PROTOTYPING CANVAS: DESIGN TOOL FOR PLANNING PURPOSEFUL PROTOTYPES

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ABSTRACT

While prototypes are critical to the creation of successful products and innovative solutions, building a prototype is characterized by large sunk costs and a plethora of unknowns. The versatility and effectiveness of prototypes paired with the ambiguous nature of developing a prototype can lead to wasted resources. Recent studies support this claim, demonstrating that under certain circumstances, designers often prototype without a clear purpose, building prototypes as a function of the design process rather than as a function of the design. These findings motivated the creation of the Prototyping Canvas, a tool to aid designers in planning for purposeful prototypes by identifying critical assumptions and questions to guide development. Business and engineering design literature influenced the development of the canvas, which was first tested with a client project in the SUTD-MIT International Design Centre (IDC). The feedback and insights from the design team guided revisions to the canvas. The updated canvas was then validated with 55 professionals during a design project sprint. The purpose of this paper is to present the Prototyping Canvas as a valid and effective design tool.

Keywords: Design methods, Prototype, Design practice, New product development

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Cite this article: Lauff, C., Menold, J., Wood, K.L. (2019) ‘Prototyping Canvas: Design Tool for Planning Purposeful Prototypes’, in *Proceedings of the 22nd International Conference on Engineering Design (ICED19),* Delft, The Netherlands, 5-8 August 2019. DOI:10.1017/dsi.2019.162

1 INTRODUCTION

1.1 Importance of prototyping

Prototyping is an important design activity that can enhance communication (Buchenau and Suri, 2000; Brandt, 2007), learning (Leifer and Steinert, 2011), and decision making (Kriesi *et al*., 2016) throughout the entire design process (Ulrich and Eppinger, 2000; Otto and Wood, 2001; Lauff *et al*., 2018a). A prototype refers to both physical and digital representations of a design, regardless of fidelity, that serves to answer a question or test an assumption (Lauff, 2018; Menold *et al*., 2018). Prototypes can be classified as a stage of the design process; they can also be described as a tool to further product development. Prototypes are essential to all design process models, ranging from waterfall, V-model, to sprint-scrum. Previous work has highlighted the ability of prototypes to improve students' technical understanding of the design space and help designers uncover "unknown unknowns," as well as explore fundamental user insights (Jensen *et al*., 2017; Tiong, *et al*., 2018). Andreasen and Hein (1987), for example, demonstrated that building prototypes in the early stages of the design process can help students visualize problems and highlight incorrect design assumptions. Additionally, prototypes have been shown to boost design performance (Neeley *et al*., 2013; Dow *et al*., 2009), influence stakeholder buy in (Greenberg *et al*., 2013), supplement designers' mental models (Lin and Seepersad, 2007; Lemons *et al*., 2010), and enhance both technical and social skills development (Lauff *et al*., 2018b). Observational and ethnographic work from the fields of cognitive psychology and sociology further demonstrate the importance of prototypes in organizations, through their ability to create shared tacit knowledge (Rhinow *et al*., 2012; Henderson, 1991), enhance stakeholder communication (Star, 2010), and improve design outcomes (Bucciarelli, 2002; Schrage, 2000).

Prototypes clearly offer a myriad of benefits to both professional designers and students, yet multiple studies point to students' tendency to limit prototyping activities to later stage design during authentic design challenges (Deineger *et al*., 2017). Research has also shown that engineering students often have a narrow perception of prototypes, believing that prototypes are only meant to test functionality of a full-scale final design (Lauff *et al*., 2017). Further, while studies underscore the abilities of professional designers to leverage prototypes more effectively than student designers in many cases, professionals still face uncertainty (Gerber and Carroll, 2012) and must balance competing demands due to budget and schedule constraints (Moe *et al*., 2004). This work is motivated by the belief that prototypes are necessary tools during the design process, and that both professional and student designers could benefit from additional guidance in prototype development efforts.

