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Envisioning entrepreneurship and digital innovation through a design science research lens: A matrix approach

Alan Hevner [a,*], Shirley Gregor [b]

[a] University of South Florida, Tampa, FL USA
[b] Australian National University, Canberra, Australia

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ABSTRACT

Design Science Research (DSR) in the information systems (IS) field is, at its essence, about Digital Innovation (DI). Innovative sociotechnical design artifacts involve digital information technologies (IT) being used in ways that result in profound disruptions to traditional ways of doing business and to widespread societal changes. The pervasiveness of DI means that the individuals involved in bringing it about have diverse backgrounds, including application specialists, software engineers, data scientists, business managers, economists, venture capitalists, various user groups, and entrepreneurial leaders. This range of backgrounds means that DI, much more than traditional innovation, leads to varied perspectives on the methods and tools to be used in the development of effective and evolvable complex systems incorporating digital innovations. In this paper we present a new matrix approach to DI based on DSR, entrepreneurship, and innovation theories. Clear strategic guidance allows these multiple stakeholders to make sense of the diverse landscape and to understand when and how different entrepreneurial strategies for innovation can best be applied. We define the combined DSR and DI matrix approach in terms of four strategies: invention; advancement; exaptation; and exploitation and their associated DI practices. The research contribution is a novel DSR-DI matrix process model. This model extends entrepreneurship theory as it enriches effectuation thinking with more detailed process guidance for ambidextrous entrepreneurship and it enriches DSR models for DI by showing more explicitly the different pathways corresponding to different quadrants in the knowledge-innovation matrix.

1. Introduction

Innovation's positive role in advancing economic growth and benefitting society has been long established [1,2]. However, recent studies have expressed concerns of an innovation slowdown with deleterious consequences [3,4]. Chief among the challenges are the difficulty of measuring the novelty and impacts of innovation outcomes, the unpredictable nature of the innovation process, over regulation by governments, the diversity of innovation stakeholders, lack of organizational readiness for disruptive innovations, difficulties of scaling digital innovations, and the lack of strong, coordinated commitments by industrial, academic, and governmental entities to enable and support an entrepreneurial culture of innovation and risk-taking [5–7].

In particular, the rapid growth of new information technologies (IT) has created a focus on digital innovation (DI) as the appropriation of digital technologies in the process of and as the result of innovation. Digital innovation emphasizes combinations of digital and physical components to produce novel products. The phenomena of DI encompasses new digital technologies, information digitization, digitally-enabled generativity, entrepreneurship, and innovation management with a greater range and reach of innovation across organizational boundaries [8–11]. Surveys show that organizations across a wide range of disciplines view DI to be of vital importance [12,13].

The goal of this research essay is to propose a novel process model of DI that supports a richer understanding of different types of entrepreneurship for the investment of DI in organizations. We ground our ideas in the rigorous paradigm of Design Science Research [14,15]. Thus, we motivate our research by addressing a key gap identified in a recent review of DI research in the IS field [16]. The authors state:

> In sum, design science is a long-standing research tradition in IS that has recently gained renewed momentum but has traditionally not been considered a research stream within digital innovation. At the same time, other management disciplines are increasingly

* Corresponding author.
E-mail addresses: ahevner@usf.edu (A. Hevner), shirley.gregor@anu.edu.au (S. Gregor).

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recognizing the importance of design science research, which provides IS with a unique and compelling contribution as an important reference discipline [17]. (p. 208)

Design science research in IS is, at its essence, about digital innovation. The goal of a DSR research project is to extend the boundaries of human and organizational capabilities by designing new and innovative sociotechnical system artifacts [18,19] in the form of constructs, models, methods, and instantiations [15,20,21]. Broadly speaking, DSR aims to add to knowledge of how things can and should be constructed or arranged (i.e. designed), usually by human agency, to achieve a desired set of goals. With its focus on the design and deployment of innovative digital artifacts, DSR is ideally positioned to make both research and practice contributions to the field of DI.[1]

