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Sustainability-oriented innovation: Improving problem definition through combined design thinking and systems mapping approaches

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ABSTRACT

Sustainability-oriented innovation (SOI) is receiving increased focus, as sustainability takes a more central role in business, development, and education arenas. SOI processes typically draw from design thinking toolkits, with a focus on the user's needs and experiences. While this is an effective way to ensure that the innovation process is grounded in real, definable needs, it's also limited in its ability to place the problem in a larger societal and systemic context. This can lead to a narrow or incomplete problem definition.

We designed and tested a new approach for eliciting and defining problems for SOI. Our work shows that using systems mapping in the problem definition phase of SOI helps set adequate boundaries for the problem space and increases understanding of how the system influences itself over time. As "sustainability" is a systems property, we find that the "helicopter view" provided by systems mapping complements the empathetic design thinking approach to form a more robust problem definition. We present this combined methodology and provide examples of where and how it's been used. These examples illustrate the potential of design thinking and systems mapping to support and enhance problem definition for SOI and provide the basis for discussing future research directions.

1. Introduction

Adequate and comprehensive problem definition is a key step in any type of innovation process, but it is particularly true when innovating for sustainability. Sustainability-oriented innovation (SOI) has defined characteristics that distinguish it from other types of innovation processes, including the need to include a long time horizon, examine the problem in a larger context, and consider multidimensional targets (ie, environmental, social, and economic impacts) (Buhl et al., 2019).

Innovation processes typically draw from design thinking toolkits. The design thinking approach focuses on the user's needs and experiences, which provide valuable insights that guide innovation development (Carlgren, Rauth, & Elmquist, 2016; Roth, Globocnik, Rau, & Neyer, 2020). While this approach is an effective way to ensure that the innovation process is grounded in real, definable needs,

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it's also limited in its ability to place the problem in a larger societal and systemic context (Hoolohan & Browne, 2020). This can lead to a narrow or incomplete problem definition. The unique characteristics of SOI heighten the importance of developing a holistic problem definition, yet current SOI development is usually characterized by ill-specified problem statements (Buhl et al., 2019).

Systems mapping is a group model building approach that focuses on empowering participants to create a shared understanding of a complex problem (Hovmand, 2014; Hovmand et al., 2012; Videira, Antunes, Santos, & Lopes, 2010). The approach to and understanding of systems is an outgrowth of systems thinking and system dynamics. The suite of tools implemented in systems mapping are particularly helpful in creating consensus around adequate system boundaries and understanding how the system influences itself over time from an aggregated and cross-disciplinary perspective (Videira et al., 2010). This approach addresses some of the key needs of SOI, but on it's own, systems mapping can lack the specificity and empathetic perspective that design thinking engenders (Buchanan, 2019). We assert that an approach that includes both design thinking and systems mapping can create a more in-depth and richly detailed problem description that includes both individual perspectives and systemic understanding.

Our approach, called systems sustainability-oriented innovation (SSOI), builds on the strengths of design thinking and systems mapping practices to create a more robust problem statement. We present the theory behind this approach and discuss the practical considerations of employing such an approach. Finally, we provide two empirical examples of a combined approach in problem definition workshops. These examples illustrate the potential of SSOI to support and enhance problem definition for sustainability innovation and provide the basis for discussing future research directions.

1.1. Sustainability and innovation

Sustainability is increasingly identified as a key driver of innovation for companies, and environmental and social criteria have been incorporated into default design criteria, in addition to traditional criteria such as profitability, aesthetics, etc. (Gaziulusoy, 2015). Sustainability is a broad and normative concept, with a problem- and process-oriented application that has grown out of a desire to ensure that both current and future generations can meet their own needs without compromising planetary life support systems (Brundtland, 1987; Nagatsu et al., 2020; Shahadu, 2016). Innovation that accounts for sustainability requires explicit consideration of sustainability's defining characteristics.

"Sustainability" is a system property, rather than a property of elements in the system. Only when the system as a whole is sustainable can the individual components of the system be considered sustainable (Gaziulusoy, 2015). This has implications for individuals embedded in a society and what level(s) of society a SOI should target. Innovation for sustainability needs a systems vantage point to evaluate the product/service innovation within the system in which they will be produced and consumed (Gaziulusoy, 2015; Gaziulusoy & Brezet, 2015).

In addition, the emergent qualities of systems mean that the consequences of working towards or achieving sustainability may be different at the individual versus the societal level, raising questions of social justice (Bennett, Blythe, Cisneros-Montemayor, Singh, & Sumaila, 2019). Individuals may need to change their lifestyles and livelihoods in ways that are difficult or uncomfortable in order to move towards sustainability at the societal level. Changes that may be experienced as negative at the individual level may have emergent positive impacts at the societal level, reinforcing the need for SOI to consider both individuals and society in an explicitly systems perspective (Bennett et al., 2019).

"Sustainability" is inherently multidimensional, and working towards sustainability innovation requires consideration of multidimensional targets (Buhl et al., 2019; Videira et al., 2010). Operationalizing sustainability requires a comprehensive consideration of actions and impacts across sectors (such as environment, society, and economy) and a recognition of interrelations and interdependency across spatial and temporal scales (including future generations) (Gibson, 2006; Hjorth & Bagheri, 2006; Videira et al., 2010).

These characteristics of sustainability have consequences for designing an appropriate innovation process. Typical innovation processes are focused on individual products or services. These innovations result in only minor improvements in sustainability terms (Gaziulusoy & Brezet, 2015), yet sustainability-oriented innovation (SOI) will often require solutions that move beyond incremental adjustments on a product or technology level (Buhl et al., 2019). Explicitly incorporating and addressing the distinctive aspects of sustainability, described above, in the innovation process is necessary for SOI. Innovation aimed at sustainability should have a systems and societal scope that accounts for multidimensional targets (Buhl et al., 2019).

