Designing a Visual Tool for Teaching and Learning Front-End Innovation

Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

" *The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill.* "

Albert Einstein (1938)

This paper presents work on the design and development of a guided visual tool, the project client map (PCM), which is intended to assist students in their class projects solving real-world problems with industry clients. We use a design science research approach to contribute to existing knowledge through the design of an artefact (the PCM) that has a clear educational and learning goal, and that provides utility. Circumscribing a problem is an essential step to seed the ideation process in front-end innovation. While this step can employ existing tools that focus separately on the organisational, environmental, and human contexts of the problem under scrutiny, there is no formalised roadmap for how to integrate these tools. The PCM addresses this gap. We present a first version of the PCM in this paper, which will be refined in further work.

Introduction

Innovation is important to the economic prosperity of nations, with governments worldwide developing policies to boost innovation for their countries (OECD, 2019). Creativity and the exploration of ideas are key components of innovation, which are encouraged within organisations, for example, Google (Adams, 2016) to enhance competitiveness. To produce benefits, creativity and ideation need to be directed at solving relevantly-framed problems. This endeavour involves developing a solid understanding of the problem of interest in order for the ideation process to arrive at a value proposition that yields benefits for users when implemented. Identifying what problem to solve is therefore an essential step, which should to be done iteratively alongside the process of ideation. Failing to clearly grasp the problem to be solved can result in developing services or products that are not useful to target users.

A 2016 McKinsey poll reported that 94% of global executives were dissatisfied with their organisation's innovation performance, attributing the main issue to unsuccessfully identifying the problem that customers needed solving (Christensen et al., 2016). A problem-based approach to teaching university courses has been questioned as graduates are seen as inadequately prepared for identifying user needs in an ever changing world (Flores et al., 2010). To address this issue, we propose a guided visual tool to teach and support the process of problem formulation in order to seed the ideation process. This tool can be used iteratively with ideation to gradually focus on framing the problem under scrutiny in order to arrive at a valuable solution. We named this tool the "project client map" (PCM). The PCM takes a "design science research" (DSR) approach and draws from evidence-based practice (EBP) to provide a series of questions to support problem understanding and ideation. Our work was undertaken as part of an integrated learning component in classroom activities, where postgraduate students were tasked to help industry partners, the project clients, solve their real-world challenges.

Designing a Visual Tool for Teaching and Learning Front-End Innovation

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Background to Study

Idea development or ideation is an integral part of the innovation process. It is often considered to consist of three parts: (1) front-end of innovation (FEI), (2) new product development, and (3) commercialisation (or implementation) (Koen et al., 2014). FEI, also known as the "fuzzy front-end of innovation", has been described as "the earliest stage of an idea's development and comprises the entire time spent on the idea as well as activities focusing on strengthening it, prior to a first official discussion of the idea" (Reid & de Brentani, 2004, as cited in Brem & Voigt, 2009). FEI therefore comprises identifing a focal problem to be solved and ideating around it. FEI is notoriously hard to tackle because there is so much uncertainty involved in the process (Moenaert et al., 1995; Verworn et al., 2008). Moreover, creativity, acknowledged as a complex and difficult to manage process, plays an important role in the idea generation part of front-end innovation (Goldenberg et al., 1999). Sawyer (2012) described creativity using an eight-stage model consisting of: problem finding, acquiring knowledge, gathering related information, incubation, idea generation, idea combination, idea selection, and idea externalization. This description reinforces the importance of problem understanding for ideation.

