Communications of the Association for Information Systems

Research Paper ISSN: 1529-3181

Positioning Design Science as an Educational Tool for Innovation and Problem Solving

Nguyen Hoang Thuan
School of Business and Management, RMIT University Vietnam, Vietnam
Thuan.NguyenHoang@rmit.edu.vn

Pedro Antunes
University of Lisbon, Lisbon, Portugal
padantunes@fc.ul.pt

Abstract:

This study discusses design science from a teaching and learning perspective. Predominantly targeted to information systems research, design science not-withstanding can also contribute as a pedagogical tool, which promotes innovation and problem solving in a variety of domains. However, the related literature still lacks experiences and best practices on how to position design science as an educational tool. We fill this gap by exploring the purpose and meaning of design science in higher education, with a focus on undergraduate courses. We elaborate a process that helps educators integrating this innovative tool into their course designs. The process has been instantiated in various undergraduate courses in different domains. Based on these course instantiations, we propose a stronger position of design science education in undergraduate curricula.

Keywords: Design science, Design science education, Design inquiry, Educational tool

Please cite this article as:

Thuan, N. and Antunes, P. (2022) 'Positioning Design Science as an Educational Tool for Innovation and Problem Solving', *Communications of the Association for Information Systems* [Preprint].

1 Introduction

Design science (DS) has become a popular research approach in the information systems (IS) field (Hevner et al., 2004; Hevner et al., 2019; March & Smith, 1995). Over the last few years, the approach has been helping to identify problems of substantial interest, design novel IS artifacts to address these problems (in the form of constructs, models, methods, and instantiations), and generate design knowledge from solving these problems (Hevner et al., 2004; Niederman & March, 2012). Therefore, DS has attracted attention from not only researchers but also practitioners and educators.

DS has largely engaged the research community. Many leading IS journals dedicated special issues to DS research (Hevner et al., 2019; March & Storey, 2008; Sundarraj, 2018; vom Brocke, Winter, et al., 2020). Researchers have applied DS to investigate socio-technical innovations, problem solving, action design research, artifact development and evaluation, and artifact design theorizing. Researchers have also made many contributions regarding the conduct of DS research, clarifying epistemological positions (Goldkuhl, 2012; Niehaves, 2007), highlighting genres of inquiry (Baskerville et al., 2015) and types of research questions (Thuan et al., 2019), proposing research frameworks (Antunes et al., 2021) and methods (Hevner & Chatterjee, 2010; Hevner et al., 2004; Peffers et al., 2007), suggesting evaluation frameworks (Venable et al., 2016), and clarifying the nature of design theory (Gregor & Jones, 2007).

From a practice perspective, DS has also been suggested as a relevant approach for the design and management of IS, which bridges the gap between theory and practice. This bridge can be regarded in two complementary directions. On the one hand, DS promotes theory-informed problem solving, using academic knowledge to solve real-world problems (Nagle et al., 2017). On the other hand, DS also links practice back to theory, establishing a common ground for evolving design theories, which concern the application of abstract designs to problematic contexts (Holmström et al., 2009). Together, DS allows us to iteratively foster the relationships between theory and practice.

From an educational perspective, we consider two spheres where DS can take relevant roles in teaching and learning. The most natural sphere concerns preparing graduate (master and doctoral) students (Herselman & Botha, 2020; Knauss, 2021; Pérez Contell, 2020), which is important if they intend to adopt DS in the development of their theses. The approach is also relevant to familiarize students with exploratory research strategies and problem solving skills in research design (Novak & Mulvey, 2021). Providing students with DS experiences can help framing research problems and applying design knowledge to research design, which may help bridging the gap between theory and practice.

The other sphere where DS education can take an important role is educating undergraduate students in a wide range of domains, including engineering, management and communications (Apiola & Sutinen, 2021; Carstensen & Bernhard, 2019; Keskin & Romme, 2020), where DS can be applied as a pedagogic tool for innovation and problem solving. This role can be traced back to the seminal work by Simon (1996), who emphasized the significance of designing artifacts in education: “design, so construed, is the core of all professional training [education]” (p. 111). Amplifying Simon, several researchers suggest that universities should prepare students to solve and manage problems they will encounter in the real world (Goldkuhl et al., 2017; Lin et al., 2020). Following this line of reason, in this paper, we are particularly focused on the adoption of DS in undergraduate studies for the purposes of learning innovation and problem solving.

Making DS a common, seamless experience in undergraduate studies can be challenging for both educators and students. Students must gain confidence in dealing with contemporary problems, which can be complex, even wicked (e.g., homelessness and climate change). Students must gain confidence in the pursuit of aha moments, creativity, lateral thinking, and abductive reasoning when addressing complex and wicked problems. And students must also gain confidence in evaluating solutions for satisficing rather than truth-or-false criteria (Goldkuhl et al., 2017; Keskin & Romme, 2020). As so, educators must create and facilitate the right type of challenges, experiences, attitudes, and behaviors.

We would expect to find examples and best practices specifically directed on how to integrate DS into undergraduate studies as an educational tool. However, not much knowledge has been shared regarding DS course design. Prior research has focused on synthesizing the concepts of DS in education (Keskin & Romme, 2020; Naukkarinen & Talikka, 2021), principles for integrating DS education in IS curricula (Goldkuhl et al., 2017), and proposals focused on DS master theses (Knauss, 2021) and doctoral seminars (Hevner, 2021). Such a lack of guidance may be frustrating to educators who want to apply DS in undergraduate courses.

Fulfilling this gap, the purpose of this study is threefold. First, we position DS as a relevant educational tool in higher education, with a focus on undergraduate courses. As so, we extend existing research targeting master and doctoral students (Hevner, 2021; Knauss, 2021), which has been mainly focused on DS research. Our study is targeted towards wide-ranging integration of DS in a variety of learning experiences and professional practices. Second, we develop a DS learning process, which captures the key features of DS education and applies them to undergraduate courses. Third, the proposed process has been used to support course designs and teaching and learning experiences in a variety of undergraduate courses across different disciplines (engineering, arts and business). All in all, we offer insights on how to maximize the potential of DS in undergraduate programs.

The paper proceeds as follows. In the next section, we provide background information regarding DS education. Next, we position DS as a learning tool. The following section proposes a DS learning process, which captures the key features of DS education. We then discuss how the proposed DS learning process has been operationalized in a variety of undergraduate courses. We finally discuss a set of design principles guiding the operationalization of undergraduate DS courses, and provide some concluding remarks.

2 Background

DS education considers knowledge acquisition related to the design of artifacts and learners' reflection on the design process (Collins, 1992; Winter & vom Brocke, 2021). Etymologically, it combines the *design science* approach, originally developed for IS research, with the *education* domain. Thus, we now review the main aspects of the DS approach, and then the application of DS in the education domain.