1.2 The need for the prototyping Canvas

To increase the efficiency and effectiveness of prototype practice, researchers have proposed multiple prototyping methods and strategies from the Prototype for X (PFX) framework (Menold *et al*., 2017) to a strategic design prototyping methodology that includes seven prototyping techniques (Camburn *et al*., 2015). Please refer to Menold's dissertation for an extensive review of current prototyping strategies (Menold, 2017), including these additional references (Camburn *et al*., 2017a; Christie *et al*., 2012; Hamon, 2017; Moe *et al*., 2004; Dunlap *et al*., 2014). Many of these strategies have been tested with student designers and are helpful in guiding them through prototyping practices, while also teaching fundamental principles about the importance of prototypes. While these methods and strategies are useful for designers and are grounded in best practices and empirical studies, research from Menold *et al*. (2018) demonstrates that students lacked a fundamental awareness of their own prototyping behaviors, even when prototyping strategies or methods were introduced through educational modules. In other words, this study found that while these methods and strategies were beneficial and lead to improved design outcomes, students may not be aware of these methods, and may be less likely to implement these methods independently during authentic design challenges (Menold *et al*., 2018). While previous research has been incredibly valuable and has empirically validated the utility and effectiveness of prototyping methods and strategies, to date, researchers have not explored how communication of these methodologies affects their adoption. We hypothesize that that by building upon past work and improving the delivery modes of prototyping methods, we can increase their use by practitioners and students. As such, the purpose of this work is to propose a new prototyping planning tool drawing on the empirical evidence of previous literature, that can be more readily implemented in design practice.

https://doi.org/10.1017/dsi.2019.162 Published online by Cambridge University Press

There are several design tools that have been adopted by universities and corporations and are grounded in empirical evidence and best practices from literature. Yilmaz, Seifert, and Daly, for example, developed the 77 design heuristic cards (Daly *et al.*, 2012; Yilmez *et al.*, 2016), which have been widely adopted as simple, yet effective tool during concept generation. Gerber developed Mockups as a tool to teach prototyping principles and mindsets, while engaging teams at the start of a project (Gerber, 2015). User journey diagrams, empathy maps, and personas are commonly used tools during the discovery phase of a project to gain empathy and understanding of the opportunity and users (IDEO, 2015; Camburn *et al.*, 2017b). The popularity of online platforms that share design tools and methods, like IDEO's Design Kit (designkit.org; IDEO, 2015) or Berkeley and MIT's Design Exchange (thedesignexchange.org; Roshuni *et al.*, 2015), points to the utility and need for such design tools.
A common theme amongst these tools is their simplicity; each tool can be easily integrated into existing design practices increasing the likelihood of their adoption by practitioners, educators, and students. We argue that while many researchers have identified prototyping best practices, and have empirically validated these practices with students, findings from research remain difficult to translate to practice due to the lack of simple and effective design tools for prototyping. In this work, we propose the Prototyping Canvas, a design tool that effectively guides designers through prototyping processes, facilitates a common prototyping language amongst team members, and encourages intentional prototyping practice. The following sections describe the development of the Prototyping Canvas tool, which includes testing its usefulness during an industry project and then iterating on the tool and testing it again with 55 professionals during multi-day design innovation project sprints.

2 PROTOTYPING CANVAS DEVELOPMENT

2.1 Inspiration from Business Model Canvas

The structure of the Prototyping Canvas was heavily influenced by the success of the Business Model Canvas (BMC). The Business Model Canvas translates key business activities into a simple, yet effective tool for companies to rapidly create and validate business models (Osterwalder and Pigneur, 2010). The BMC is arguably the most recognizable and successful business design tool in use. Strategyzer reports that in 2015 there were over 5 million downloads of the canvas (strategyzer.com). Research has found that using the BMC leads to shared language amongst teams, better conversations on strategy, more ideas shared, and a structured plan to implement concepts (Amarsy, 2015). The BMC has been adapted for other situations, such as the Mission Model Canvas for mission-driven organizations (Blank, 2016) and the Lean Canvas for start-ups (Maurya, 2010). Likewise, we have evolved the BMC for prototyping during product development, thus creating the Prototyping Canvas.