An important challenge to effective DI in organizations is the goal of *ambidextrous entrepreneurship*; i.e. entrepreneurship of different types [22–24]. Ambidextrous organizations should be capable of both exploring new opportunities and working diligently at exploiting existing capabilities [25]. To illustrate, a large bank is successfully using a 'labs' approach with many innovation techniques such as rapid prototyping and co-design with users to achieve the goal of getting new digital products and services to market in 12 week cycles [26]. At the same time, the bank has to implement new advances in platform technologies to serve as a base for the innovative applications that are developed in these short cycles. The new platform development work is considerably more substantial, expensive, longer-term, and relies on rigorous design practices of a professional IT staff. A McKinsey report describes this situation as 'two speeds' innovation, with rapid cycle innovations occurring alongside slower, more substantial innovation activities [27]. However, no detailed advice is given as to how to bring about this 'two speed' strategy. Our initial exploratory field work has shown that managers in digital innovation labs can be largely unaware of the longer term innovation strategies at play elsewhere in the organization.

A further example of the need to recognize different types of DI comes from the personal experience of one of the authors. In some countries organizations can claim tax write-offs for expenditure on research and development (R&D). Where the claimed R&D is for a large software development project, many tens of millions of dollars can be involved. In one country the legislation as to what constitutes R&D is cast very much in the terms of the traditional scientific method, which can be translated to being equivalent to mainstream DSR and equivalent to the *advancement* quadrant in the matrix discussed later in this essay. However if the organization does not take care beforehand, then their project could easily be viewed as in the *exploitation* quadrant in which there is no claim to new knowledge and, thus, not scientific R&D. More thought beforehand could mean the project can be positioned as being in one of the research oriented quadrants in the matrix, with advantage in terms of tax benefits and the ongoing accumulation of explicitly documented knowledge within the organization (see [28]).

We argue the need for a higher order, sense-making process model that defines, structures, and manages multiple innovation strategies in an ambidextrous entrepreneurship portfolio. We see an opportunity to build on prior influential work on portfolio approaches to innovation (e.g. the ambidextrous approach as in [25]) combined with recent thinking that the strategic management of innovation should be based on "innovative design activities" [29].

Further, we posit that the pervasiveness of DI means that the individuals involved in bringing it about have many diverse backgrounds, including application domain specialists, software engineers, data scientists, business managers, economists, venture capitalists, various user groups, and entrepreneurial leaders as co-designers. This range of backgrounds means that DI, even more than traditional innovation, requires many different perspectives on the methods and tools to be used in the development of effective and evolvable complex systems incorporating DI. Thus, there is need for a new conceptual model with resulting strategic guidance that allows the various entrepreneurial roles[2] involved in DI to make sense of this diverse landscape and to understand when and how different strategies for innovation can best be employed.

In building our novel process model, we draw on our prior stream of research on digital innovation over a period of some years; combining work in design science research (DSR) [15,21] and the application of DSR concepts to digital innovation as presented in [30–32]. Based on this background of synergistic experiences with DSR and DI, we define and explore four entrepreneurial strategies: *invention*; *advancement*; *exaptation*; and *exploitation*. The research contributions of this research essay will provide a common language and process model that can be understood and used by people with many different backgrounds in entrepreneurial activities. In particular, it highlights the multiple entrepreneurial roles required to successfully conceive, design, implement, deploy, and evolve digital innovations in complex sociotechnical systems [18,19].

2. Research essay roadmap

The research essay is grounded on theories from the fields of innovation and entrepreneurship. We begin by staking out the scope of our essay as shown in the Venn diagram of Fig. 1. Innovation is defined broadly as "An innovation is the implementation of a new or significantly improved product (good or service) or process." ([33], p. 146) and "Innovation is a process of turning opportunity into new ideas and of putting these into wide used practice." ([34], p. 16). We note the duality of innovation as both an innovation process and an innovation artifact. Novelty (newness) is an essential aspect of innovation but the range of novelty can vary from 'new to the project', 'new to the organization', all the way to 'new to the world's knowledge.'