DS has become a popular approach in the IS field, supporting new methods for investigating substantial problems (or authentic problems (Minichiello & Caldwell, 2021)), which occur in the real-world and are worthy of study, i.e., unique, challenging and impactful (Pries-Heje & Baskerville, 2008). These problems can be identified in the application domain by researchers, educators and practitioners, as suggested by Hevner (2007; 2021). DS tackles substantial problems through the design, development and evaluation of information technology and related socio-technical artifacts (e.g., models and methods) (Hevner et al., 2004; Hevner et al., 2019; March & Smith, 1995).

Hevner et al. (2004) suggest that DS involves three cycles of design, relevance and rigor. The relevance cycle anchors DS to the application domain. The design cycle iterates between two main activities, build and evaluate. Build refers to the construction of artifacts, and evaluation refers to the assessment of artifacts with respect to solving the problem. The rigor cycle bounds the search for a solution to the knowledge base, using existing knowledge as a foundation for design, and contributing new knowledge through the design process (Gregor & Hevner, 2013; Hevner et al., 2004).

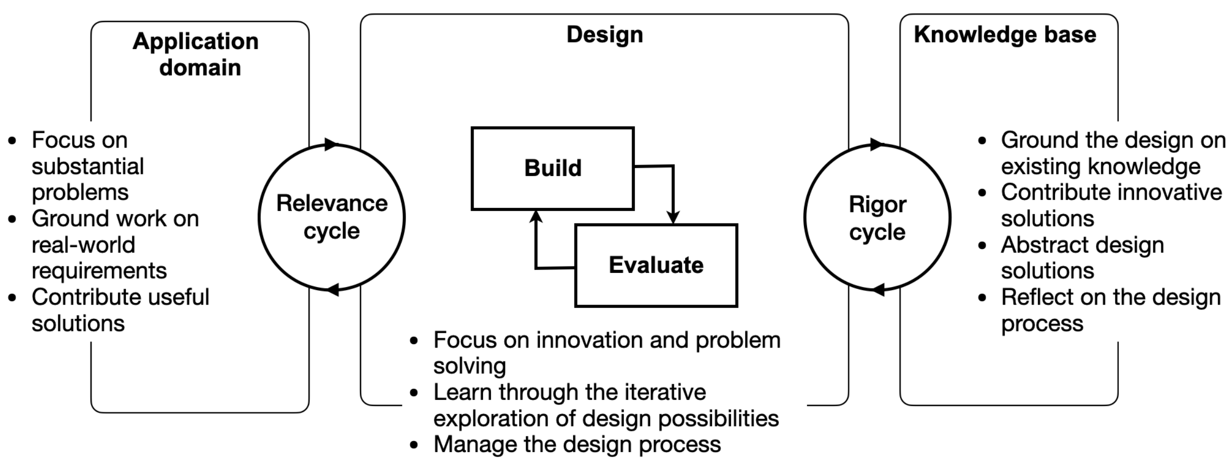

Figure 1. Main aspects of DS as an educational tool (adapted from Hevner et al. (2004))

In Figure 1, we underline the three cycles posited by the DS approach and indicate the potential roles of DS as an educational tool in each cycle. In particular, we suggest that the relevance cycle has potential to engage students with substantial problems, focusing on contributions deemed useful to people, organizations and society. We also suggest that the design cycle brings students to focus on innovation and problem solving, and learning through the iterative exploration of design possibilities, while managing the whole process. Finally, the rigor cycle provides an important backdrop for students to engage in learning activities, grounding the design on existing design knowledge and artifacts, allowing students to contribute innovative solutions, focusing on the essential properties of design solutions, and finally, enabling students to reflect on the design process.

Recently, DS has made significant advancements in aspects crucial to research, considering in particular design theory (Gregor & Jones, 2007; Iivari, 2015; Kuechler & Vaishnavi, 2012; Mandviwalla, 2015), design research methodology (Goldkuhl & Karlsson, 2020; Peffers et al., 2007; Venable et al., 2017), and publication of design research contributions (Gregor & Hevner, 2013). Further, there are an increasing number of studies adopting DS to address a variety of problems in the IS domain (vom Brocke, Winter, et al., 2020). Given these fundamental advancements, plus the understanding that the approach may extend well beyond the IS domain, DS has attracted multiple interests, including the interest from educators.

In Table 1, we review and summarize a set of studies related to DS education. The review is structured according to four dimensions of analysis: core discipline of the study, targeted educational level, purpose of the study, and main propositions. The first dimension considers the discipline where DS education has been applied. The second dimension looks at the education level addressed by the study (e.g., undergraduate and postgraduate). The third dimension considers the purpose of the DS education study. Aligning with Goldkuhl et al. (2017), we consider if the purpose of the study is to prepare students for professional practice or research (or both). Finally, the last dimension briefly summarizes the main propositions of the reviewed studies.

Table 1. Literature review on DS education

References	Discipline	Level	Purpose	Main propositions
(Goldkuhl et al., 2017)	IS	Undergraduate	Research and practice	• Proposes a DS approach to IS education, which combines reflection and action • Defines a set of principles guiding DS learning through design • Stimulates movements back and forth between abstract design knowledge and concrete design actions
(Carstensen & Bernhard, 2019)	Engineering	Undergraduate	Research	• Suggests a laboratory approach, which links the use of theories/models to objects and events • Students are involved in iteratively theorizing and modeling systems through measurements • Students learn by experiencing difference instead of similarity
(Herselman & Botha, 2020)	IS	Postgraduate	Research	• Mainly concerned with the quality of DS postgraduate research • Proposes a minimum set of requirements for rigorous DS research
(Keskin & Romme, 2020)	Management	Undergraduate and graduate	Practice	• Proposes a consistent approach to DS methodology and DS education • Focuses on generalized problem solving • Develops a generic framework for DS practice, which combines theory-driven and practice-driven research strategies
(Naukkarinen & Talikka, 2021)	Engineering	Not specified	Research	• Reviews the use of DS in engineering education research • Highlights an increase of utilization of DS experiments in engineering education research
(Mdletshe et al., 2021)	Medical radiation science	Undergraduate and graduate	Research	• Demonstrates the application of DS in medical radiation science education • Suggests that DS could be beneficial to engage students in multidisciplinary and collaborative research