In particular, problem definition is an often neglected phase in SOI, and current SOI processes are usually characterized by poorly-specified problem statements (Buhl et al., 2019). Defining the scope of the problem defines the space in which innovative solutions can be developed. A problem defined too narrowly limits the space of available solutions and might therefore lead to solutions that are too confined to have a meaningful impact (Hoolohan & Browne, 2020). Traditional approaches to innovation tend to focus on individual users and their needs when defining the problem. This focus, though valuable, can exclude the broader, cross-sectoral and systems perspectives needed to adequately define a sustainability related problem.

1.2. Current approaches to problem definition

The innovation and design fields are characterized by plurality and, as a result, ambiguity in terms and approaches (Buchanan, 2019). While other academic fields typically emphasize convergence on canonical theories, the shifting and distributed nature of social innovation's theoretical foundation is often viewed as an asset for further development (Bijl-Brouwer & Malcolm, 2020). Approaches overlap (and complement) in name and methodology, with some based in theories of constructivist learning and others derived from practice and experience (Buchanan, 2019; Sevaldson, 2018). Rather than defined methodologies, design tools can be better understood as a suite of adaptive practices tailored to the specific needs of the problem being examined (Bijl-Brouwer & Malcolm, 2020).

Among these many adaptive practices, we focus on design thinking as a well-established and widely applied approach within the design practitioner SOI community. Design thinking is a suite of practitioner-based, problem solving approaches that typically emphasizes a user-centered, empathetic process (Buhl et al., 2019). The approach is loosely characterized by a blend of creative and analytic modes of reasoning and various hands-on tools and techniques (Buhl et al., 2019). As a suite of practices, design thinking implementation varies across contexts, with some practices emphasizing iteration and others focused on deep user empathy and understanding (Carlgren et al., 2016). As such, there is no single accepted definition of design thinking (Buhl et al., 2019; Carlgren et al., 2016; Jones, 2014). Most existing literature on design thinking is aimed at practitioners rather than academics, and it tends to emphasize tools and activities rather than theoretical foundations (Buhl et al., 2019).

Design thinking projects typically start with an exploratory phase that seeks to empathetically understand the given problem from the user's perspective. Through observing users in real-life situations in context, the practitioner defines an adequate problem and solution space (Buhl et al., 2019; Carlgren et al., 2016). This focus on immediate users can infuse the design process with empathy and realism, providing valuable insights into what people do, value, and desire (Hoolohan & Browne, 2020).

One common, established expression of design thinking is the “double diamond” (Clune & Lockrey, 2014; Conway, Masters, & Thorold, 2017) (Fig. 1). As a practice, the double diamond is typically defined as having five steps that are iteratively applied. The five steps are divided into diverging and converging phases, where diverging phases widen perspectives and converging phases increase focus.

Within these double diamonds, five steps are typically defined. (1) Empathy: the point of view of the user is elicited.(2) Define: Knowledge about the user is distilled and formulated as specific needs, wants or requirements (problem definition). (3) Ideation: ideas for solutions are formulated based on the specific needs and requirements one is aiming to satisfy.(4) Prototyping: ideas are implemented in first stage products or services.(5) Testing: potential users and other relevant stakeholders test and provide feedback on the prototypes. These five steps are iterative and the process may be partially or completely revisited several times.

We recognize that the double diamond approach is one of many approaches to design thinking, and design thinking is only one of many approaches to innovation. Still, many SOI processes are framed around design thinking methodologies (Buhl et al., 2019). While design thinking tools are commonly used for innovation processes, a user-focused innovation process such as design thinking can limit the innovation scope in ways that exclude multidimensional targets, societal impacts, and systemic understanding, further contributing to poorly defined problems (Buhl et al., 2019; Hoolohan & Browne, 2020). This limitation of design thinking to meet the needs of SOI are well documented in the academic literature, yet there are few studies that propose or implement methodologies to address that gap (Jones, 2014; Pourdehnad, Wexler, & Wilson, 2011). A key research question for SOI is how design thinking can progress beyond its focus on individual users and also engage in reconfiguring social, political, and material systems (Hoolohan & Browne, 2020).

1.3. The systems mapping intervention in SOI

Systems approaches to design have long been seen as valuable for placing design processes and products in larger contexts (Buchanan, 2019), and the benefit of combining elements of design thinking with elements of systems methodologies as a path towards robust innovation processes for complex challenges is highlighted in several studies (Bausch, 2002; Conway et al., 2017; Jones, 2014; Pourdehnad et al., 2011).

A number of systems-oriented methodologies have been developed to aid in problem definition, including systems mapping, gigamapping and synthesis maps. These methodologies vary in scope, stakeholder involvement, and required resources and skills (Jones & Bowes, 2017). All three approaches produce a collaborative visual artifact that represents the participants' learning and understanding of a complex system. Gigamapping demands the most time and expertise, and results in the highest level of detail of the three approaches, while systems mapping, the focus of our research, requires the least time and no expertise and produces a lower level of detail in the resulting map (Jones & Bowes, 2017).