Digital innovation (DI) is a subset of innovation in which information technology (IT) and digitization of information are embodied in the innovation or enable the innovation [8,10]. As in general innovation, the range of novelty can vary. Design science research (DSR) can apply to both general innovation and digital innovation. DSR in the study of sociotechnical information systems creates and evaluates IT artifacts to

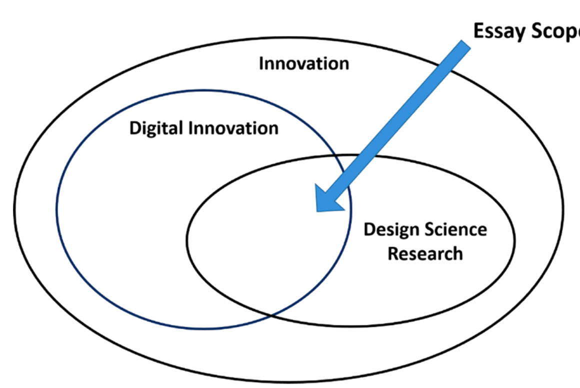

Fig. 1. Scope of Essay – Digital Innovation and Design Science Research.

[1] A recent editorial by Hevner, vom Brocke, and Madche [36] highlight the multiple roles of DI in DSR projects.

[2] The term 'entrepreneurial roles' refers to the roles adopted by multiple stakeholders in bringing about a range of DI across organizations of many types. As Sarasvathy et al. [42] show, an entrepreneurial team in a company such as Starbucks adopted multiple entrepreneurial roles which involved planning, adapting, providing a vision, etc. The roles and strategies we depict here are similar but are more firmly based in an IT and IS environment requiring DI.

solve organizational problems [15]. The important difference between DSR and innovation in general is a rigorous research focus in DSR that requires the contribution of new, transferable knowledge not known to previously exist. Novelty in DSR is 'new to the world.' Thus, the scope of this essay as seen in Fig. 1 is the intersection of DI and DSR within the boarder scope of innovation. The synthesis of DI and DSR provides significant value in that the knowledge contribution, an explicit requirement of DSR, is made visible in order to provide greater validity, credibility, acceptance, and reusability of the innovation results.

We embrace the entrepreneurial theory of effectuation to support a focus on rapid DSR-DI build and evaluate cycles that support methods of adaptive controls over the reliance on theoretical predictions in the design of complex sociotechnical systems. Based on this grounding, we then move to a principal contribution of the essay - that organizational digital innovation should recognize and manage multiple entrepreneurial strategies based on the DSR knowledge-innovation matrix (KIM). This recognition leads to an expanded understanding of *ambidextrous entrepreneurship* that goes beyond previous literature in the multidisciplinary fields of DI. Using the KIM quadrants, we then present an actionable set of DI practices for each of the four entrepreneurial strategies. This logical flow of argument culminates in a well-defined DSR process model for DI that incorporates recognition of multiple stakeholder roles with a clear decision point on which entrepreneurial strategy is being applied during the current DSR-DI cycle. Via disciplined use of the DSR-DI matrix process, an organization can strategically construct an ambidextrous portfolio of DI projects. We are confident that the logical flow of argument is well-grounded in rigorous theory from the fields of innovation, entrepreneurship, and DSR and leads to a rigorous and relevant result with both important research and practical implications.

3. Effectuation theory and digital innovation

A key insight in our research thinking is that digital innovations are embedded in complex, sociotechnical systems whose development requires multiple types of entrepreneurial roles and strategies ([19,35,36]. The sociotechnical nature of these systems means that a complete understanding of such systems is difficult or even impossible. Such complex systems combine human and technology components whose functional and quality attributes are not necessarily known separately or as an integrated whole. A critical question is - How can a rigorous collaborative discipline in a formal process model be defined for designing, building, evaluating, evolving, and operating such massive, complex, and unpredictable DI-embedded systems?

Among the challenges for the entrepreneurial team is how best to ground and to perform the search for novel solutions that satisfy the problem constraints (i.e. application context, means, and requirements) while achieving the desired goals (i.e. aspirations and opportunities). The desired process must support the simultaneous building of a problem space and a solution space; both of which grow in completeness and evolve through multiple iterations. Thus, a premise of our argument is that a new model of DI entrepreneurship must deal effectively with the messy complexity of real organizational contexts and avoid the reductionism found in much research that simplifies the problem space to one in which known theories and solutions readily apply. Truly new and interesting opportunities and problems rarely accommodate existing theories and application artifacts easily or exactly. Instead, the entrepreneurial team must have the skills to apply control techniques of adaptive learning via iterative and rapid design cycles to grow a satisfactory solution that meets the fitness and sustainability requirements of the problem environment [37].