2.2 Methodology for development

The main contribution of this paper is the development of the Prototyping Canvas planning tool, which is grounded in existing evidence and translates validated prototyping methods to practice. The methodology for developing the Prototyping Canvas is depicted in Figure 1. The process began with a literature review surveying relevant prototyping literature in engineering design to build a strong evidence base. From these articles, prototyping strategies, frameworks, and approaches were identified. Findings from research were used as the building blocks for the content of version 1 (V1) of the Prototyping Canvas, which was then tested with an industry project in the SUTD-MIT International Design Centre (IDC, idc.sutd.edu.sg). Four professional designers, with industrial design and engineering backgrounds, used the Prototyping Canvas during this project and provided continuous feedback to improve the tool. From their feedback, version 2 (V2) of the Prototyping Canvas was developed. Then, the revised V2 canvas was tested with 55 professionals during 2 and 3-day design sprints to validate the usefulness of the canvas. Future research studies will be conducted to further validate the utility of the Prototyping Canvas. The remainder of this section details the development and validation of the Prototyping Canvas.

Figure 1. Methodology for developing and revising the prototyping Canvas

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2.3 Synthesizing prototyping literature into Prototyping Canvas V1

The content of the Prototyping Canvas is grounded in empirical evidence from literature. Most notably, the two dissertations from the co-authors influenced the development of the canvas as they were on the topics of "prototyping in the wild" studying companies' usage of prototypes throughout the entire design process (Lauff, 2018), and developing a "prototyping for x" (PFX) framework to prototype creation (Menold, 2017). After surveying literature in the field of engineering design, three principles were identified as critical to prototyping efforts: identifying the (1) purpose of the prototype, (2) resources to build the prototype, and (3) strategy to execute building and testing the prototype. The literature related to each of these principles is listed below, and exemplars of each principle are described in Table 1.

- **Purpose:** All prototypes should answer a question, and thus have a purpose for the prototype development. One must identify assumptions and questions that motivate the need to build and test a prototype. This was based on the following literature: (Lauff, 2018; Lauff *et al.*, 2018a; Houde and Hill, 1997; Rhinow *et al.*, 2012; Lande and Leifer, 2009; Deiniger *et al.*, 2017; Ulrich and Eppinger, 2000; Otto and Wood, 2001). On the canvas, this motivates the creation of three categories: "Stakeholders", "Assumptions and Questions" and "Critical Assumption/Question."
- **Resources:** When building a prototype, one must take note of all the resources that are available and sources for these resources, including the materials, time, and cost, to guide development of the simplest prototype possible. This was based on the following literature: (Yang, 2005; Menold, 2017; Menold *et al.*, 2017; Thomke, 1998; Dow *et al.*, 2009; Buchenau and Suri, 2000; Gerber and Carroll, 2009; Viswanathan and Linsey, 2011). On the canvas, this motivates the creation of one category: "Resources Available."
- **Strategy:** To prototype effectively, one should formulate a strong plan and approach to building and testing the prototype. Many strategies aim to minimize the resources used to maximize the desired outcome. This was based on the following literature: (Menold 2017; Menold *et al.*, 2017; Menold *et al.*, 2018; Camburn *et al.*, 2015; Camburn *et al.*, 2017a; Christie *et al.*, 2012; Hamon, 2017; Moe *et al.*, 2004; Dunlap *et al.*, 2014). On the canvas, this motivates the creation of three categories: "Building Plan", "Testing Plan", and "Insights."