(Apiola & Sutinen, 2021)	Software engineering	Undergraduate and graduate	Research and practice	• Proposes DS as a framework for higher education in computational thinking and software engineering • Relates DS to the development of soft skills, creativity and critical thinking • Suggests adapting educational institutions and curricula to combine routine and non-routine problem solving, curiosity and fun • Suggests topping strong mathematical and technological skills with practical DS projects
(Knauss, 2021)	Software engineering	Master	Research	• Emphasis on empirical research methods in collaboration with industry • Suggests that DS enables balancing research with practical value to industry • Provides concrete advice for framing research questions, structuring a report, and planning and conducting DS research with industry
(Winter & vom Brocke, 2021)	IS	Master and PhD	Research	• Identifies a set of challenges in teaching design science research • Formulates eight principles on how to teach design science
(Hevner, 2021)	IS	PhD	Research	• Identifies a set of challenges related to PhD research and pedagogy • Proposes a doctoral seminar curriculum

From Table 1, we note three important points. First, DS education has received attention from a variety of disciplines including engineering (Carstensen & Bernhard, 2019), management (Keskin & Romme, 2020), medical sciences (Mdletshe et al., 2021), software engineering (Knauss, 2021), and information systems (Goldkuhl et al., 2017; Hevner, 2021). Second, DS education has been mainly applied to guide postgraduate studies (Herselman & Botha, 2020), focusing in particular on PhD studies (Hevner, 2021). Much less attention has been given to DS education at the undergraduate level. Third and finally, most studies consider DS as a research tool, and thus teach students on how to integrate DS, in particular DS methodology, in their research studies (Goldkuhl et al., 2017; Hevner, 2021; Knauss, 2021).

This suggests a gap on investigating DS with a broader educational view, considering in particular how to use DS as a learning tool, engaging students in the process of designing artifacts and reflecting on the design process, focusing on innovation and problem solving, and learning through iterative design and exploration. Next, we position DS as a learning tool in undergraduate studies.

3 Positioning DS as a Learning Tool in Undergraduate Studies

We identify five factors driving the adoption of DS as a learning tool: learn through problem solving, bridge the gap between research and practice, focus on student engagement through design, highlight the iteration of design and evaluation, and facilitate digital innovation.

First, DS can provide learners with a distinctive type of knowledge, which concerns problem solving. Since DS is essentially a problem-solving approach (Hevner et al., 2004; vom Brocke, Hevner, et al., 2020), learners can apply DS to efficiently solve problems arising from practice. Differently from a more conventional educational approach, which requires students to understand core topics in a specific knowledge domain (e.g., databases, security and systems analysis and design in the IS domain) before attempting to address real-world problems, DS education can foster students to learn through problem solving (Boehler et al., 2020). DS focuses on the acquisition and development of knowledge related to the design process (Goldkuhl et al., 2017). With the DS mindset, learners change their role from passive knowledge receivers into active knowledge engagers: dipping in the domain knowledge required to solve the problem, applying that knowledge in a specific context, tailoring knowledge to specific interventions, and, to some extent, generating new knowledge from their reflections about the design process. Problem solving abilities are particularly important in domains where wicked problems are common and decisions require reflection on how to deliver satisficing solutions (Simon, 1996). In such domains, DS may help learners become more confident in their problem solving abilities (Keskin & Romme, 2020; Novak & Mulvey, 2021).

Second, DS can bridge the gap between research and practice. Here, we consider three aspects. One aspect is that DS helps learners to identify and frame problems in the application domain, and then assessing that designed solutions deliver utility to the application domain (referring to the relevance cycle in Figure 1). This focus on delivering utility to the application domain brings learners closer to practice. Another aspect is that DS also bridges the gap between practice and research, as the design process is structured by a regulative and reflective cycle, which adds rigor to design activities (Holloway et al., 2016). This focus on rigor brings learners closer to research. Finally, outcomes from the design process feed both the knowledge base (with abstract design knowledge) and the empirical knowledge of the learners (with concrete design experiences (Goldkuhl et al., 2017)). By integrating these three aspects, DS enables learners to naturally focus on delivering valuable design solutions, applying rigorous approaches to the design process, while adding abstract design knowledge (Baloh et al., 2012).

Third, DS education focuses on student engagement where students actively design artifacts that address stated problems. The value of DS education lies in promoting students' engagement with problem and solution frames through reflective practices (Goldkuhl et al., 2017; Schön, 1983). Students can develop self-efficacy as active reflective practitioners in building and evaluating artifacts, which is similar to the application of action research in education (Gibbs et al., 2017). Further, when successfully building and evaluating artifacts, students also develop ownership of the solution (Savery & Duffy, 1995), as well as ownership of the design methods and processes leading to the solution.

Fourth, DS education highlights the importance of trial-and-error, an essential aspect of design. Students can learn how to demonstrate and evaluate design artifacts and methods (Goldkuhl et al., 2017). In a classroom context, demonstration and evaluation can be performed by the students themselves, and cross-evaluated in cooperation with other students (e.g., peer reviews, walkthroughs and scenario-based evaluations). We align with recent studies suggesting to perform the artifact build and evaluate activities concurrently (Hevner & Chatterjee, 2010; Sonnenberg & vom Brocke, 2012; Winter & Albani, 2013), which helps improving solutions and fuels learning and reflection about design processes.

Finally, we align DS education and digital innovation. Digital innovation has been a key concept in various domains, such as engineering, information systems and management (Fichman et al., 2014). However, a key question is what methods we can teach students to foster digital innovation. Innovation requires understanding problem complexity and the impact of designed solutions and interventions on socio-technical systems, which can be difficult to frame in a comprehensive, systematic way. According to Hevner and Gregor (2020), DS is an important method to foster digital innovation. As so, students may learn digital innovation through the design of innovative artifacts.

All in all, we suggest that DS is ideally positioned as a learning tool for undergraduate studies in various domains. We have discussed five driving factors. Next, we propose a process that operationalizes DS as a learning tool.

4 Operationalizing DS as a Learning Tool

We now develop a process that operationalizes DS as a learning tool in undergraduate courses. We base the process on two theoretical foundations: the core characteristics of the DS paradigm (Hevner, 2007; Hevner et al., 2004) and elements of Schön's reflection-in-action theory (Schön, 1983). The integration of reflection-in-action and DS seems logical, as we aim to place DS in the educational space and Schön's reflection-in-action theory has been widely influential in that space (Koschmann et al., 1994). Furthermore, many researchers have also noted the entanglement between the design process and the reflection that happens during the design process (Ghajargar & Wiberg, 2018).

We discuss the proposed process in two levels of detail, considering first the abstract process, and then the detailed process. Figure 2 shows the abstract process, which highlights four essential steps in DS education: substantial problem, problem framing, solution framing, and artifact design.