Systems mapping, one of a suite of tools for group model building, is a participatory approach to creating a shared understanding of

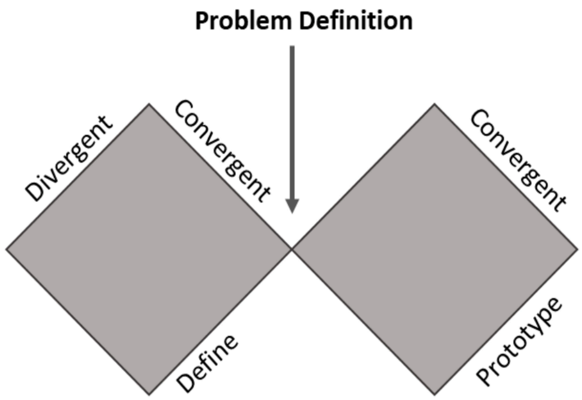

Fig. 1. A typical representation of the design thinking “double diamond” (adapted from Conway et al., (2017)).

and communication about a complex problem (Videira et al., 2010). Systems mapping can be a stand alone stakeholder engagement process or a starting point for developing a system dynamics model, which is a mathematical model based on differential equations. Systems mapping includes a toolbox of scripts, or activities, that can be implemented in a variety of stakeholder contexts to elicit understanding of a complex problem, identify leverage points for intervention, and more (Hovmand et al., 2011, 2012). Systems mapping is often considered a tool for implementing systems thinking. Though systems thinking is poorly defined in the literature, it's broadly understood as an approach to complexity that emphasizes feedback and an awareness that a system's structure creates its behavior.

Systems mapping's particular strengths include eliciting a shared, visual understanding of a problem and its interconnections across disciplinary and sectoral boundaries. Further, through that process, the systems mapping creates a forum for discussion that can formalize understanding of a complex problem (Scott, Cavana, & Cameron, 2016; Videira et al., 2010; Videira, Antunes, & Santos, 2017). The resulting systems map typically has a focus on feedback within the system and on developing an adequate system boundary. It makes causal relationships explicit and can function as a reference point and boundary object for further discussions of leverage points and interventions in the system. In systems mapping, emphasis is not on the individual's experience but on the aggregated structure of a complex issue. In contrast to design thinking, systems mapping takes an aggregated perspective and can provide a "helicopter view" of a problem.

The systems mapping intervention as implemented in this study is a "quick and dirty" approach, especially when compared with approaches such as gigamapping and synthesis maps. Designers implementing gigamapping or synthesis mapping can use months to create a comprehensive and visually detailed map (Jones & Bowes, 2017; Sevaldson, 2018). Our implementation of systems mapping (outlined in the following section) generally takes less than two hours and requires no formal training for participants. Though less richly detailed than other approaches, the systems mapping intervention is designed to quickly give non-experts an aggregated and dynamic perspective on their sustainability issue.

2. Method: applying systems sustainability-oriented innovation

We propose employing systems mapping in the problem definition phase of design thinking as a way to address the user-focused limitations identified above. We call this approach systems sustainability-oriented innovation (SSOI). We modified the standard five step design thinking approach by adding a systems mapping activity in the first divergent phase of the design thinking process (Fig. 2). By adjusting and adding to the design thinking practitioner process, we were able to enlarge and contextualize the problem scope for SOI.

Our systems mapping activity was based on the open source "Initiating and Elaborating a Causal Loop Diagram" facilitation guide (also called a script) in Scriptapedia (Hovmand et al., 2011). This script is especially valuable for creating consensus and improving communication around a problem. While systems mapping facilitation guides are intended to be implemented in person, in our case, we modified the guide to move the process online due to Covid-19. Online systems mapping is a relatively new practice, but has been shown to provide valuable experiences and insights for participants (Wilkerson et al., 2020).

In the facilitation guide, participants are asked to identify a key problem variable for the specific case they are working on. Once participants agree on the variable, they start tracing causality by asking "what causes this variable to change?" This question helps identify the variable(s) that influence the original variable. As each new variable is added to the map, the group connects it to existing variables with arrows to indicate influence (Fig. 3). This process is informally referred to as "mapping backwards," as chains of

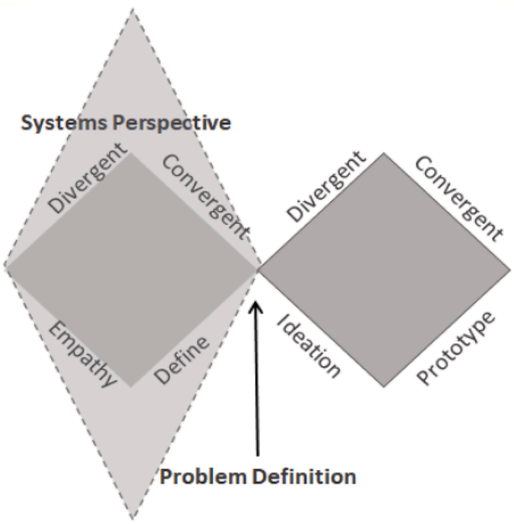

Fig. 2. Elaborating on (Conway et al., 2017) - introducing a systems perspective in the early phase of an innovation process allows for sustainability to be more fully considered throughout the process.

influence are traced back from the key variable.

By repeating this process, the systems map evolves. Participants are further challenged to consider polarity of relationships by asking " if there is an increase in variable A, is that causing an increase or a decrease in variable B?" Through noting variables' relationships and polarities, participants build the systems map. Towards the end of the process, participants are asked to identify loops, or cyclically chained variables, in the system. Feedback loops are also classified as either "balancing" or "reinforcing," where balancing loops dampen and reinforcing loops amplify phenomena over time. Identifying loop characteristics helps participants understand how the system influences itself over time.

The output of this SSOI process is a systems map (also known as a causal loop diagram) that illustrates relationships among major variables in the system and clearly delineates the system boundaries (i.e. the problem space) relevant to the key variable. The systems map provides a "helicopter view" of the problem that complements the empathetic, individual perspective in design thinking.