Table 1. Exemplars of prototyping literature influence on Canvas' three principles

Exemplar Literature	**Prototyping Insights from Exemplar Literature**	**Key Principle**
Lauff, 2018; Lauff *et al.*, 2018a	Prototypes are tools for communication, learning, and decision making. Prototypes are active objects that impact social situations. Prototypes need to have an underlying purpose to test assumptions.	Purpose
Moe *et al.*, 2004; Camburn *et al.*, 2017a	Moe *et al.* proposed a method for prescribing a partitioning strategy that is tailored to the specific characteristics of a project and is based upon the three components of requirement flexibility: cost, schedule, and performance. Camburn *et al.* identified six techniques for prototyping that can minimize resources used during development: iteration, parallel concepts, scaling, subsystem isolation, requirement relaxation, and virtual prototypes.	Resources
Menold 2017; Menold *et al.*, 2017; Menold *et al.*, 2018	The Prototype for X (PFX) framework is a strategy that breaks prototyping efforts into three key phases: (1) Frame, (2) Build, and (3) test. Through these phases, PFX helps designers develop a strategy to focus resources and efforts on building prototypes that test core assumptions and lead to deeper and richer learning about specific aspects of the design, at the time of testing.	Strategy

The layout of the canvas was influenced by the layout of the Business Model Canvas (Osterwalder and Pigneur, 2010). A user can fill out the canvas in any order, with the most structured approach starting with the "Stakeholders" and "Assumptions & Questions", moving left-to-right, until the "Insights" are documented. The contents of the Prototyping Canvas are described next.

- **Stakeholders.** Stakeholders refer to all people who have some stake in the project. This can include end-users, consumers, clients, project managers, investors, manufacturers, or similar. The

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stakeholders need to be considered throughout the building and testing of their prototype, especially in how they will be communicated with using the prototype.

- **Assumptions & Questions.** This section is meant to identify all the assumptions about the problem or design, along with all questions that are unanswered. There are three sub-categories related to feasibility, desirability, and viability to encourage deeper thinking about the problem or solution.
- **Critical Assumption/Question.** This section assesses the assumptions and questions listed prior to determine which is the most critical to the success of the project. This validates why it is necessary to prototype. The critical assumption/question should guide the prototype development.
- **Resources Available.** Resources refers to materials, money, people, and time collectively. You must first consider what resources are readily available, and the sources of those resources, followed by what resources you must obtain, so that the simplest prototype can be built to test the critical assumption/question.
- **Testing Plan.** This section acts as a guide to create a simple, yet comprehensive testing plan for the prototype. The guiding questions include: How will you test your assumption/question using a prototype? How will you assess success or failure? What metrics are needed to assess the performance? How will the stakeholders be impacted? Where, when, and with whom will you test?
- **Building Plan.** This section is used for sketching the intended prototype and documenting a plan before building and testing occurs. The previous answers to the resources block will guide material selection, prototype medium, and construction method for the prototype. The goal is to determine the simplest way to build and test the critical assumption/question, while keeping the relevant stakeholders in mind.
- **Insights.** The final section is meant for reflections, insights, and documenting any new assumptions and questions that arose after testing the prototype. The intent is that prototypes are iterative, meaning there are more assumptions, questions, and unknowns to test. This section may lead to the next prototype iteration or development of an entirely new concept to prototype.

2.4 Testing of Prototyping Canvas V1

The first version of the Prototyping Canvas was tested with the SUTD-MIT International Design Centre (IDC) team working on an industry-client project. The IDC team was tasked with designing a launch mechanism for a large construction kick-off event. There were four professional designers on the project, and they each used the Prototyping Canvas to guide their prototyping efforts. Before using the canvas, one of the researchers gave a 20-minute presentation that covered the importance of prototyping in the design process and walked the designers through the Prototyping Canvas. The team then spent 15-minutes filling out the canvas in pairs, followed by a larger 30-minute discussion amongst the team. They then spent two days developing and testing six different parallel prototypes based on the canvas' before filling in the final "Insights" section.