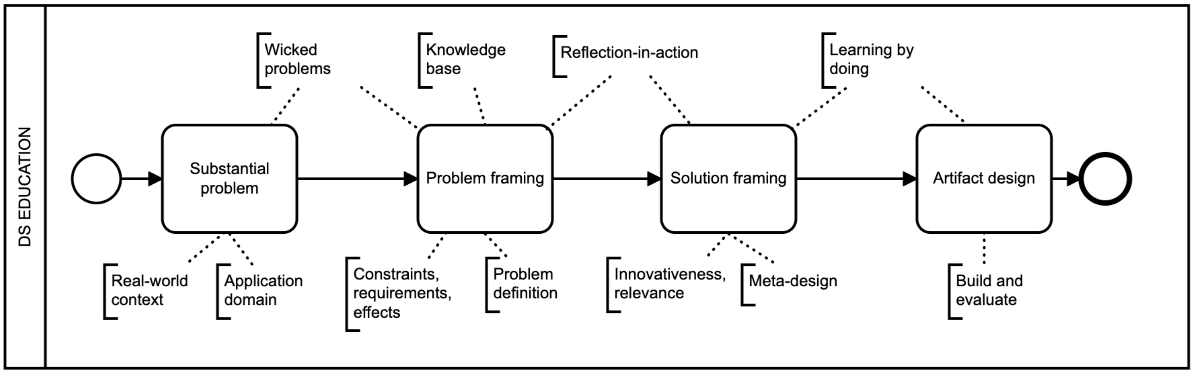

Figure 2. Abstract DS learning process

In the beginning, students identify a substantial problem. We have discussed the importance of identifying substantial problems in Section 2. This viewpoint is supported by Winter and vom Brocke (2021) who suggest the identification of substantial problems as a key starting principle for teaching DS. We further note that the identified problem should be challenging and impactful, and grounded on a real-world context (stakeholders, organizations) and specific application domain (e.g., public administration).

Then, students perform problem framing, which is a crucial step to understand the problem (Holmström et al., 2009). The main purpose of problem framing is to analyze the problem and come up with a problem definition. During problem framing, students identify a set of constraints, requirements, causes, and effects. Wicked problems theory helps understanding that problems can be ill-defined, do not immediately lead to desired outcomes, and can be symptomatic of other problems (Rittel & Webber, 1973).

Another relevant aspect of problem framing involves exploring the knowledge base. Students are stimulated to (more or less extensively) review the research literature related to the problem. The main goal is to gain familiarity with what experts in the domain say about the problem. Therefore, the search is not restricted to theories and models explaining or describing the problem, but can encompass other types of knowledge, including concepts, viewpoints, and a variety of constructs (e.g., ontologies and taxonomies).

The outcome of problem framing is a visual schema, which we designate problem framework. The problem framework sensitizes students about the problem, and helps students communicate about the problem. At a more theoretical level, the problem framework also helps students build a "theoretical lens" about the problem (Niederman & March, 2019).

After framing the problem, students explore and frame the solution space. Hevner (2021) supports this movement and notes "once the research problem has been understood and represented, the DSR project moves to the solution space in which satisfactory solutions are designed" (p. 188). Several solutions may be identified and delineated during solution framing. Concepts may be taken from the problem framework and explored during solution framing. This helps contextualizing and justifying the identified solutions. New concepts may be added during solution framing, for instance to help identify the expected properties and values of the identified solutions.

Another relevant aspect of solution framing concerns meta-design. As noted by DS methodologists, DS should not be strictly concerned with delivering a solution to the framed problem; instead, DS should deliver abstract solutions to classes of problems (Walls et al., 1992). By requiring students to frame solutions before committing to specific solutions, educators can raise attention and control the students' focus on the abstract solution, rather than letting them jump immediately to a defined solution.

The outcome of solution framing is another visual schema, which we designate solution framework. The consideration of problem and solution frameworks in the learning process is in line with DS, which is centered on iterative artifact development. This arrangement is also aligned with reflection-in-action theory, as students are required to stop-and-think about the method of design (Schön, 1983).

Finally, the process finishes with artifact design, which involves a build/evaluate cyclic activity. It represents Hevner et al.'s (2004) design cycle. It also stimulates students' reflection-in-action and learning by doing. More details about this activity are given below.

Overall, the abstract process highlights the main activities of DS education. It also defines the conceptual structure of DS education, which educators can base on to plan their courses. To further guide educators planning and detailing their courses, we now move to the second level of detail over the DS learning process. Figure 3 shows the detailed steps of problem framing, solution framing and artifact design.