In order to address the challenging issues of designing complex sociotechnical systems with embedded digital innovations, we ground our thinking in effectuation theory from the research field of entrepreneurship. Sarasvathy [38] conceptualizes *effectuation* as the opposite of *causation.*[3] Unlike causation, effectuation does not focus on finding causes that explain or achieve a given (intended) effect, but considers available actions through given means and their spectrum of possible effects. Effectuation therefore is about designing and evaluating alternatives with differing effects (and choosing one of them) instead of choosing among given alternatives which all lead to the same effect. Thus, effectuation logic constitutes a logic of controls; specifically controlling the future by actively shaping one's environment within one's possibilities[4] .

In applying effectuation, the choice of action depends on the three given means of: (a) the actors (effectuators) themselves and their traits ("who I am"); (b) their knowledge ("what I know"), and; (c) their social connections ("whom I know"). It also depends on what the entrepreneurial team can imagine to be possible effects and what they perceive the corresponding risks or potential losses of those effects to be. These risks and losses are matched with the team's set of aspirations, leading to the eventual choice of action. Neither the means nor the aspirations are treated as invariant, leading to a concept that embraces flexibility and dynamism, allowing the exploitation of emerging contingencies [38]. Sarasvathy [39] further states that entrepreneurs first find possibilities in the world, turn possibilities into opportunities, and go from there to start an ongoing, typically path-dependent, process of designing new and transforming products, services, firms, and, eventually, markets in ways they perceive as suitable to exploit the perceived opportunities, such as digital innovations, and implement the possibilities.

We see effectuation's greatest potential for the design of sociotechnical systems that contain a dominant social component and social context that can be greatly enhanced and/or disrupted by DI technologies. These features allow the necessary space for opportunities, contingencies, flexibility, and emergence that is a prerequisite for taking the greatest advantage of innovation potentials [40]. We posit that the application of effectuation theory for DI-embedded systems highlights and supports a fuller understanding of the two key issues that drive our research goals for this essay – the multiple entrepreneurial strategies and roles essential for effective DI-embedded system designs.

Based upon a 2 × 2 matrix with axes of control and prediction, Wiltbank et al. [41] describe four strategies that entrepreneurs can apply to design innovative products, services, firms, and markets: 1) by planning; 2) by adapting to the environment; 3) by following a clear vision, and; 4) by being transformative in the sense of applying effectual logic. In a sample case, Sarasvathy et al. [42] illustrate that the Starbucks organization has employed all four strategies with varying degrees of success. In the next section, we apply a design science research lens to propose four new and different entrepreneurial strategies that provide more prescriptive guidance for DI in IT and IS contexts.

Entrepreneurial research applying effectuation also finds clear distinctions among stakeholders with different means and aspirations. From an effectuation perspective, a transformation of the current reality into a different future reality takes place during the iterative cycles of system design. Here, the growing system artifacts serve as part of the extant means to guide this transformation by highlighting an alternative

[3] "Effectuation processes take a set of means as given and focus on selecting between possible effects that can be created with that set of means. Causation processes take a particular effect as given and focus on selecting between means to create that effect." ([38], p. 245)

[4] Effectuation logic has some commonality with the idea of "need-solution" pairs advanced by von Hippel and von Krogh [64], who argue that problem formulation need not precede problem solving, but rather a need and a solution may be discovered together.

future with disruptive potentials to achieve the desired aspirations.[5] Various entrepreneurial roles over the project's timeframe will participate in the transformation process. These roles may be filled by the system's designers, implementers, end-users, or other groups of people who have a defined stake in the success of the new system. We further contend that effectuation highlights the importance of *creativity* for the various system transformers. Here, effectual logic provides a frame to stimulate and bound creativity as Sarasvathy et al. [38,42] demonstrate in several case studies. When DI-embedded system design and instantiation is a journey into the unknown, a key question for the entrepreneurial process is when and how the researchers can track and evaluate their journey? Whereas research in entrepreneurship leaves this question largely unaddressed [43], we extend current thinking and provide guidance for this question in the following sections.

4. Design science research process models

The widespread interest in performing DSR projects has led to several proposed process models for scheduling and coordinating design activities. Seminal thinking in this area is by Nunamaker et al. [44]. They focus on the central nature of systems development with five stages: conceptual design, constructing the architecture of the system, analyzing the design, prototyping (may include product development), and evaluation.