The systems map is one of several inputs into following design thinking exercises, where participants conduct interviews and explore the points of view of people within various parts of their system map. The aim of including systems mapping in design thinking is not to seamlessly integrate the two methodologies. Rather, the systems map participants produce is intended to provide a new perspective that can both enhance and disrupt the standard empathetic, human-centered perspective of design thinking.

3. Examples SSOI in practice

To test the potential of SSOI, we applied the methodology and collected data on the process and results in two settings: a problem-definition workshop for sustainable business innovation and a sustainable innovation course for bachelor degree students. Both cases were run online, using Zoom (zoom.us) for communication and Miro (miro.com) for activities.

3.1. SSOI in business settings

The Bergen2030 innovation competition was run by a business incubator that gathered sustainability "headaches" from businesses

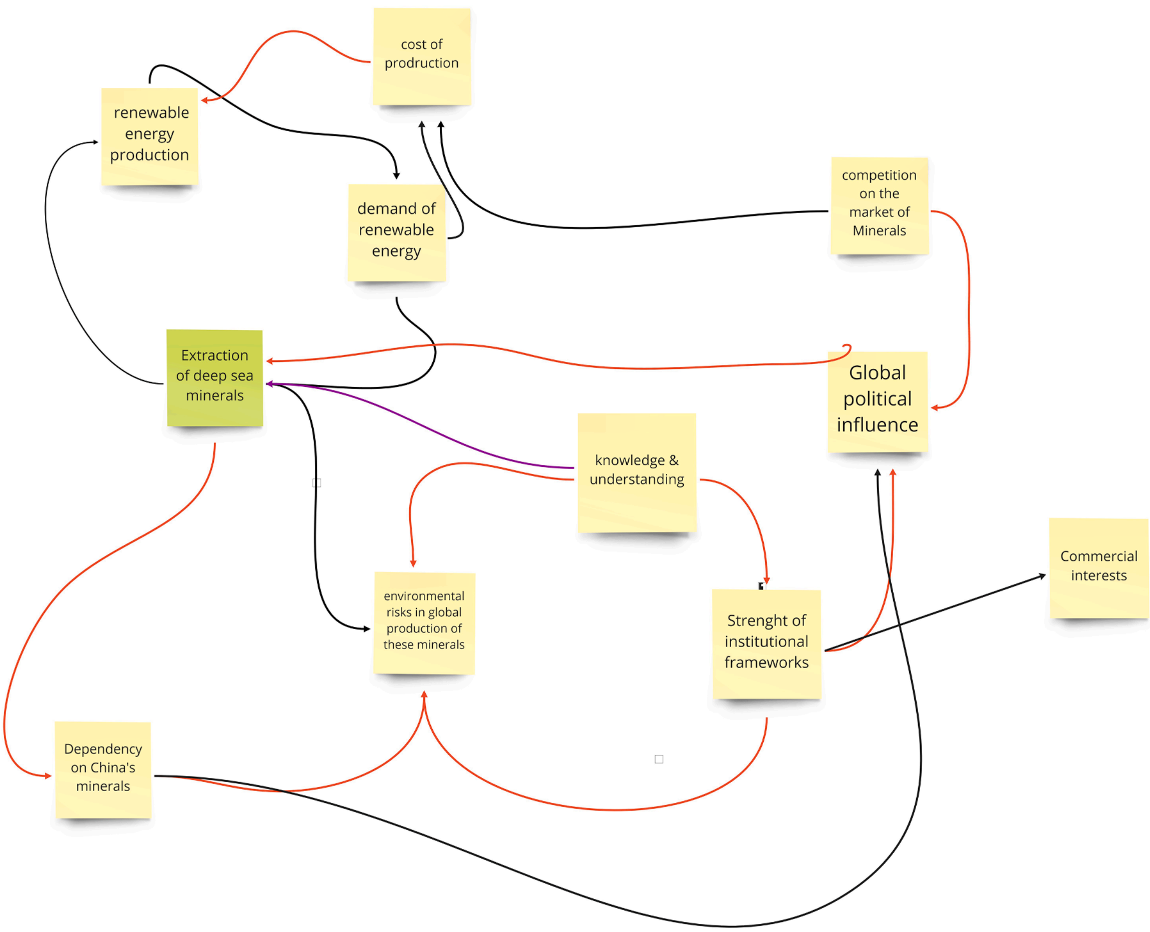

Fig. 3. Example systems map developed by students.

and a municipality. Examples of headaches included emissions from construction sites, waste material from Omega-3 fish oil production, and electricity management in housing associations. The aim of the competition was to gather and refine the sustainability problems, then allow interdisciplinary teams to compete to solve or improve the problem. The organizations with the headaches first gathered in a workshop to refine their problem description, and then the team competition took place several weeks later. In relation to the double diamond, the problem description workshop corresponded to the first diamond, while the team competition corresponded to the second diamond.

We applied the SSOI methodology in the problem description workshop. The explicit aims of the two day workshop were to 1) Further develop and increase the quality of the organization's problem description to be used in the following phases of the innovation process; and 2) provide training in a set of activities and tools that participants could use independently in other innovation processes. Each of the five participating organizations (total of 20 participants) had different levels of experience and formal competence in innovation practice. The participating organizations included large corporations with business activities within shipping, aquaculture, real estate, and power-grid services. A municipal public management body also participated. The team members represented a wide array of professions and experience levels within innovation processes. One team consisted of a company's internal innovation department, where all members had both experience and academic training in design thinking and product/services design, while other teams included accountants, marketing-personnel, VPs, engineers and architects – all with widely varying previous training or experience with innovation and product/service design.