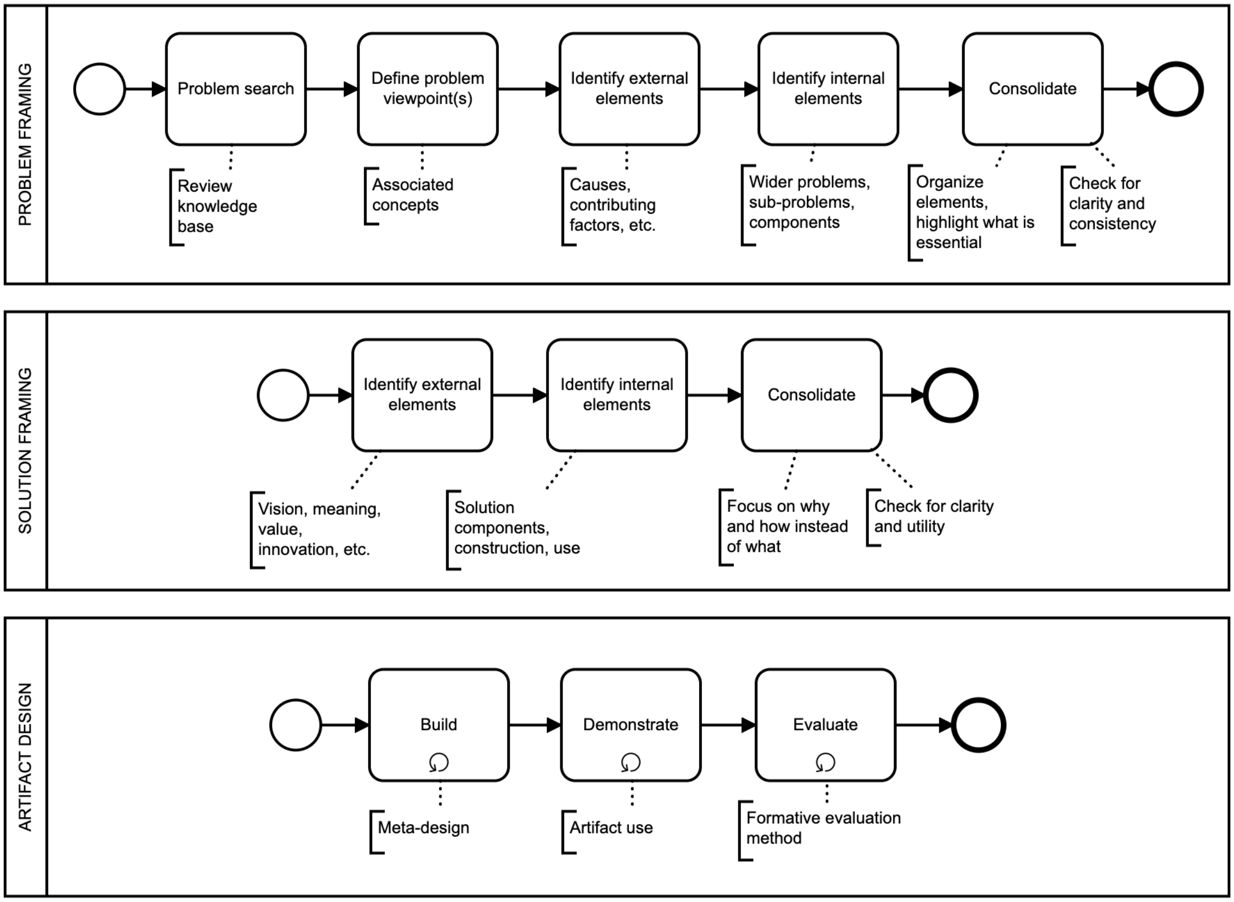

Figure 3. Detailed DS learning process

Problem framing. Problem framing starts with problem search. This involves reviewing what the knowledge base says about the problem. Depending on the problem domain and educational context, educators may focus more on research databases, industry documentation, media, and other sources of knowledge. The next activity involves defining the problem viewpoint(s) and associated concepts. This is relevant because wicked problems often have a variety of viewpoints involving different concepts (Holmström et al., 2009). The next activity requires identifying the external elements of the problem, including causes, effects, and other contributing factors. This is followed by an activity focused on the internal elements of the problem. This may include identifying problem components, wider problems and sub-problems. The final activity involves consolidating the schema. This involves organizing elements in the schema, highlighting what is more and less relevant, checking for clarity and consistency, and making sure that the problem "comes into focus" (Niederman & March, 2019).

Solution framing. Solution framing starts by identifying the external elements of the solution, which includes identifying the vision, meaning, value and innovation brought by the solution artifact. Elements from the problem framework may be integrated in the solution framework, which helps explaining the rationale leading from problem to solution. The next activity involves identifying the internal elements of the solution, which includes identifying the solution components and other aspects such as context of use and context of construction (McKay et al., 2012). In this activity, students are recommended to focus on the abstract aspects of the solution, emphasizing objectives/functions and qualities/capabilities (Rohde et al., 2017).

The next activity involves consolidating the diagram, organizing the elements in a way that highlights why (the design is driven in a certain way) and how (the design delivers value) instead of what (the solution actually is). The diagram should be checked for clarity and utility.

Artifact design. Regarding artifact design, we consider three activities. The first activity involves building a prototype: a material artifact providing a proof-of-concept of the solution (Baskerville et al., 2015). We note the ambiguity between this design *activity* and the whole design *process*, since both concern 'design' (McKay et al., 2012). This ambiguity is common in DS. For instance, the process proposed by Peffers et al. (2007) includes an activity named 'design and development'. Artifact design should contemplate the concept of meta-design, providing an abstract solution to the defined problem and making the artifact design transparent (Iivari, 2005).

The next activity concerns in-class demonstration, where students show the prototype and explain how it addresses the problem. This can be done using a variety of techniques, such as storytelling, storyboarding and role playing.

The final activity concerns the prototype evaluation. Students have to select a method to evaluate their prototypes, and are presented several evaluation methods from Venable et al. (2016). Venable et al. (2016) identify both summative and formative methods for artifact evaluation. As summative methods, e.g., experiments, may be difficult to operationalize in the classroom, we suggest that students select formative evaluation methods.

We note that the build, demonstrate and evaluate activities can be performed multiple times. Such iteration realizes DS as an iterative, trial-and-error process.

5 Course Iterations

The DS learning process described above has been implemented and refined in various courses. These courses were developed in different domains, covering engineering, information and communications technology (ICT), arts, and business, which emphasizes the eclectic nature of teaching design. In these example courses, we illustrate the iterative development of the DS learning process, highlighting not only the similarities but also the differences between the generic process and the instantiated courses.

5.1 Iteration 1: Product Design

This course was our earliest approach towards the development of the DS learning process. The course has been taught in a faculty of arts for four years and involved arts students with an interest in the design of software products. It was an optional course in the curriculum, with small cohorts of 10-20 students.

Students were free to select a problem of their choice, the only constraint being that the solution would have to involve a software product. The selected problems were uneven. Examples included developing tools that helped car parking, supporting blind people navigating metro stations, and helping workers chill out in office spaces. The unevenness of selected problems, combined with lack of control over the problem selection, created uncertainty and risks regarding the creativity and utility of designed solutions.

After selecting the problem, students developed a conceptual framework. The purpose of this artifact was to structure the whole design process, from problem to solution. This adopted a common approach in qualitative research, where conceptual frameworks help structure the research process (Miles et al., 2014). Therefore, in this course there was no clear separation between problem and solution frameworks. This allowed students to focus more on the solution than the problem.

After developing the conceptual framework, students engaged in the design activity. In this particular course, the focus was on paper prototyping. The paper prototypes were demonstrated and evaluated in class using walkthroughs. Finally, students were asked to submit a short report with a reflection about the design process.

The project assessment was based on three elements. The first element considered the evolution of the conceptual framework, which was expected to demonstrate increasing understanding of the problem and increasing relationship with the solution. Another element was the design method/process, which was informed by the reflections submitted at the end of the course. The last element was the proposed solution, which was informed by the prototype, walkthrough, and feedback received during the demonstration.

In summary, the DS learning process was operationalized in this course through the iterative development of artifacts, explicit consideration of the design process, and adoption of known evaluation methods (promoting rigor). Reflecting on this course iteration, a positive aspect was that students were really appreciative for being free to choose a problem of their interest. By doing so, students had ownership of the projects, seeking solutions for problems that would resonate more with their interests (Wood, 2003).

Students were also surprised by the role of the conceptual framework in driving the project through, as a form of design theorizing. On the other hand, students selected a wide range of problems, some offering limited potential for exploration and innovation, a problem that was only obvious as the project progressed. Some students, at the beginning, found it difficult to differentiate the problem from the solution, which also contributed to narrow down too early the set of potential ideas and design options. With this reflection, we decided to separate the problem framing and solution framing in the next iterations.

5.2 Iteration 2: Design Science Studio

This course allowed to further elaborate and refine the DS learning process. The course has been taught for two years in a business school, as part of an IS minor in a business major. The main course objectives were to “bring DS to the everyday practice of consultants, developers, project leaders, and any other professional involved in technology and business design”, and “integrate and consolidate prior competencies in systems analysis and design, business analysis, and project management”. The course involved small cohorts of 10-20 students.