A number of FEI models have been proposed (Koen et al., 2002, Gregor & Hevner, 2015). Koen et al.'s new concept development (NCD) model, recognises five activity elements of FEI: opportunity identification, opportunity analysis, idea generation, idea selection, and concept definition. Koen et al. (2014) used the NCD in a later study and noted a difference in processes undertaken for radical innovation compared with incremental innovation. Another model by Gregor and Hevner (2015), presents a finer-grained picture of processes involved in FEI using the lens of a knowledge innovation matrix (KIM), as they introduced it in 2014. In the KIM, innovation processes are classified into four quadrants across two dimensions: the knowledge (solution) maturity dimension and the application domain (problem) maturity dimension. The knowledge maturity dimension refers to the capture of knowledge in innovation processes, such as new ideas, insights, and technological know-how. The application domain maturity dimension refers to the identification of problems requiring solutions as revealed in new opportunities, markets, and needs. Chadha et al. (2015) identified eleven commonly used innovation techniques classified across the KIM quadrants. The authors recognised that the techniques could often be placed in more than one quadrant at different points in a project. This work suggests that regardless of the type of innovation we are considering, a fit between problem formulation and solution development is key, and often the two co-emerge in an iterative process (Maedche et al., 2019). This idea is congruent with the work of Von Hippel and Von Krogh (2016), who argue that a market need (the industry challenge in our case) and its solution are often discovered together, and developed as a "need-solution pair". In sum, formulating a problem appropriately (that is, defining a problem space) is an essential step for delivering innovation, which is recognised as being far from a simple matter.

Many analytic tools and frameworks (some of which are presented in the next section) exist to support the problem formulation and ideation phases of innovation. However, to the best of our knowledge, the extant literature does not contain a formalised roadmap on how to use them together as a way to help in the process of problem identification for FEI. Existing tools tend to be used in isolation and students often find it confusing to choose which tool to use and at what point in a project. This issue led us to develop the PCM to assist in problem formulation for FEI by providing a roadmap that integrates the relevant existing innovation tools.

Conceptual Background

The new visual PCM tool for facilitating the front-end innovation builds on and integrates ideas and theories drawn from a number of underlying areas. These areas include: visual representation in problem solving, visual tools in innovation, design science research, design thinking, and evidence-based management. An overview is provided below for each of these areas of thought.

Visual representation in problem solving

Visual representations such as diagrams, modelling tools, pictures, equations, and graphs provide forms of external representation that have been found to facilitate internal representations for people engaged in problem solving processes. An internal representation, or mental model, helps the problem solver store components of a problem space in their mind (Solaz-Portolés & Lopez 2007). Scaife and Rogers (1996) discuss important considerations for the effective design of external visual representations, relating to: (1) explicitness and visibility, (2) cognitive tracing and interactivity, (3) ease of production, (4) combining external representations, and (5) distributed graphical

Designing a Visual Tool for Teaching and Learning Front-End Innovation

Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

representations, as in idea sketching.

We took these guidelines into account while developing the PCM tool. In particular, the PCM builds on prior knowledge regarding users, which allows users to make use of it interactively, including a group innovation mode, where text can be integrated into the diagram. The visual format allows for simultaneous representations of a large number of dimensions in a compact form, as a useful way to show interconnections and patterns (Langley, 1999).

An overview of research on how internal representations (mental models) are constructed during problem solving was provided by Solaz-Portolés and Lopez (2007). These authors showed how using multiple external representations when problem solving can be beneficial for students of innovation and also influence innovation performance.

Visual representation tools in innovation

Organisations use multiple analytic tools and techniques when trying to innovate (Chadha et al., 2015), many of which take either a human-centred or a strategic management perspective. Human-centred tools, for example, IDEO and Mozilla, provide guidance and insight into understanding the challenges facing potential users for which the designers are seeking a solution. Strategic management tools, like CIMA (2007), help in grasping internal and external factors affecting an organisation's success. Both can provide great insights to spark innovation. The PCM combines both a human-centred and strategic management perspective to help develop insights into formulating the actual problem that needs solving. Moreover, it points to three existing visual analysis tools to delve deeper (see Figure 1): two human-centred tools, namely the value proposition canvas (VPC) (Osterwalder et al., 2015) and the empathy map canvas (EMC) (Gray, 2017), and one strategic management tool, which is a strengths, weaknesses, opportunities, and threats (SWOT) analysis (see Phadermrod et al., 2019).