Vaishnavi and Kuechler [45] extend the General Design Cycle model of Takeda et al. [46] to apply specifically to DSR. In this process model, all design begins with an awareness of the problem. The next stage is a preliminary design suggestion for a problem solution. The next stage is the development stage where the design is further refined and an actual artifact is produced through many iterations. Then the artifact is evaluated according to the functional specification implicit or explicit in the suggestion. There are iterations and feedback involved in these stages cited as circumscription. Finally a project is terminated and concluded.

Peffers et al. [20] propose and develop a design science research methodology (DSRM) for the production and presentation of DSR. This process model includes six steps: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication; and four possible entry points: problem-centered initiation, objective-centered solution, design and development-centered initiation, and client/context initiation.

By combining the research methods of action research with DSR, Sein et al. [47] propose the Action Design Research (ADR) process model. Their model begins with a problem formulation stage followed by multiple iterations of the build, intervention, and evaluation stage along with reflection and learning in each iteration. The ADR project completes with a stage of formulation of learning for system evolution. Action research principles of guided emergence, iterative intervention, and co-creation between research and practitioner are highlighted. An elaborated ADR process model has been proposed by Mullarkey and Hevner [48].

We observe in this brief survey of DSR process models that none of the models differentiate among different types of digital innovation. Thus, the need for new thinking on a DSR-DI process model that supports differing entrepreneurial activities for the four types of strategies found in the DSR matrix discussed next.

5. The knowledge innovation matrix (KIM)

We propose that effective entrepreneurial strategies will vary with the type of innovation being designed. For instance, Koen et al. [49] show in an empirical study that processes for radical innovations differ from those for incremental innovations. Distinguishing more clearly between the strategies and practices that occur with different innovation types is a core objective that drives our conceptual model of DI. Thus, we build a categorization schema that is suitable to distinguish four different entrepreneurial strategies.

There are many ways to classify innovations, as noted in reviews by Garcia and Calantone [50] and Miller and Miller [51]. Some basic dichotomous classifications include the distinction between *exploration* and *exploitation*, introduced by March [52] in relation to learning. March saw exploration as "search, variation, risk taking, experimentation, play, flexibility, discovery, innovation" (p. 71). Exploitation was "refinement, choice, production, efficiency, selection, implementation, execution" (p. 71). Another important dichotomous classification is that between *radical* and *incremental* innovations. Rothwell and Gardiner [53, p. 16] see a radical innovation as a major advance in the technological state of the art, while an incremental or improvement innovation is the utilization of even small changes in technological know-how. Recent studies on diverse entrepreneurship strategies in startups [24] and small and medium-sized enterprises [22] have used the term Entrepreneurial Ambidexterity to describe the need to define and manage multiple goals for organizational DI.

To support a richer diversity of DI, we apply the Knowledge Innovation Matrix (KIM) as initially developed in Gregor and Hevner [30] and refined in [31,32]. KIM is built firmly on the most fundamental features of innovation – new knowledge creation and application in some tangible form to achieve human goals. The tangible forms that digital innovations take include products, processes, and services that involve advances in digital technologies [7]. Taking knowledge and its application (to human needs) as the keys to understanding innovation means that many other labels and categorizations that only partly deal with the innovation space are encompassed: ideas, creativity, technological know-how, products, competencies, organizational learning, and exploration versus exploitation. That knowledge is the key feature in all of these terms is apparent on reflection. Companies do not value the innovative products they produce so much in themselves as the knowledge assets they embody. After all, they sell these products to consumers. What they value is the knowledge asset represented in the product – the intellectual property that may be worth protecting by patents, trade secrets, and/or copyrights – including the need it meets.

The 2 × 2 KIM typology, as seen in Fig. 2, offers a finer-grained view than simple dichotomous classifications and is firmly based in the fundamental differences in triggers of an innovation; needs-pull (problem trigger) and technology-push (knowledge trigger) [34] and the combinations of these two triggers. KIM extends and combines prior work from varied fields of practice on classifying innovations on two dimensions (e.g. [51,54–56]). The two dimensions that form the basis of the matrix are:

1. The knowledge (solution) maturity dimension, which resonates with the key roles in innovation of new ideas [57,58], new insights [59], new knowledge and skills [60], technological know-how [53], new knowledge [61], and learning [52].
2. The application domain (problem) maturity dimension, which resonates with the key roles in innovation of opportunities [34], tasks and problems [62], markets [63], needs [64] and fields [65].