In this course, we introduced the separation between problem and solution frameworks. The ‘studio’ term in the title signaled the adoption of cultural attitudes and teaching strategies often associated to the Bauhaus school, in particular the socialization of experiences (thinking, discussing and doing) in an open, exploratory and hands-on working environment. It also signaled that the course was an experiment in DS teaching and learning.

Students selected the problems they would like to explore. However, the selection was highly supported in order to increase the potential for creativity and innovation. The focus was on wicked problems with broad societal relevance. Simple and solution-oriented problems were rejected. Examples of selected problems included eating healthy, reducing the carbon footprint, troubleshooting cybersecurity problems, and promoting sustainable tourism.

After selecting the problem, students reviewed the scientific literature related to the problem and developed a problem framework. Significant guidance was provided to ensure that the problem frameworks considered a variety of viewpoints, external elements and related problems. Students had to associate references to relevant research literature to main framework concepts.

The next step involved the development of a framework expressing the main features of the solution. Support was given to make sure that students identified the external and internal elements of the solution. At this stage, a constraint was introduced, requiring the solution to involve decision-making support. This constraint was introduced so that students could more easily converge their solutions towards a particular type of innovation.

Both frameworks were then evaluated by students in class. Various evaluation techniques have been used in different editions of the course, including provocation workshops, where colleagues criticized the frameworks, and card sorting, where design teams gave decks of cards to the evaluation teams, who then organized the cards in categories related to issues, good/bad, missing features, priorities, and other categories selected by the design teams. One edition of this course required the evaluation to be done remotely (because of restrictions related to the Covid pandemic). The remote evaluation adopted the card sorting technique, which was realized using a shared Kanban board (using Trello). Feedback from these evaluation actions was analyzed by students and resulted in actions points and revisions to the frameworks.

The next step involved prototyping the solution. Prototyping was based on Excel, as it facilitated realizing decision-making support (using tables and formulas). The prototypes were evaluated in demo sessions. The demo sessions provided feedback for the next cycle of build and evaluation. Two cycles were done in this course. The project was finalized with a short report where each student reflected on the design process (reflection-on-action).

Regarding assessment, all submitted artifacts were individually assessed using a variety of criteria. For instance, the evaluations done by students were assessed using two criteria: method and reflection. The final prototype was assessed using five criteria: idea, empathy, structure, user experience, and demo.

Overall, this course operationalized all main steps of the DS learning process, of which detailed teaching and learning activities were implemented. As so, we suggest that the DS learning process can be used as a basis for DS education. Different with the first iteration, this iteration separates problem framing and solution framing, which enables students to immerse themselves in the problem space before considering the solution space and landing on a solution. Many students found the development of the problem framework as puzzling, as the definition is open and few guidelines on how to build a framework exist. The problems disappeared when developing the solution framework. We noted the appropriateness of using demo sessions as an evaluation technique in the context of iterative prototype development. Demo sessions not only allow students to receive feedback (from peers and educators) about their prototypes, but also allow them to get detailed feedforward on how to improve them (Koen et al., 2012). We further note the small student cohorts in this course, which may raise a concern with scaling up the DS learning process. The next iteration addresses this concern.

5.3 Iteration 3: Systems Analysis and Design

This iteration consolidated the DS learning process and allowed it to scale up. The course has been running for two years in the current format. Additionally, it has two editions per year, one in an informatics engineering program, and another in an ICT program. The course is mandatory for undergraduate students in both programs. The engineering edition has cohorts of 150-160 students, and the ICT edition has cohorts of 120-130 students.

The course replaces a core course in the computing and IS Curricula (Leidig & Salmela, 2020), keeping the original name and objectives: to understand "analytical techniques to develop the correct definition of business problems and user requirements". However, arguably traditional analytic techniques have been aging (e.g., specification of functional and non-functional requirements, and data and systems modeling). The adoption of DS was an opportunity to focus more on systems design and less on specification and modeling, taking a more contemporary approach to the course objectives.

To keep the course manageable, students work in groups of three to four. All elements of the proposed DS learning process have been implemented, although with some variations. The course requires students to select a problem from a main theme, which changes every year. Example themes include "digital transformation in the public administration", "making good locally", and "crowdsourcing". Example problems selected by students include "supporting the elderly in your neighborhood", "increasing public participation in local administration", and "crowdsourcing the learning of musical instruments". As in the previous iteration, substantial support is given to make sure the selected problems have enough breadth and depth, and potential to generate innovative solutions. In particular, we disallow the typical solution-first approach: "I would like to build a software tool that…".

After selecting the problem, students develop the problem framework. In the initial editions of this course, students were not required to review the scientific literature. However, in later editions we introduced this requirement. This allows students to enrich their views about the problem.

After developing the problem framework, students interview people knowledgeable about the problem (e.g., public administrators, and members of non-profit organization delivering food to homeless and other people in need). These interviews serve to evaluate the problem framework, as the participants are shown the framework and asked to criticize it. The next step involves the construction of empathy maps and affinity maps, which summarize the data gathered from the interviews.

Students then develop the solution framework, considering the empathy maps and affinity maps as inspiration. The solution framework is peer-reviewed in the classroom. If necessary, the problem and solution frameworks are revised based on the feedback.

The next step involves prototype development. Prototyping tools are used at this stage (initially, Evolus Pencil, and more recently Justinmind Prototyper). These tools enable students to design their prototypes in a quick and easy way, which can be continuously tested. The last step involves the prototype demonstration and evaluation in a demo session, which is done in class. A storyboard is built to support the demo.

At the end of the project, students put together all developed artifacts in a project canvas. In Figure 4, we present the project canvas template, which we supply to students. We find the project canvas very useful, as it gives a comprehensive perspective of the project, and helps assessing the consistency of design activities and qualities of developed artifacts.

Regarding the project assessment, all artifacts and activities receive preliminary marks immediately after they are submitted. However, a final mark is only assigned when the project is completed. This allows the project to be assessed holistically, and also allows students to improve their artifacts until the very end of the project. There assessment criteria were used to evaluate projects: overall consistency, viability and creativity.

Our reflection on this course iteration suggests that the DS learning process can be operationalized in courses with large student cohorts. We further note three interesting points. First, this iteration requires students to conduct interviews in between problem framing and solution framing. These interviews help students ground the problem in the real world by empathizing with others' viewpoints. The interviews revolve around the problem framework, which helps students get detailed reactions about the problem (e.g., which elements are wrong or missing), rather than abstract opinions. Second, this iteration allows students to use interactive prototyping tools, which help developing, demonstrating and evaluating quasi-realistic solutions. Finally, a new artifact brought into the project development is the project canvas. This artifact has revealed useful in two different aspects. One aspect is providing an anchor for the discussions between educators and students, which is very helpful when working with large student cohorts developing distinctive projects. By showing the canvas, students bring about the whole project context and its evolution. Another aspect is providing a holistic view over the project, which helps the project assessment.