Design Science Research (DSR)

DSR is an approach that focuses on trying to develop a "scientific" process for designing, as argued for by Simon (1968) in his seminal work Sciences of the Artificial. It emphasizes the building and application of a designed artefact in order to develop knowledge and understanding of a problem domain and its solutions (Hevner et al., 2004). We consider here a DSR process with six steps, as described in Peffers et al. (2008), which can be undertaken iteratively. These steps are described in the following section, as they informed our own process of developing the PCM.

We were interested in how to help students and practitioners develop skills in problem formulation. This made DSR a relevant approach to develop the PCM as an artefact with a clear utility (to guide students in learning how to succinctly formulate a problem to be solved) and a clear goal (to teach students how to tackle complex problems at the FEI stage). DSR is also particularly relevant for students studying information technology and computer science, as it embodies the methods used in computer science (Dodig-Crnkovic, 2002). However, it should be noted that DSR can differ from innovation, as DSR has a goal of contributing to a relevant disciplinary body of knowledge, as well as constructing an artifact with utility, whereas innovation is about applying ideas to create value. The criteria in DSR may not always apply in cases of innovation (see Hevner & Gregor, 2020). In addition, DSR has been criticized by some as paying too little attention to the complexities of problem formulation in the DSR process (see Maedche et al., 2019). For this reason, we found it helpful to consider the design thinking approach in addition to DSR.

Design Thinking (DT)

DT is a paradigm drawn from the design community that has been adopted to solve problems in many professions, including engineering and computing (see Brooks, 2010; Plattner et al., 2011). One widely used definition of DT, given by Tim Brown, CEO of the design firm IDEO, is: "a human-centred approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology and the requirements for business success" (IDEO, 2019). The DT process is captured in a framework that supports problem understanding and ideation, as well as implementation and testing. The framework consists of five iterative elements: empathise, define, ideate, prototype and test (Hasso Plattner Institute of Design, 2020). DT helps in dealing with the uncertainty involved in the FEI process. We used the DT process in the classroom to create scaffolds for how students tackle an industry problem to be solved. The PCM served as an aid in focusing on the 'empathise' and 'define' elements of the DT process.

Evidence-based Practice/Management (EBP/EBM)

The data-driven evidence-based management (EBM) framework (Barends et al., 2014) defines evidence-based

Designing a Visual Tool for Teaching and Learning Front-End Innovation
Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

practice being "about making decisions through the conscientious, explicit and judicious use of the best available evidence from multiple sources through the following main skills:

1. Asking: translating a practical issue or problem into an answerable question

2. Acquiring: systematically searching for and retrieving evidence

3. Appraising: critically judging the trustworthiness and relevance of the evidence

4. Aggregating: weighing and pulling together the evidence

5. Applying: incorporating the evidence into the decision-making process

6. Assessing: evaluating the outcome of the decision taken to increase the likelihood of a favorable outcome."

This framework can be used to support exploring the 'empathy' and 'define' phases of DT, as a means to conceptually break down the problematisation process, that is, the path from problem identification to decision-making, where a solution to a given problem is found based on evidence gathered from a variety of sources. Furthermore, the emphases of EBP/EBM on applying critical and analytical skills together with moments of reflection that tap into metacognitive skills, ensure that students are faced with learning about their own learning by visualizing and questioning the possible directions and impacts of their solutions and decisions. The PCM tool we present in this paper uses EBP/EBM to develop a series of linked questions that require answers in order to capture the context surrounding a problem. EBP/EBM supports the PCM as a visual analysis tool to teach and support FEI.

Method

Artefact development

This early-stage study presents a novel artefact (the PCM) developed using a DSR approach (Hevner et al., 2004) for students working with industry partners, as a way to solve a real-world challenge as a classroom project. The tool was specifically developed for engineering and computer science students undertaking a professional practice course. The PCM aims to assist in the problem formulation part of FEI, before going into ideation.