The problem definition workshop consisted of a series of exercises that built on each other. At the start of each exercise, participants were given a brief introduction to the activity and its aims and purpose. Participants then worked within their groups with facilitators circulating to provide assistance as needed. Exercises included traditional design thinking activities, such as "empathetic interviews"

Table 1
Workshop Summary.

Activity	Description	Prompts	Time (minutes)
Introduction	Presentation by facilitators.Introduction to systems mapping with two examples of systems maps: one addressing population dynamics and one addressing urban housing development.Focus on understanding: • A Variable as a phenomenon, element, or entity that can be measured and either increase or decrease in magnitude. • A Causal Link as a connection between Variables that indicates how a change in one variable would affect another variable. • A Feedback Loop as a circular arrangement of causally connected variables.		15
Identify a key variable	Facilitated group discussion.Identify key variable as a point of departure for the mapping exercise.	• Business case: Is there anything in the material produced in the previous exercises that you consider a key variable particularly important for your understanding of your challenge? Or can you think of something completely new that would be important for your challenge? • Student case: Can anyone suggest a relevant key variable to start with here? It does not have to be the most critical or most important, but we need a place to start.	5
Causal mapping	Facilitated group discussion.Team members add variables and connect them via causal links; thereby iteratively expanding the systems map in a "mapping backwards" process as described in section 2.	• What causes your variable to change? Or is your variable causing a change in another variable? • Is the change in the same or in the opposite direction? • What else can cause a change in X variable? • What would a change in X cause down the line?	40-50
Identify Feedback Loops	Facilitated group discussion.Participants are challenged to identify closed loops where chains of variables are linked together to form full circles. Facilitator may identify first feedback loop and emphasize the "story" each loop tells (ie, how it relates to the larger system).	• What is the feedback story here? • What is the nature of this feedback loop is it reinforcing or is it balancing?	10
Debrief	Facilitator summary and facilitated group discussion. Facilitator summarize the findings in the Systems Map focusing on identified feedback loops and loose ends. Facilitator highlights that the work is not complete and encourages the participants to keep working to expand the Systems Map to be more comprehensive, and to use it as a boundary object for their further work with the innovation challenge.	• What system behaviors have we found that should be considered when we move forward with our innovation process? • Are there any counter-intuitive or potentially undesired effect loops we should be aware of?	15

and "points of view," in addition to the systems mapping exercise. The outcome of the two day workshop was a comprehensive problem description that could be delivered to teams working on the problem in the competition.

3.2. SSOI in educational settings

The Sustainable Innovation course at the University of Bergen is an optional course for bachelor level students from all faculties, and students must apply and be accepted into the course. The focus of the course is teaching students innovation methodologies and sustainability concepts. The bulk of the course is a project in which students work in teams with five to seven members to address a "real world" sustainability challenge presented by a client.

In 2021, the course had 30 students from four faculties. Almost none of the students had previous experience or training in systems mapping or design thinking. The systems mapping workshop was the first exercise the students did in their teams and the first activity related to their innovation challenge.

The workshop consisted of a 15 minute introduction to systems mapping by the authors, one hour of facilitator-assisted workshop in the teams, and a 15 minute plenary debrief. In the workshop, the teams agreed on a key variable for their problem, then built a systems map using that variable as a starting point. Though the workshop was short, many teams continued to work on their systems map after the workshop had ended. In class meetings subsequent to our workshop, students received training and facilitation in design thinking.

3.3. Workshop structure

The idea of expanding the traditional design thinking approach to include a systems perspective in SOI emerged in discussions between the business workshop organizers and the authors. In preparation for the business workshop, the authors worked closely with the workshop organization team and facilitators. The workshop program was developed over a period of four months and was considered a pilot project for innovation.

The student systems mapping workshop built on the experience, feedback and evaluation of the business workshop. Few adaptations were necessary, though the participants and starting points were different in this setting. In both cases, the systems mapping workshop was based on the "Initiating and Elaborating a Causal Loop Diagram" facilitation guide in Scriptapedia (Hovmand et al., 2011) (Table 1).

After the business workshop the system maps remained available for the participating teams. They were also collated into a more comprehensive insight report (including the results of exercises they did prior to systems mapping) that was delivered to the teams. Teams continued work with the "second diamond," where solutions to the predefined "headaches" were sought over the course of a 48 hour hackathon.

Students in the academic course maintained access to their systems maps, and many teams continued to work on, and with, the systems maps generated through the workshop.

4. Data collection and analysis

For both cases, we analyzed the systems maps generated by participants for evidence of multidimensional perspectives and inclusion of both individual and societal aspects. We also conducted and analyzed interviews and surveys to better understand the learning process and perceived value of systems mapping for problem definition. The systems maps provide insights into the problem descriptions, while surveys and interviews provide insights into the process.

4.1. SSOI in business settings

After the workshop, we conducted semi-structured interviews of five professionals (one from each participating team). The semi-structured interviews were carried out along a predefined interview protocol; all respondents were interviewed by the same protocol. The interview protocol consisted of three main lines of questions: (1) Baseline – assessing the previous experience with innovation, design and systems thinking. (2) Workshop Execution – assessing how the respondents experienced the theory, examples, exercises and facilitation of the workshop. (3) Utility – assessing to what extent components of the workshop were found to be useful by respondents. The protocol also included room for any other remarks or comments observed by the respondents.

Interviews were conducted by both co-authors via video meeting. The interviews were 30–60 min in length and were later transcribed and analyzed. The analysis was carried out in several iterations during which the authors reviewed the responses for mentioning or discussing the key elements of SOI, including longer time horizons, problem definitions spanning individual and societal aspects, and multidimensionality (Buhl et al., 2019). In addition, the systems maps generated by participants were collected for analysis and assessed for the same elements.