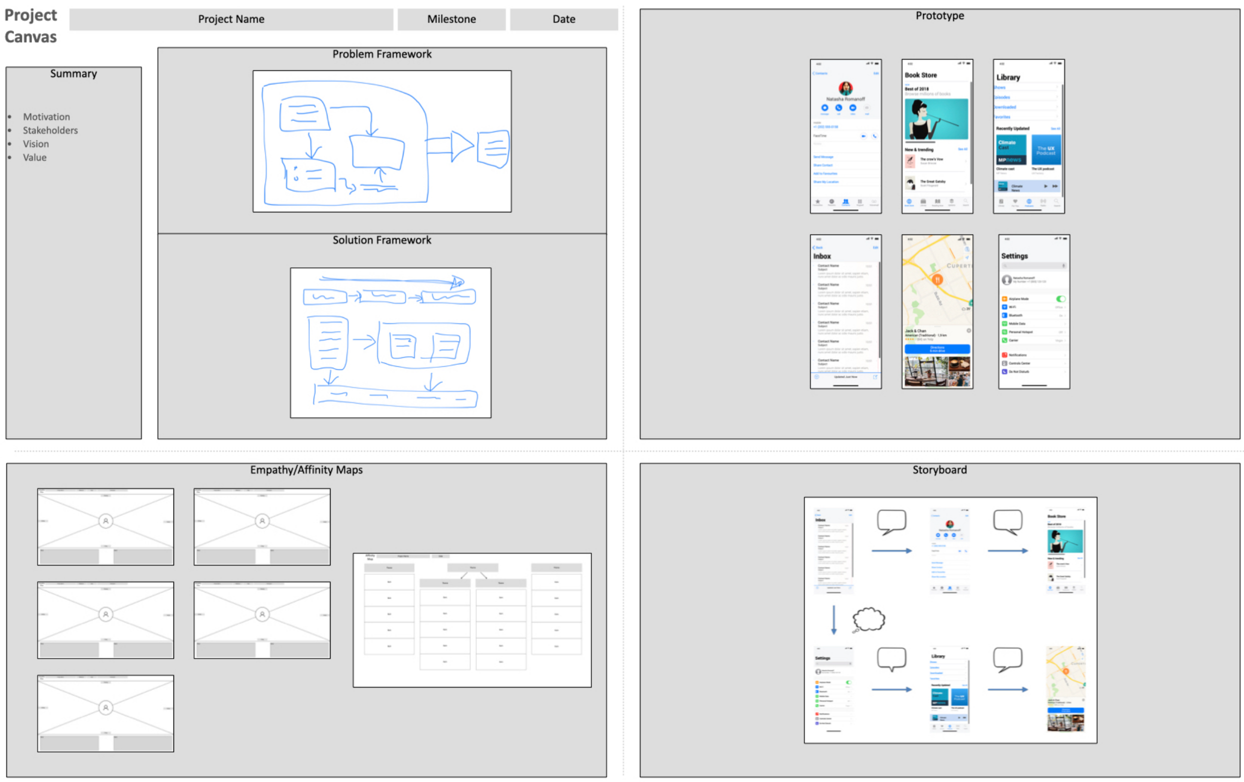

Figure 4. Project canvas

In summary, we consolidated the DS learning process through the three courses and ten instantiations. Table 2 overviews the three courses. Key activities matching the DS learning process are marked with 'Y', while missing activities are marked with 'N'. Minor additions and omissions are marked with '+' and '-'.

Table 2. Overview of course iterations

DS learning process	Iteration 1 Product design (arts)	Iteration 2 Design Science Studio (business major, IS minor)	Iteration 3 Systems Analysis and Design (engineering and ICT)
Authentic problem	Y - Students freely selected the problem	Y	Y (from a main theme)
Problem framing	N + Students developed a conceptual framework of the project	Y	Y + Evaluating the problem framework in interviews + Empathy and affinity maps
Solution framing		Y	Y

		+ Evaluation of problem and solution frameworks using various techniques	+ Peer review of solution framework
Design iteration	Y (paper prototype)	Y (initial prototype developed in Excel) + Focus on decision support	Y (prototype developed with Evolus Pencil or Justinmind Prototyper)
Demonstration/evaluation iteration	Y (walkthroughs) + Reflection	Y (demo sessions)	Y (demo sessions) + Storyboard + Project canvas
Design iteration	N	Y (final prototype developed in Excel)	N
Demonstration/evaluation iteration	N	Y (demo sessions) + Reflection	N
Number of instantiations	**4**	**2**	**4** (2 engineering and 2 ICT)

We note that some deviations were fostered by programmatic and practical issues. For instance, conducting interviews in the systems analysis and design course was seen as instrumental for engineering and ICT students to gain experience interacting with stakeholders, but not as necessary for business students, as they could acquire that experience in other courses. An important practical consideration was the number of students in class, as the engineering and ICT courses are significantly larger than the other courses. With larger courses, we need more structure and control over the learning experience. However, we see these deviations as minor and not conflicting with the DS education process.

Even though we have discussed how projects were assessed when describing the three iterations, we do not include assessments in Table 2 (and indeed in the proposed process). The main reason is to emphasize the structure behind the learning process. We suggest that the project assessment can be done in a variety of ways; and, arguably, suggest that assessment should follow learning and not the other way around.

Overall, these courses indicate that the DS learning process can serve as a basis for structuring DS education, while respecting the different domains, course sizes, and contexts of each course. By working through these teaching and learning activities, the DS learning process provides the necessary focus and clarification on how to apply DS education.

6 Discussion

We started our paper with an observation about the lack of guidance regarding the adoption of DS in undergraduate curricula, in contrast with research practice (Apiola & Sutinen, 2021; Hevner et al., 2019; vom Brocke, Winter, et al., 2020). Likewise, Winter and vom Brocke (2021) note that "DS research is often insufficiently represented in scholarly education" (p. 1). These observations are further clarified in Table 1, which indicates that the existing studies mainly consider DS as a research tool for postgraduate and PhD studies, rather than an educational tool for undergraduate students. Addressing this gap, in this study we position DS as a learning tool for undergraduate studies. We identify five factors contributing to align DS with undergraduate studies (Section 3). As so, we extend existing research on DS education from a postgraduate motivation (Hevner, 2021; Knauss, 2021; Winter & vom Brocke, 2021) towards an undergraduate focus.