We adopted the DSR approach following Peffers et al. (2008), consisting of the following steps: (1) problem identification, (2) defining the solution objectives, (3) design and development, (4) demonstration, (5) evaluation, and (6) communication. We first identified our research problem as the difficulty students have in grasping what industry problem they are actually trying to solve. The students were often confused about what existing tool they should use to assist them in the 'empathy' phase of DT that could help them define an industry problem (step 1). We clarified the objective of the PCM to serve as a development tool to guide students through the problematization process as they tackle an industry challenge (step 2). We used an exploratory research method based on participant observation by three researchers in a 'Lego Serious Play' workshop (Lear et al., 2020) during semester 2 of 2018, which was repeated for eight different tutorials. The results revealed that students struggled with problem identification (the rationale to the challenge) and formulating the problem to be solved.

We extracted key elements from EBP and DT to leverage the 'empathy' phase of DT as a way to determine what characterises evidence for the PCM. The intended outcome was for students to better circumscribe problematisation, so that based on the evidence collected they could better formulate their specific problem. Our research showed that students often revealed struggles with both problem identification and formulation. An initial PCM was built (step 3) based on the general concepts gleaned from EBP and DT literatures, together with insights gained in classroom observation. The components of the resultant 'map' were derived by synthesizing step 2 and 3. The PCM, in its initial form, was then introduced as a visual tool to the classroom in semester 1, 2019 (step 4). We then carried out an initial evaluation of the PCM for the purpose of preparing this paper through a case study (step 5). The demonstration (step 4) and evaluation phases (step 5) are both still works in progress, and we intend to further deploy and refine the PCM. This paper shares our findings so far regarding the PCM (step 6).

Artefact evaluation

Venable et al. (2014) proposed a four-step framework for DSR to evaluate an artefact : (1) explicate the goals of the evaluation, (2) choose the evaluation strategy, (3)

Designing a Visual Tool for Teaching and Learning Front-End Innovation
Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

determine the properties to evaluate, and (4) design the evaluation episode(s). Following this framework, we evaluated our visualisation tool to establish whether the PCM works in a real situation (step 1). We used the strategy described as 'quick & simple' (Venable et al., 2014), as the project scope was relatively small (step 2). We examined two broad aspects of our artefact, form and function, and sought to find answers to the following questions (step 3):

Table 1. The Project Client Map

	Component	*Short description*	*Questions*
1	Initial Challenge Description	This is what the industry project client initially brings to the students.	N/A Industry challenge as is.
2	Personal (personal-level information)	Relevant information about the project client on a personal level to get to know them and an understanding of their motivation.	Who is the Client? Names, Positions, Experience, etc. What motivates the Client? Why are they interested in this challenge on both a personal and an organisational level?
3	Organisational level (taking stock)	Current operational details of the organisation	What is the current operation of the business like?
4	Organisational level (reflections)	Reflecting on current operations of the business	What is currently working? What are the strengths of the business? What can be improved? What are the current weaknesses?
5	Environmental level (taking stock)	State of current operating environment and competitors	What environment do they operate in? What sector? What are the relevant statistics? What are the trends?
6	Customers / Users	Understanding the customers/users	Who do they currently see as their user/customer segments? Are there other customer segments? Who are they? What drives them?
7	Value Proposition	Perceived value proposition	What is/do they think is their current value proposition?
8	Environmental level (reflections)	What is the 'gap' or 'perceived pap'?	What do you see as the gap? What does the client see as the gap? What opportunities does this create?
9	Redefined Project Challenge	Iterated problem definition	What problem are you actually solving? What do you need to find out further?

Designing a Visual Tool for Teaching and Learning Front-End Innovation

Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

A. How did students interact with the form of the PCM (colour, shape and size)?

B. How did students use the PCM for analysis (function)?

C. Did the students successfully complete a problem formulation using the PCM (task-at-hand)?

D. Did the problem formulation (task-at-hand) have a valuable impact on solving the industry challenge (goal-at-hand)?

Our evaluation was done ex post using a case study approach (step 4) that focussed on one tutorial where students worked in two groups, hence providing a case study with two embedded units (Baxter & Jack, 2008). The following three factors were constant in both groups: tutor, industry client, and industry challenge. To answer question D, we interviewed the industry client and assessed the two groups' final project reports for their solutions (as presented below in the 'Preliminary Results' section).