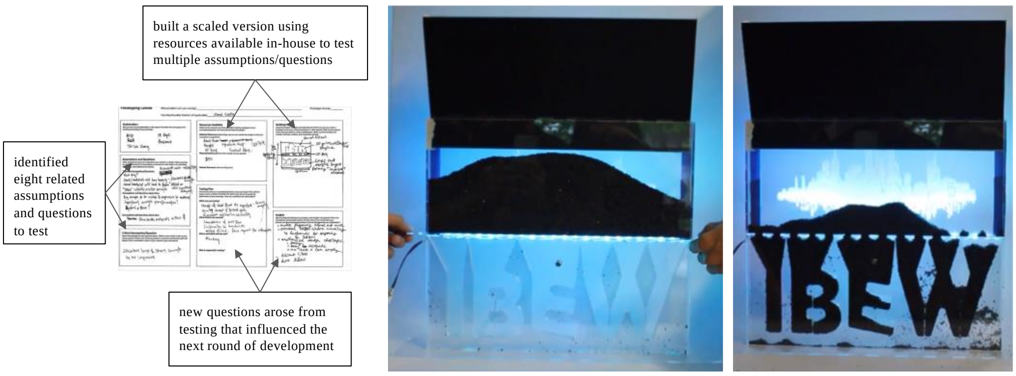

Figure 2. Completed Prototyping Canvas with call-outs (left) and scaled prototype (right)

One completed V1 Prototyping Canvas is shown in Figure 2, alongside images of the tested prototype entitled "Sandcastle." The designers started with the Sandcastle concept, and then used the canvas to develop a prototyping plan. They documented eight assumptions and questions about the concept and listed available resources in the IDC to build the prototype. The engineer chose to create a scaled down version of the Sandcastle to test appeal to the client, the ease of movement of sand, the overall "wow" factor, and structural integrity of the system. They built the scaled Sandcastle prototype in less than one day, using materials and resources in-house. A digital model was created in CAD, acrylic was laser engraved and cut

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to size, sand and LED lights were found in the IDC, and the entire structure was assembled. As shown on the right of Figure 2, a locking mechanism releases sand from the upper reservoir when the acrylic tabs are pulled, resulting in the "IBEW" logo in the lower reservoir being filled with sand. This movement of sand also displays the engraved futuristic city-scape in the upper reservoir, which is illuminated by the LEDs. New insights arose after testing the prototype, such as what materials would be used in the final version and how the scaled-up design would support the weight of the sand. These insights were recorded on the canvas and influenced further prototype development.

The IDC designers completed a survey after they finished using the Prototyping Canvas. This survey included four 5-point-scale Likert-type questions (1=low, 5=high) and three open-ended questions. The survey questions, in an abbreviated form, and the summarized results and feedback from the designers are displayed in Table 2. In addition to the survey, the designers were provided with a blank Prototyping Canvas and asked to "mark" the canvas with suggestions, noting elements that were confusing, useful, or needed improvement. Based on feedback from the IDC designers, as shown in Table 2, the research team summarized seven benefits of using the Prototyping Canvas: 1) provides utility, 2) saves resources, 3) prepares a plan to build and test, 4) systematic and objective focused, 5) decreases mental burden, 6) identifies unforeseen issues, and 7) aids in communication amongst the team. Based on the survey, with an average survey score of 4 on a 5-point-Likert scale, the designers believed that the Prototyping Canvas provides utility, saves resources, and prepares a plan to build and test. This validates, even in a small sample size, that the Prototyping Canvas is an effective design tool for planning intentional prototypes. Additionally, seven suggestions to improve the canvas were captured from the designers' feedback: 1) improve ability to inspire, 2) show more examples of how to use the canvas, 3) add more specifics, like prototyping strategies and types of materials listed, 4) create a larger format, including more space to sketch, 5) include a section for how to communicate the prototype to stakeholders, 6) further emphasize 'simplest' prototype possible, and 7) improve aesthetics of the canvas. This important feedback guided the research team in revising the Prototyping Canvas tool into V2.