The KIM quadrants are described here briefly and the reader is referred to [21,30] for further detail. Exemplar digital innovations are provided for each quadrant. The exemplars represent the broader understanding of DI by Fichman et al. [10] as well as the more targeted understanding of Yoo et al. [8], which has a focus on digital innovations as "novel products". Yoo et al. [8] explain how these novel products, such as mobile phones, e-books and Google Maps, rely on underlying platforms such as the Internet that enable "generativity" - a technology's capacity to produce unprompted change and innovation by a large, varied and uncoordinated audience [66]. Thus, many digital

[5] "… the specific type of artifact creation at the core of effectuation is interesting – since artifacts emerging from such contexts are more likely to be novel, surprising, and potentially influential on the economy." ([43])

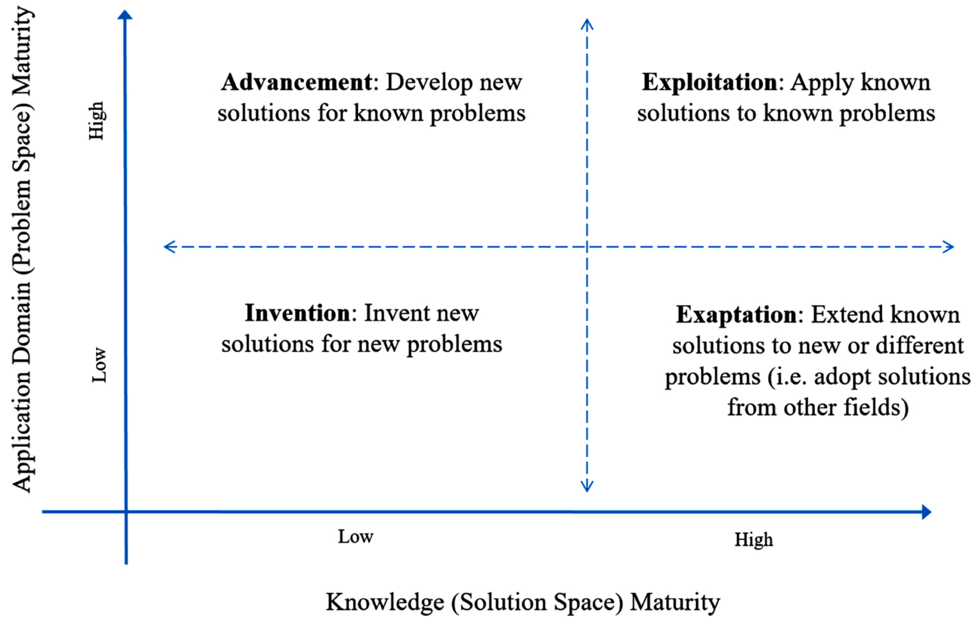

Fig. 2. Knowledge Innovation Matrix (Adapted from [30]).

innovations represent a chain of innovations across the quadrants, as seen below.