DSR (Design and Development): The Project Client Map (PCM)

The PCM built in step 3 (design and development) is a visual mapping tool with nine components (Figure 1). Each component encapsulates questions that capture key aspects of an industry challenge under scrutiny by students (Table 1).

The following components can be explored further as follows: 4,5 and 8 using a SWOT analysis, 6 using Empathy Map Canvas and 7 using Value Proposition Canvas.

Preliminary Results

Table 2 shows the results of a preliminary evaluation of the PCM for the two embedded student groups in the tutorial. This work facilitates the building of a mental model (Scaife & Rogers, 1996; Goldschmidt, 2007) of the process of problematisation through a visual representation of the context surrounding a problem as its key contribution.

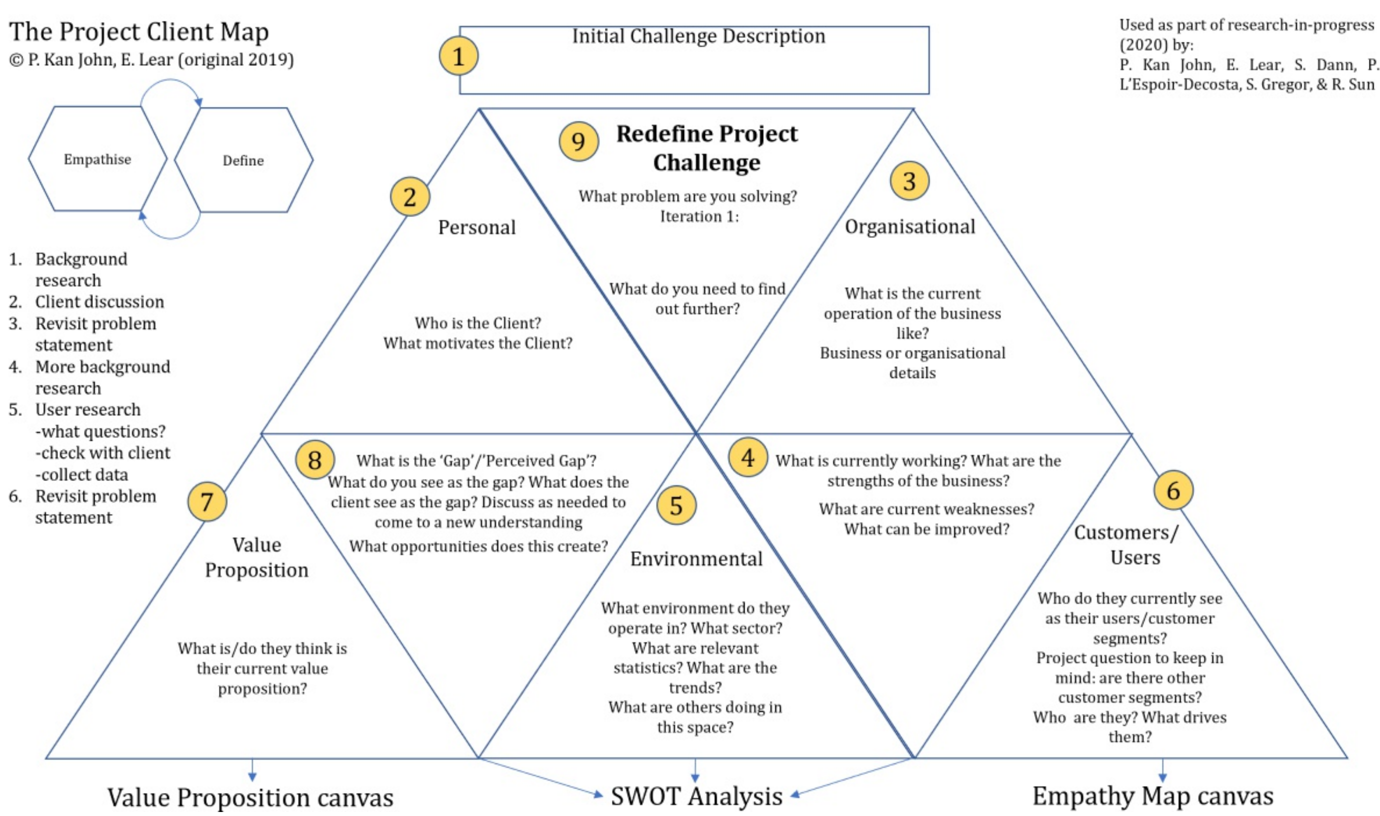

Figure 1. The Project Client Map (PCM)

Designing a Visual Tool for Teaching and Learning Front-End Innovation
Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

Table 2. Case Analysis The PCM as used by 2 student groups in a tutorial

	Group X	***Group Y***
Group Characteristics	6 members (5 from Computer Science, 1 from Engineering)	5 members (4 from Computer Science, 1 from Engineering)
A: How did the students interact with the visual form of the PCM (colour, shape, and size)?	Group X uploaded an image file (png format) to their project repository. They made the colour of the PCM more pastel and wrote directly onto the different components.	Group Y uploaded a Word document (doc format) to their project repository. They kept the PCM as it is and pasted a reduced-size copy at the top of the Word document. They wrote text below this image to address questions.
B: How did students use the PCM for analysis (function)?	The students wrote a brief answer into the triangles representing each component, providing a response for the components. Their answers touched on the overall aspect of the components, but did not cover all PCM questions.	The students wrote detailed answers to most PCM questions asked in the different components. They completed a SWOT analysis and a VPC as part of the PCM, but left out addressing components 8 and 9.
C: Did the students successfully complete a problem formulation using the PCM (task-at-hand)?	The students distilled the problem given (see Appendix B) and presented a problem definition under component 9 as expected. Surprisingly, they also presented a problem definition under component 1. The definition under component 1 is more succinct and focussed in scope (but a bit too narrow), suggesting it was produced after iterating on the definition under component 9. Both problem definitions arising from use of the PCM are relevant to the industry challenge. Therefore, we can say that the PCM helped the group in problem formulation.	Although the students did not answer component 9, they provided a problem definition under component 1, which adequately addresses the industry challenge. Hence, we deduce that the PCM did help the group in problem formulation.