Table 2. Prototyping Canvas (PC) quantitative and qualitative survey results

Survey Qs	**Quant. Results**	**Qualitative Feedback**
How much utility does PC provide?	Avg: 4/5	"Assumptions/questions and critical assumptions were very helpful and the breakdown was great to guide through that."
How well does PC aid in saving resources?	Avg: 4/5	"Wanted to start 'fiddling with things' when it got time to identify resources and build and test instead of writing them down…"
How prepared for building/testing?	Avg: 4/5	"Emphasize building and testing the simplest prototype possible even more throughout the canvas, as this is a key takeaway."
How well does PC inspire you?	Avg: 2.75/5	"The current version works well for distinct separate ideas, but it's cumbersome if I just want variants of the same idea."
List 3 things you love about PC.	Systematic stated 3x	Systematic; Objective focused; ensuring "the point" of the prototype; Decrease mental load, structure thoughts; Identify assumptions and unforeseen issues; define metrics; determine materials/resources
List 3 surprising aspects of PC.	Reduce mental burden stated 3x	Simple yet effective; Reduce mental burden; Worked well discussing in pairs; Thinking about human resources
List 3 ways to improve PC.	Improve aesthetics 3x	Scale to A3; examples; visual/intuitive interface; less text; more room to sketch; communicate to stakeholders; hard to remember strategies

2.5 Incorporating feedback into Prototyping Canvas V2

The feedback from the IDC team was used to guide revisions to the Prototyping Canvas. The revised version is shown in Figure 3. To increase the size and spacing, the revised canvas is scaled from A4 to A3, the text descriptions for the categories were streamlined, and descriptive icons were added to represent the main goal of each box. Additionally, changes were made to the font, text size, and colour scheme to improve the overall aesthetics. The research team also launched a free online Design Innovation (DI) learning module on the Prototyping Canvas (www.dimodules.com/prototypingcanvas). On this website, there are guidelines for how to use the canvas, examples working through the canvas, and a free downloadable canvas for anyone to use.

The content of the canvas changed to include two new categories: 1) "Communication Strategy for Prototype", which lists four types of communication that are often associated with prototyping: explain, feedback, negotiate, and persuade, and 2) "Prototyping Approaches", which lists thirteen prototyping strategies, including: parallel prototyping, sequential prototyping, sub-system isolation, scaling, requirements relaxation, remove unessential features, wizard-of-oz, repurpose existing products, experience prototyping, paper prototyping, role playing, storyboarding, and mockups. The Communication Strategy section was added so that teams would be more explicit about how the prototype would be used to explain the concept, gather feedback, negotiate requirements, or persuade stakeholders (Lauff, 2018). The Prototyping Approaches section was added to directly link validated prototyping strategies and reduce cognitive load of participants. This section lists thirteen different prototyping strategies, which were identified from the literature review on prototyping strategies in engineering design (Menold 2017; Menold *et al.*, 2017; Camburn *et al.*, 2015; Camburn *et al.*, 2017a; Christie *et al.*, 2012; Hamon, 2017; Moe *et al.*, 2004; Dunlap *et al.*, 2014). The content of both categories was discussed in the presentation given before the earlier version of the Prototyping Canvas was tested, but they were not explicitly listed on the canvas in the previous version. Overall, these changes to the Prototyping Canvas directly address the seven areas of improvement from the designs' feedback.