Along with our focus on undergraduate education, we further provide educators with a DS learning process, which defines a set of abstract steps and detailed learning activities that, taken together, help educators integrate DS into undergraduate courses (Section 4). Our DS learning process contributes to prepare students to develop their DS skills, regarding Nelson and Stolterman (2012) "it is necessary to engage in learning processes that lead to our development as skillful individuals" (p. 215). We do not consider the proposed DS learning process from a closed viewpoint. Instead, we provide a set of tried and tested courses. With the DS learning process and example courses, we hope to inspire educators to address the main features of DS education in their course designs, leading students to tackle substantial problems through problem framing, solution framing and artifact design.

We have instantiated the DS learning process in various courses (Section 5). The practical knowledge gained through these instantiations is distilled in the DS learning process, which offers the basis for structuring DS-related courses. In relation to the instantiation of the DS learning process, we further seek to establish four design principles (Baskerville et al., 2018; Nguyen et al., 2021) guiding the operationalization of the DS learning process to a wider educational context: Motivate students to address real-world problems, explicit development of problem and solution frameworks, balance between artifact development and theory-informed design, and flexibility to accommodate a variety of backgrounds and experiences.

Motivate students to address real-world problems. Our reflections on the three course instantiations suggest that students are keen to address real-world problems of their interest. Depending on the course learning objectives, we can motivate students to freely choose a problem of their choice, or ask them to choose a problem within a certain theme. By doing so, students can develop self-efficacy as active reflective practitioners to look for real-world problems and take ownership of their projects (Wood, 2003). This design principle is aligned with Winter and vom Brocke (2021) who suggest DS education for real-world problems and contributions. Taking a more pragmatic view, we suggest that working on projects that address real-world problems provides unique experiences that can feed into interesting curriculum vitae. Students are well aware of this possible outcome, which is another motivator for the project.

Explicit development of problem and solution frameworks. A central aspect of the proposed DS learning process is the explicit development of two intermediary artifacts, the problem and solution frameworks. For expert designers, the separation between problem and solution frames (or spaces) may seem staged, as the two frames are natural, seamless components of their reflection-in-action. However, such internalization may not have yet occurred to students. By defining a learning process where students have to frame separately the problem and solution, and making such separation explicitly in two diagrams, we contribute to internalize a practice that has been observed in expert designers.

Another important aspect of the proposed DS learning process is spending time selecting and framing the problem, rather than jumping straightaway to a solution. We find this strategy relevant to address wicked and complex problems (Hevner, 2021). Responding to wicked and complex problems requires a good balance between rational and pragmatic approaches to problem solving. The combination of both approaches, which is promoted by the DS learning process, helps students gain confidence with dealing with complex, vague and intractable situations. Through the DS learning process, we purposefully create learning experiences that avoid simplistic, unchallenging solutions, such as designing a "website or application for doing X". We instead focus on problems with wider societal impact, which by their own nature have no defined solution, and ask students to contribute with innovative, creative ideas. We offer two examples from our practice. A group of students in the Product Design course, who were seeking to reduce the negative impacts of humans on the environment by increasing recycling, explored the ideas of recycling bins that talk to people, fostering proper recycling behaviors, which detect when they are full and autonomously move to empty themselves. A group of students in the Design Science Studio course, who were seeking to improve healthy lifestyles, prototyped a tool that allowed users to play with different behaviors (e.g., smoking, eating and sleeping), while showing the impacts on life expectancy. Another group interested in adoption problems, developed a "having a child simulator". Even though these ideas cannot be claimed to be innovative in absolute terms, they allowed students to experience innovation from their own points of view.

Balance between artifact development and theory-informed design. In this design principle, we regard the development of problem and solution frameworks as a form of theorizing, which is highly relevant to DS. DS not only concerns building and evaluating artifacts, but it also involves finding the right balance between artifact and theory (Baskerville et al., 2018). While the artifact represents a practical contribution, which meets some defined needs, theory supports an in-depth understanding of the object and process of design. This is referred to as theory-informed design, as suggested by Goldkuhl et al. (2017). Both problem and solution frameworks help students develop their viewpoints, structuring a set of concepts and relationships about an artifact, which can be regarded as design statements, which can be tested if/when necessary. In turn, successful solution artifacts are also statements about the supporting problem and solution frameworks. The articulation between design statements and artifact testability are central to design theorizing.

Flexibility to accommodate a variety of backgrounds and experiences. Fourth and finally, as illustrated by the three course instantiations, the proposed DS learning process is flexible and accommodates a variety of cultural backgrounds (Antunes et al., 2014), educational backgrounds and student's experiences (Table 2). The process can be configured to emphasize more or less the links between design and the knowledge base. The process also accommodates a variety of evaluation points, promoting the use of formative, lightweight evaluation methods. The discussed process instantiations emphasize the use of peer reviews as an evaluation method. It is a lightweight evaluation method, which is easy to implement in class. It also seems highly relevant for DS education, as students can share and reflect about their work in a friendly environment.

7 Conclusion

Design science has important roles in research, given its capability to solve substantial problems through innovative artefacts (Hevner & Gregor, 2020; Maedche et al., 2021). However, questions remain as how to position DS in wider educational scenarios. In this paper, we position DS as an educational tool for undergraduate courses. Although prior studies have already contributed principles of DS education (Goldkuhl et al., 2017; Winter & vom Brocke, 2021), our study goes one step further, proposing a DS process and providing specific guidelines and experiences on how to integrate this educational tool in undergraduate courses.

When positioning DS as a learning tool in undergraduate courses, we further extend Schön's (1992) remark that "there is a great potential for learning through design" (p. 131). In particular, we realize this potential through the concept of DS education and operationalize it with the DS learning process. Based on our propositions, educators can develop DS related courses where students engage in design experiences structured around problem identification, problem framing, solution framing, and artefact design. Consequently, we align with Goldkuhl et al. (2017), who suggest learning through DS experiences.

We also propose four design principles that highlight actionable guidance for operationalizing DS learning process. We hope that these design principles help educators to design, structure, and operationalize DS related courses. We regard our design principles as complementary to the ones proposed by Winter and vom Brocke (2021), and Goldkuhl et al. (2017), regarding how to operationalize a DS learning process. As so, we do not regard our design principles as mandatory, but suggest educators use them dynamically regarding the related DS courses.

Our study has at least three limitations. First, while the proposed DS learning process has been operationalized in three different courses and instantiated ten times, there is a need to formally evaluate the process. Our future work aims to evaluate how students experience DS teaching and learning. Second, we also need to examine the impacts of the DS approach across whole curricula (in particular engineering, ICT, and IS). We understand that integrating DS education into undergraduate courses may extend beyond the courses and subjects discussed in this study (e.g., web development, user interface design and project management). Finally, even though the topic addressed by this study relates to learning outcomes (Biggs & Collis, 2014), we have not yet explored how the DS education process impacts learning outcomes.

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