D: Did the problem formulation (task-at-hand) have a valuable impact on solving the industry challenge (goal-at-hand)?	In their final report, Group X recommended a system that can (i) digitise paper documents, (ii) classify digital documents by user role, and (iii) evaluate the document classifications to recommend relevant documents to users based on their role. The industry client indicated that they liked aspects of the solutions presented by both groups and are going forward with prototyping a	In their final report, Group Y recommended a system that focusses on three aspects: (i) a gamified pre-question session to induct new volunteers and identify their level of knowledge so that relevant material can be recommended, (ii) a document classification function to organise documents in the system,

Table 2. Case Analysis The PCM as used by 2 student groups in a tutorial (cont'd)

	system that has elements from both reports received. They mentioned that, out of Group X's solution, the ability to detect the content of documents and assign them to users based on relevance was of particular interest. This demonstrates valuable impact in solving the industry challenge.	and (iii) an automated FAQ function that can also be searched to provide a Q&A service. As mentioned for Group X, the industry client is planning to use elements of the solutions presented by both groups. They mentioned that the solution proposed by Group Y showed deep understanding of the problem they brought to be solved. This attests to valuable impact in solving the industry challenge.

In the tutorial, students were tasked with an initial challenge described as follows:

> "A solution is being sought to assist a time-poor group of widely dispersed volunteers to become more efficient and effective. Due to the demands of studying medicine, the group of 200 volunteer staff is required to step back from roles, and team members rotate every 12 months to avoid burn-out. The project challenge is to provide a framework and set of tools for the effective management and operation of the group of volunteer staff. This may involve looking at means to communicate effectively and share knowledge during rotations and hand-overs. Finding relevant information at the right time is an important consideration."