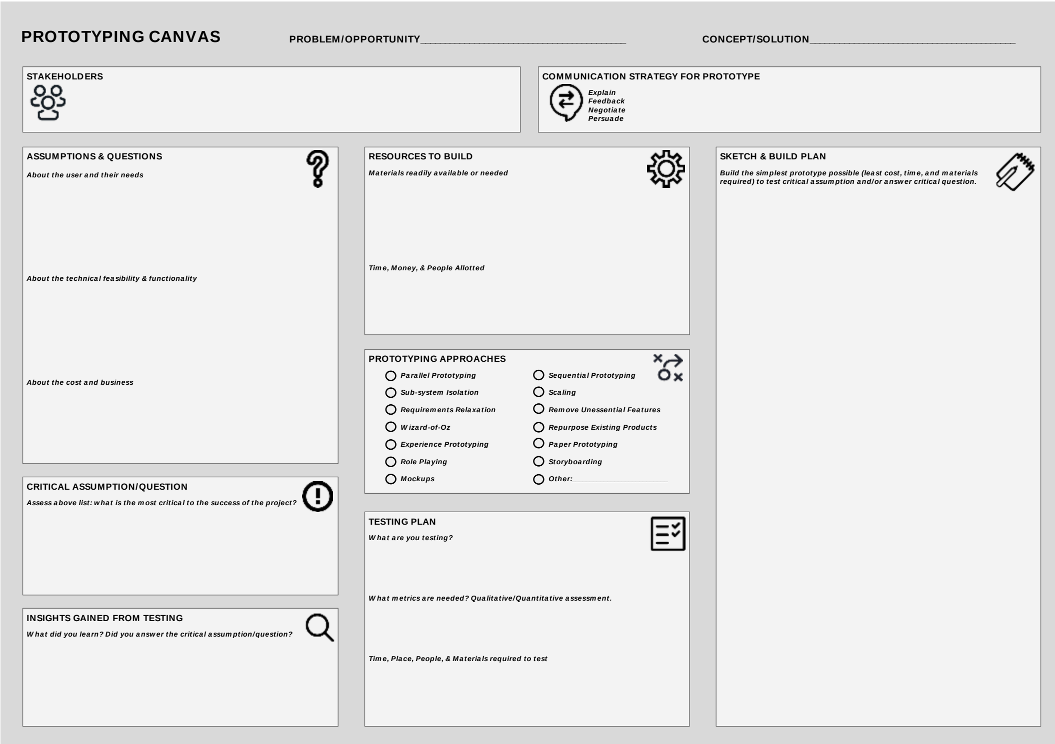

Figure 3. Revised version 2 of Prototyping Canvas, available for download at www.dimodules.com/prototypingcanvas

2.6 Validating Prototyping Canvas V2

The revised Prototyping Canvas was tested with three groups of professionals over the course of three different design innovation sprint workshops. The first group had 12 professionals over 3-days, the second group had 17 professionals over 3-days, and the third group had 27 professionals over 2-days. In each session, teams were divided by business unit and had between 3 and 7 team members. This totalled 55 engineering and design professionals that engaged in a multi-day design innovation sprint on their own company challenge. The professionals were from two large organizations, groups one and two were from the same engineering and defense company and group three was from a telecommunications company. These professionals were trained in the Design Innovation process over 2 or 3 days, where they actively engaged in all 4 stages of the process: Discover, Define, Develop, and Deliver on their own company

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design challenges (Camburn *et al.*, 2017b). These challenges ranged from designing for autonomous vehicles to enhancing safety protocol in the field to planning for the future of 5G networks.
The Prototyping Canvas was introduced on the final day of each workshop at the start of the Deliver phase. The researchers described the canvas and walked through an example with the group before they were asked to use it for their own projects. The teams then used the Prototyping Canvas to plan for a prototype, build and test their solution, and reflect on the experience. At the end of the workshop, the teams each pitched their final prototyped solution. Finally, the 55 professionals completed a survey at the end of the workshop, after they finished using the Prototyping Canvas. This survey included four 5-point-scale Likert-type questions (1=high, 5=low) about using the canvas. The summarized questions and results of the survey are displayed in Figure 4. The first question asked if they learned new prototyping strategies using the canvas, and the average response was 1.67. The second question asked if the canvas supported intentional prototyping practices, and the average score was 1.69. The third question asked if the canvas enhanced team communication, with average score of 1.62. The fourth question asked if the canvas added value during the Deliver phase of the design process, with an average score of 1.44. Overall, there was a very positive response to using the canvas, with only six responses as neutral and one response in disagreement out of 220 total responses (4 questions x 55 people).