1 *The invention quadrant* includes radical innovations that are seen as 'new to the world,' where both the both the idea of the problem or opportunity, and the knowledge to solve it, have not been recognized before. Recognition of the application domain and the related solution knowledge are both low. To be an invention the innovation must be qualitatively different from what has gone before. Inventions are rare in occurrence, with approximately 10 percent of innovations classified as radical innovations ([50], citing [53]). Examples of DI inventions in IS include the first thinking on Decision Support Systems (DSS) by Scott-Morton [67], with the subsequent evolution of DSS into Executive Support Systems (ESS) and Group Decision Support Systems (GDSS) [68]. Further exemplars are the invention of the Internet, which grew out of a principle proposed for network packet switching [69], followed by the protocols for the World Wide Web [70]. In the latter case the inventor was working on personal projects outside his normal work duties and 'tinkering.' The development of the Global Positioning System (GPS) by the American military is also recognized as an invention with several scientists given recognition for its invention [71]. Inventions such as the Internet, the World Wide Web and GPS have had a major impact as generative platforms for further digital product innovations.
2 *The exaptation quadrant* includes innovations where knowledge of how to satisfy one particular need or application function is applied to another need or market in a completely different field. Solution knowledge is well advanced, but recognition of how to apply that solution to the new, specific application area is low. The term comes from evolutionary biology where bird feathers, which were originally for keeping warm, were exapted for flight. The term was coined by Gould and Vrba [72] to mean "characters evolved for other usages (or for no function at all) and later coopted for their present role." An interesting study of exaptation DI in IS is the study by Chaturvedi et al. [73] who propose design principles for user experiences in virtual worlds where the experiences could be expected to be significantly different from online experiences in general. A number of digital product innovations are exaptations, where an entrepreneur takes an existing analog product such as a book or a map, and exapts it to a new role in the digital world. An e-book allows many functions not available with a hard copy book, such as automatic searching. Similarly, Google Maps re-purposed the traditional map concept to give a tool that relies on GPS to give directions for navigation and other functions.
3 *The advancement quadrant* includes innovations where a better solution is developed for a known problem. The difference between this quadrant and the invention quadrant is that here the goal of the innovation effort can be specified at the outset. Solution knowledge is suboptimal, but recognition of the problem is high. There are many examples of innovations in this quadrant and a majority of DSR IS projects fit here. Recent advances in technologies such as cloud computing, mobility, internet-of-things, social media, and business analytics are making major innovation improvements possible in sociotechnical IS. The development of small portable tablet computers such as the iPad was an advancement on larger laptop devices. Tablets then serve as a platform for many digital products in the exaptation category, such as e-books and Google Maps.
4 *The exploitation quadrant* includes innovations which are seen as 'new-to-us' rather than 'new-to-the-world.' Known solutions are applied to known problems, possibly with some relatively minor change or customization. Innovative work in this quadrant can be seen as professional design and development and an organization could derive considerable value from this limited form of DI. An example is the adaptation of the latest ERP systems into an organization's business processes.

It seems likely that the invention quadrant corresponds to radical innovations, while the exploitation quadrant corresponds to incremental innovations; with the exaptation and advancement quadrants falling somewhere between. Koen et al. [49, p. 28] say that "Incremental innovations include cost reductions, improvements to existing product line, and repositioning efforts. Radical innovations are additions to existing product lines, new product lines, and new-to-the-world products" – citing Booz and Hamilton. [74] In terms of the exploration-exploitation dichotomy, the exploitation quadrant in KIM corresponds to exploitation in the March [52] conceptualization, while the other three quadrants are variants of exploration.

6. Entrepreneurial strategies and innovation practices

The KIM framework as presented above captures clear distinctions among DIs in each of the four quadrants. In this section we present the associated entrepreneurial strategies and innovation practices that are associated with each quadrant, drawing on entrepreneurial theory and a recent exploratory study [75]. In the following section, we then place these strategies in an integrated DSR-DI process model.

6.1. Invention strategy and practices

The invention quadrant is the one in which both existing problem space knowledge and solution knowledge are low, thus high levels of creativity will be required to generate novel ideas and the support of conditions fostering creativity are important. Radical, out-of-the-box thinking is valued and non-conventional approaches for the development of ideas will be employed. Organization policies that foster creativity are key; particularly those that provide the entrepreneurial team time to think and try out their own ideas. Specific techniques that could be used with this strategy include *genius grants* and *bootlegging*. Genius grants allow time granted to employees to work on individual innovation projects apart from their normal routine work. A similar practice is bootlegging, although this is a clandestine bottom-up activity hidden from the top management of the organizations [76,77]. Other examples are *tinkering time* and *hack-a-thons*.

Invention Practices:

a) Organizational attributes that foster creativity, including policies that give freedom to individual employees and focused teams to investigate problems of their own devising in free time, allowing innovators to incubate ideas (e.g. bootlegging policies).
b) Supportive teams with colleagues who encourage original thinking and tolerate eccentricities.
c) Individual characteristics that typify highly creative people, including strong intrinsic motivation. However, the innovators may be fringe experts in so far as the innovation is concerned.
d) Activities as in the creative process: preparation, incubation, evaluation and elaboration.

These practices are needed because the invention quadrant is the one in which high levels of creativity are expected, so theories of creativity are especially relevant [78,79].