Of the six participating teams in the business case, all teams identified a minimum of five different sectors or dimensions intrinsic to their problem space. Typically, these dimensions included economic sectors (finance and market structures), social sectors (various user groups and government policies), and environmental sectors (for example, waste management, climate footprint, water quality).

Four out of six teams identified a minimum of two feedback loops. Of the two teams that did not identify feedback, one team did not participate in the whole workshop. The second team stated that they did not have sufficient time to complete the task during the workshop, but that they had continued to work with the systems mapping exercise after the workshop both as a team and individually, and that continued work revealed interesting and potentially important dynamics.

One team drafted a comprehensive systems map during the workshop and identified about a dozen minor and major feedback loops, straddling several dimensions. Their map included both individual and societal perspectives and identified tensions between these perspectives. This team reported that identifying causal feedback in their problem space was particularly useful for moving forward with the innovation task.

4.2. SSOI in educational settings

At the end of the course, we conducted a brief survey of students (response rate = 52%) to gauge their experience and learning. We also collected the systems maps created by the students for analysis.

Five out of six teams developed detailed systems map during the workshop, including a minimum of four and a maximum of eight dimensions spanning environmental, economic, and societal sectors. Two teams continued to work on their systems map after the workshop, and both of these teams increased the number of variables and links in their systems maps by a factor of three. All teams who successfully created a systems map also identified key feedback loops and interactions among sectors in their system.

Fig. 4 shows the work of one of the teams in the student case. The team worked on defining a SOI problem related to an emerging industry of deep water mineral extraction on the Norwegian continental shelf. None of the team members had any prior knowledge of the subject, and information about the case was given to them on the morning of the workshop. The systems map they created is not comprehensive, but instead represents the group's status at the end of the 1.5 hour workshop.

The systems map introduces a number of dimensions into the problem space beyond the individual "user," in this case a company invested in deep sea minerals. The team started with the key variable "Extraction of minerals in the deep sea." Using a "mapping

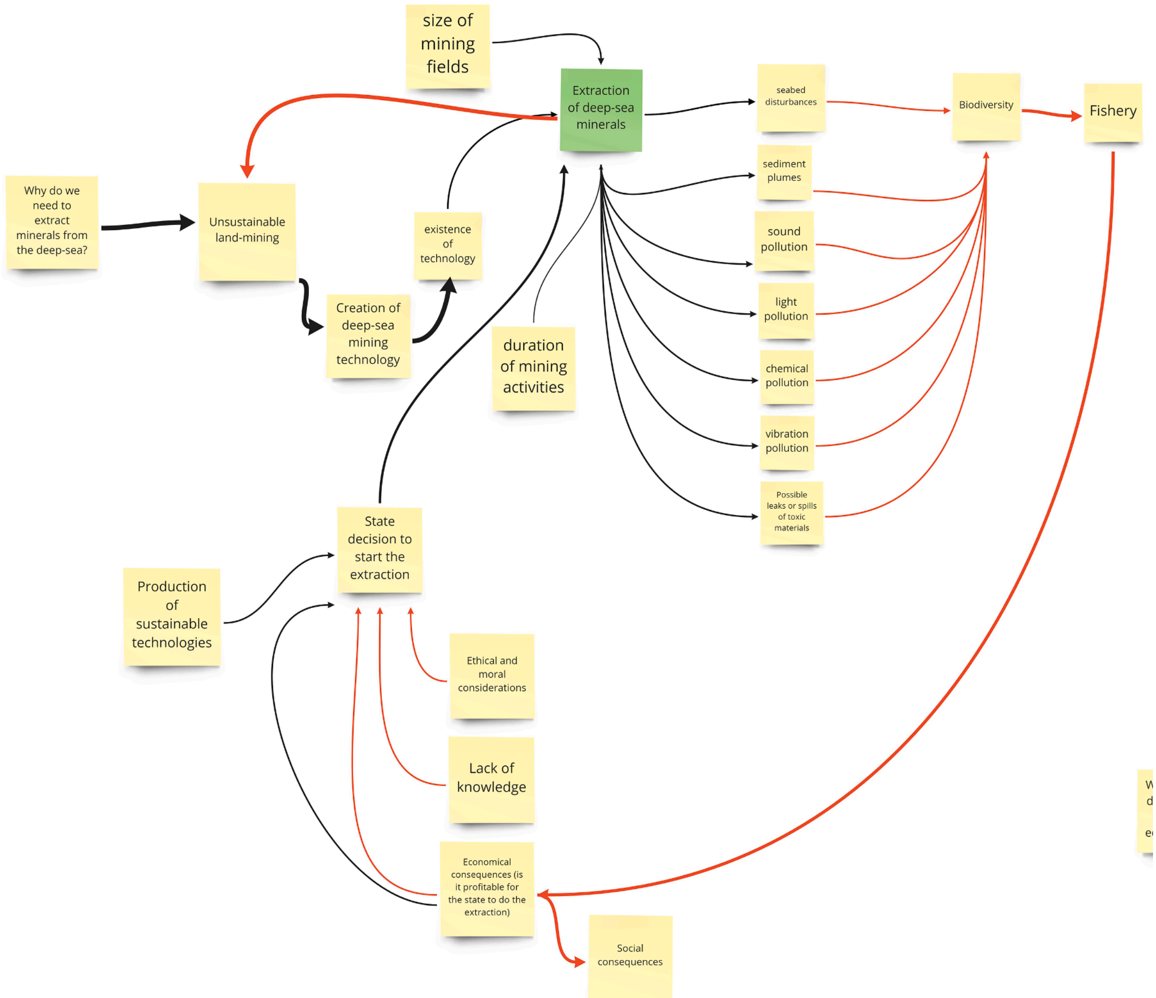

Fig. 4. Example systems map from the education case. Students identified interactions among economic, environmental, and societal sectors within their problem definition.