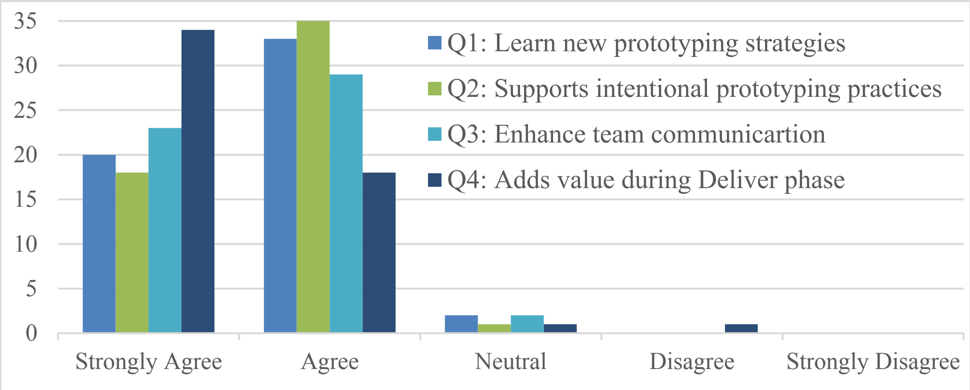

Figure 4. Survey responses from 55 professionals after using Prototyping Canvas V2

3 FUTURE RESEARCH

The revised Prototyping Canvas (Figure 3) will be validated for its usefulness in immediate future studies with senior capstone Engineering Product Development students working on industry-sponsored projects and with professional engineers and designers. This future work will focus on answering the following research questions: 1) Does using the prototyping canvas improve teams' strategy for prototyping? 2) Does using the prototyping canvas aid teams in creating more purposeful prototypes? 3) Does using the prototyping canvas reduce cognitive load on individuals? For each of the research questions, we will compare individuals and teams using the Prototyping Canvas against individuals and teams who prototype "freely." Answering these questions will extend our understanding of how the Prototyping Canvas affects individuals and teams and provide more rigorous validation of the tool.

4 CONCLUSION

The Prototyping Canvas is a strategic prototyping tool that guides users to build the simplest prototype possible to answer critical assumptions or questions about their design. This tool was systematically developed from surveying prototyping literature and distilling three key principles related to prototyping purpose, resources, and strategy. The layout and structure of the canvas was also inspired by the highly successful and widely adopted Business Model Canvas. This Prototyping Canvas acts as a roadmap to guide designers through identifying their assumptions and questions around the desirability, feasibility, and viability of aspects related to their opportunity or concept; then, the canvas lists all the "key ingredients" necessary to plan for building that minimal viable prototype, including the resources, strategies, prototyping principles, and testing plan. Finally, the canvas prompts users to reflect, listing insights and lessons-learned from the testing of the prototype. The Prototyping Canvas effectively guides designers through creating a prototyping plan, and it also facilitates a common prototyping language amongst teams. To encourage purposeful prototyping, the researchers launched a free online Design Innovation (DI) learning module on

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the Prototyping Canvas, which includes guidelines for using this tool, worked examples, and a free downloadable canvas (www.dimodules.com/prototypingcanvas).

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ACKNOWLEDGMENTS

The team would like to acknowledge the SUTD-MIT International Design Centre (IDC). The IDC design engineers were critical to the testing and iterations on the Prototyping Canvas. Additionally, many conversations with other IDC members influenced the direction and evolution of this tool.