop the survey at any time if you no longer want to participate. All you need to do is close your browser. I will not include any incomplete surveys in my analyses. If you decide to withdraw your participation after completing and submitting the "Client Satisfaction Questionnaire," you can do so by emailing the lead researcher. After participating in the study, you can decide for up to 6 months if you want us to remove your data. After that time, it will become impossible for us to remove it because the key-code and data will have already been destroyed.

You will be asked to include your name on the survey. This is the only identifying detail that the survey will ask for. Your name will only be used to link your survey results with your student team's stakeholder maps (if all team members have consented to their release) and to the "Conceptions of Design" survey results of individual members of your student team. Once your results have been linked with those of your student team, your name will be replaced by an alphanumeric code. Only Heather McIntosh will have access to the key-code and to the survey results.

I will describe and share general findings of this research in my Master's thesis, conference presentations, in academic journals, and on the Dalhousie design website (http://design.engineering.dal.ca). I will destroy all the collected information 6 months after completing/reporting the results.

The risks associated with this study are no greater than those you encounter in your everyday life. There is a chance that you may experience slight boredom while completing the survey.

The input you give in your responses to the online survey may help us support more productive student/client relationships in future capstone courses. As such, participating in this research may directly benefit you if you intend to return as a client in a future capstone course. Participation may also help contribute to our understanding of how to best support students at incorporating stakeholder input into their engineering projects. If you would like to see how your information is used, please feel free to visit my website: http://design.engineering.dal.ca/ after September 30th, 2021.

You should discuss any questions you have about this study with Heather McIntosh and Dr. Clifton Johnston. Please ask as many questions as you like before or after participating. My contact information is heather.mcintosh@dal.ca, and Dr. Johnston's is clifton.johnston@dal.ca.

If you have any ethical concerns about your participation in this research, you may contact Research Ethics, Dalhousie University at (902) 494-3423, or email ethics@dal.ca (and reference REB file # 2020-5269).

If you agree to complete the survey, please follow the link here/click continue:

(Link to survey)