backward" technique, they identified both the presence of mining technology and state policy as primary factors affecting deep sea mining. State policy is affected by technological development and knowledge status, ethical considerations, and profitability. Profitability is affected by activities in the fisheries sector (a major industry in Norway). The fisheries sector is affected by changes in the physical and biological environment, and those environmental factors are affected, in turn by deep sea mining, the key variable. Further, students identified link polarity (shown as black and red arrows in Fig. 4). Link polarity refers to the direction in which one variable affects another over time. For example, increased seabed mining increases seabed disturbances (black arrow), which has a negative impact on biodiversity (red arrow).

In sum, we can see that the students identified economic, environmental, and societal sectors and explored how those sectors relate to and influence each other. The system map identifies important dynamics in the problem space as it evolves over time. It implicitly includes a long time horizon, as the causal loop described above will play out dynamically over many years.

Survey results indicate that most students had no previous experience in system mapping or design thinking (Fig. 5). Almost all respondents found the SSOI workshop to be useful or very useful. The strongest values they reported from the workshop include using the systems map as a discussion tool and reference object and identifying innovation ideas (intervention points) within the map. Almost 30% of respondents continued to develop the systems map on their own after the workshop.

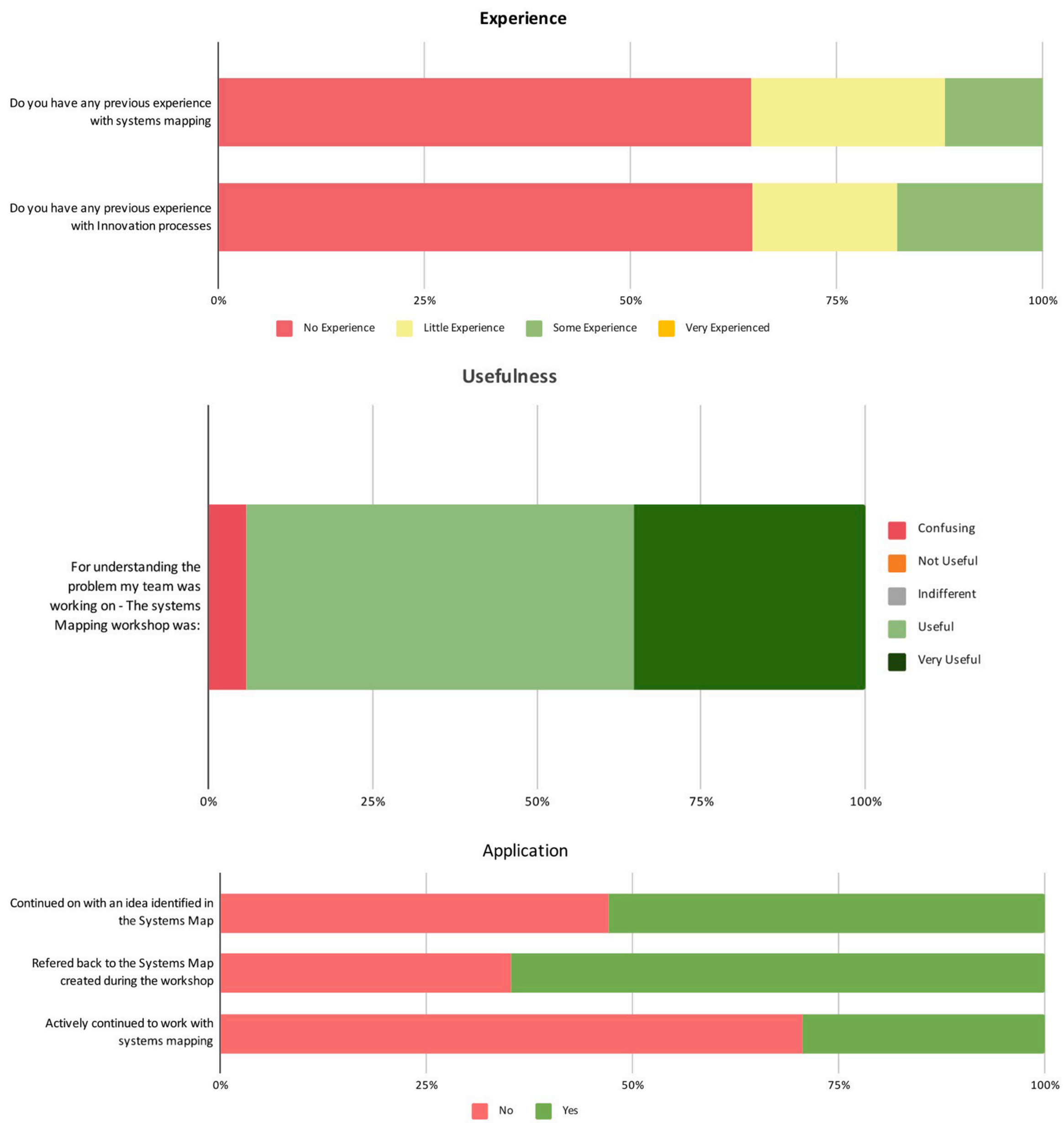

Fig. 5. Summary results from student survey after the workshop.