Comparison
A scheduled session with the client occurred within the two weeks following the introduction of the PCM. The client was pleased with the content and solutions that both groups produced. As a way to evaluate the PCM, the client was asked to suggest which group looked better prepared in the sessions. Group Y was praised for their "out-of-the-box" thinking that helped better showcase their understanding of the problem.Their solution subsequently was able to more closely solve the problem at hand. Group X demonstrated a structured approach with technical details that also impressed the client. Both groups seemed to have used component 1 to present the outcome of their analysis using the PCM, instead of just inserting the initial project challenge as intended. This suggests that component 1 either needs to be clarified or perhaps adapted.

Discussion and Future Work
This early-stage work describes a visual mapping tool to help students identify and formulate problems as part of tackling a real-life industry challenge in a classroom project. A DSR approach was useful in drawing from existing knowledge and observations to assist in designing the tool. The tool allowed exploration of the human, organisational, and environmental context of the innovation problem to be solved, which was presented in a compact visual form to aid in making connections among the components.

We evaluated the PCM using a case study analysis and followed the DSR evaluation framework in Venable et al. (2016) to provide both formative and summative insights. Our evaluation showed that the PCM helped students come up with an appropriate problem formulation, which subsequently lead them to propose a useful solution after ideation. The components of the PCM are not fixed at this stage, and may need to be adjusted as we do more in-depth analysis and evaluation. We note that the problem definitions presented by each group in our case study guided and influenced their final solution, thus emphasizing the importance of spending time doing problem formulation carefully, and hence the relevance of using the PCM.

Group Y presented many details of their solution in their PCM, thus suggesting that the completed PCM is likely not the first iteration. Studying how the PCM is

Designing a Visual Tool for Teaching and Learning Front-End Innovation

Priscilla Kan John, Emmaline Lear, Patrick L'Espoir Decosta, Shirley Gregor, Stephen Dann, and Ruonan Sun

used in successive iterations would make for interesting future class planning. As a next step, we would like to apply the same approach in other classes so we can eventually analyse more cases to further evaluate the PCM and update this visual tool based on insights gathered. Another interesting avenue to pursue will be to look at how to adapt the PCM for use in non-academic environments, such as start-ups, which would appear to have a natural affinity and progression with the DSR approach. Validating the process of problem identification by various industries might be another interesting avenue for applying the tool.

Another point to note is that in one group, students left out addressing some of the tool's components. This suggests that more guidance on how to use the tool is needed from educators. As a future step, it would also be useful to think about how to deliver the tool in a digital format for online collaboration.

Conclusion

In this paper, we presented a visual mapping tool for problem formulation and identification as part of tackling FEI. The context for the study was teaching Master-level students how to solve unstructured real-world industry challenges through their project work. The outcomes of this preliminary study show the potential of the PCM to support processes involved in problematisation. Two groups of students in one tutorial successfully derived problem definitions using the PCM to solve the same industry challenge. The group that did a more detailed exploration of the PCM components came up with the more innovative solution. We believe therefore that the PCM can be used iteratively throughout a project, and not just at one point in time.

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Designing a Visual Tool for Teaching and Learning Front-End Innovation

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Priscilla Kan John obtained her Ph.D in Computer Science from the Australian National University (ANU) in 2013. She then took a detour from academia and worked in facilitating innovation between business and universities, including setting up an Innovation Hub at the College of Business and Economics, ANU. She is currently a lecturer at the College of Engineering and Computer Science, ANU. Her research interests are in Artificial Intelligence (especially exploring concepts such as trust, autonomy and decision-making), Human Computer Interaction (exploring the social and design aspects of using smart machines) and Computer Science Education (developing pedagogical frameworks and tools for nurturing skills to face disruption).

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