5. Discussion

Through employing systems mapping in the problem definition phase of design thinking, we aimed to incorporate the specific requirements of sustainability in an innovation context: a systems vantage point, individual and societal interactions, and multidimensionality. Our analysis shows that SSOI provides value as both as a capacity-building process and as a product for highlighting sustainability aspects in problem definitions.

The usefulness of design thinking for innovation processes has been well documented (Carlgren et al., 2016; Roth et al., 2020). Originally designed as methodology for product development, design thinking has been adapted and adopted to a broader range of innovation processes in recent years. While use of different design thinking tools may emphasize different qualities and criteria, the design thinking approach has remained more or less bounded within the double diamond framework. We find design thinking's simplicity and ubiquity to be advantageous, as it provides simple "scaffolding" on which to test new approaches. We recognize, however, that design thinking takes many forms, and the design thinking approach discussed in this article is not the only form of design thinking.

Our case studies illustrate the potential role of systems mapping as an intervention in design thinking innovation processes in business and educational settings. While the main goals of these two examples were different, both cases demonstrate how systems mapping can be applied to increase understanding and definition of the problem space for sustainability-oriented innovation. Further, the cases demonstrate that systems mapping methodology can be implemented by and provide useful results for participants in different phases of their education and career and with different levels of background and experience in the problem being discussed.

In both cases, systems mapping contributed to a more holistic understanding of the problem. Our analysis of the systems maps indicates that participants both expanded the boundaries of their problem and, in most cases, included environmental, economic, and social sectors. They could also see connections between elements that they hadn't focused on before, which provoked new thinking about the problem. Several groups explicitly identified tensions and interactions between individual users and broader segments of society. Though almost none of the students in the education case had previous experience in design thinking or systems mapping, 94% reported that the systems mapping workshop was useful or very useful for understanding the problem space. As one business case participant commented, "We saw complexity in the issue that we hadn't seen before, especially as we came from different perspectives… We saw that we could come to a completely different solution than what we had originally thought."

While the primary goal of SSOI has been to set the problem in a systems perspective to improve problem definition, we also found that systems mapping contributed to creating a shared understanding of a complex problem and aided communication among team members. This is a documented effect of systems mapping (Rouwette, Korzilius, Vennix, & Jacobs, 2011; Videira et al., 2017), but we argue that this effect is especially valuable in the context of SOI, where diversity in background and perspective contributes to a more holistic problem definition.

In the business case, systems mapping as a communication tool proved particularly beneficial for teams from large companies, where team members typically came from different departments, with different backgrounds and responsibilities. These teams in particular remarked on the usefulness of the systems map to create a shared understanding of a complex problem and generate discussion around how the system functions over time.

Several student teams also continued to build on and refer to their systems map throughout the innovation process. Survey results indicate that 42% of students actively used the systems map as a tool for framing discussions within their teams throughout the course. Further, more than half the students continued to refer back to the systems map they developed as the course progressed and continued to work with an idea that was identified during the brief workshop.

In the business case, both observations during the workshop and interviews confirmed that systems mapping was the most cognitively demanding step in the workshop, even with facilitator support. Connecting variables and describing relationships was new for most participants, as was the concept of feedback. In the education case, most students were able to quickly get started and work independently in teams. In both cases, facilitators periodically "checked in" with groups to ensure they understood and were making progress on the systems map. Our experiences indicate that while participants were able to successfully build a systems map in both cases, facilitators trained in systems mapping are needed to support teams through the process.

Subsequent to both of the workshops, some teams, both advanced and more inexperienced, reported that they planned on, or already had, employed the methodology in other sustainability innovation processes. This indicates that participants were able to internalize and gain confidence in the methodology despite receiving only a brief introduction. It also indicates that participants identified a clear value in the perspective and insights that systems mapping have to offer SOI. In particular, several interviewees from the business case mentioned the value of having a tool that helped them visualize connections that were often otherwise not articulated.

The SSOI approach has particular relevance to education. Systems thinking, put into practice as systems mapping, lies at the intersection of many modern higher-education priorities, including training students in collaboration, problem-based learning, and communicating across disciplines. We propose that incorporating systems mapping into innovation courses will not only improve student-generated projects, but will also strengthen students capacities to meet complex, real world challenges outside the university.

These brief (less than two hour) systems mapping interventions allowed participants to clearly see and define the sustainability aspects in their problem definition. Participants valued the actual systems map as a tool for problem definition and a boundary object for communication. They also valued the learning process and capacity building generated through creating the map. Though further development and testing is needed, our initial results indicate that systems mapping can be a valuable and efficient addition to standard design thinking approaches to SOI.

6. Conclusion

Innovating for sustainability requires a deep understanding of a system and its interactions. We present SSOI as an approach to advance the research, practice, and implementation of SOI practices. Our work demonstrates the potential of this approach to improve problem definition for sustainability innovation. Our results also show that participants valued and learned from the SSOI process, and that many planned on incorporating systems mapping into future innovation processes. Using SSOI to define the problem space supports sustainability aims by enforcing a holistic, coherent perspective that connects individuals and society.

Participants confirmed that SSOI is valued as a process for learning and internalizing a systems understanding of sustainability as it relates to innovation. As an intervention to standard design thinking practices, SSOI requires further study to evaluate how it can be used to improve SOI processes and products. Process- and results-based comparisons among various SOI approaches would be a significant contribution towards understanding how innovation processes relate and contribute to sustainability and systems perspectives. In addition, developing quality criteria for problem definition in innovation would allow for a standardized analysis of results. These are vital next steps if we expect design thinking to be a valuable tool to shape innovations for sustainability.

CRediT authorship contribution statement

Brooke Wilkerson: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Lars-Kristian Lunde Trellevik:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

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