6.2. Exaptation strategy and practices

In the exaptation strategy a novel association is found between existing solution knowledge in one field and a challenging opportunity in another field. A relatively high level of creativity and associative thinking are required to generate the novel relationships between the existing knowledge and a new application. The important thing here is to conceptualize an association between the existing technology and some purpose that is different from what was originally envisaged. We want to find new niches for existing technologies in which connections are made between apparently disparate ideas, either from very creative individuals or from a group with diverse ideas. Specific techniques that could be used in this strategy include *crowd-sourcing*, *open-sourcing*, *out-of-the-box design thinking*, and *collaborative design* activities that allow connections between a technology (knowledge) and a new use for the technology.

Exaptation Practices:

a) Organizational attributes that include resources to encourage contributions of diverse ideas and connections between these ideas, for example, open innovation through crowdsourcing.
b) Collaborative teams with diversities in domain expertise and technical skill sets.
c) Individual characteristics that typify highly creative people, including strong intrinsic motivation in many cases.
d) Activities termed application discovery, where individuals, teams or groups are encouraged to generate ideas for re-purposing existing knowledge (e.g. brainstorming, ideation exercises).

These practices are suggested because the exaptation quadrant is the one in which knowledge and creativity across boundaries are expected, so theories of creativity [78,79], associative thinking [80], open innovation [81,82], and exaptation [83] are relevant.

6.3. Advancement strategy and practices

The advancement strategy is the one in which there is less than optimal solution knowledge for addressing a relatively well-understood problem. The goal is to achieve a significant advance on existing knowledge for solving a particular problem. People are needed who are experts with deep relevant domain knowledge. However, these experts may lie outside the organization. Methods for this strategy might include traditional research and development (R&D) activities either internal or external to the project organization. Many companies often prefer to 'buy in' R&D projects with promise rather than depending on innovation activities within organizational walls.

Advancement Practices:

a) Environmental factors such as access to important knowledge sources in the knowledge base, including the latest scientific research. What improvements will make a true difference in the current IT environment and how is that improvement measured?
b) Organizational attributes that include an open, innovative culture that allows experimentation and risk taking.
c) Research and development teams with collaborative, disciplined, and creative colleagues.
d) Individual characteristics that typify creative people, including strong intrinsic motivation. The innovators will require true expertise and in-depth domain knowledge to fully understand the current state of knowledge and envisage potential solutions that will make a difference.
e) Activities as in problem solving, with heuristic search for a solution taking place in a problem space, with actions such as experiments.

These practices are proposed because the advancement quadrant is the one in which theories of human problem solving [84] and new technologies [85] are highly relevant.

6.4. Exploitation strategy and practices

The exploitation strategy is the one in which there is mature solution knowledge for achieving a well-understood problem or opportunity. The goal then is to optimize the functioning of a state-of-the-art technology in a new application environment. The innovation is 'new-to-me' or 'new-to-us' rather than 'new-to-the-world.' Specific techniques that could be used in this strategy include *benchmarking* and *managerial scanning* (as in [57]). Benchmarking involves measuring and comparing the organization's operations, practices and performance against other organizations. It is a market-based management tool by which the firms identify the best practices that have produced superior results in other firms and replicate these practices to improve its own competitive advantage. [86–88].

Exploitation Practices:

a) Environmental factors such as competitor threats, customer and worldwide trends, and regulatory changes that supply an innovator with an opportunity that could lead to value-added advantages. A knowledge base is required from which the ideas behind the innovation can be retrieved and applied.

b) Organizational attributes that include senior management vision and organizational strategy.
c) Development teams that can apply cutting-edge technologies to interesting problems.
d) Individual characteristics that typify creative people in a professional role with expertise in the restructuring and redefining of the innovation to fit a new context, e.g. software engineering or change management expertise.
e) Activities as in the innovation appropriation process: agenda-setting, matching, redefining/restructuring, clarifying, and routinizing.

These practices are advanced because the exploitation quadrant is the one in which existing innovations are adopted, adapted and refined to suit a new context [57].

7. Preparatory workshop applying KIM

Before developing a new process model that integrates DSR with the four DI strategies, we gathered preliminary data on how the strategies resonated with innovation practitioners. Since the Knowledge-Innovation Matrix (KIM) is central to the new process model and is relatively new to the IT community [30], we determined that a practical demonstration of its usefulness was needed. Thus, we investigated its applicability in a workshop with 11 practicing entrepreneurs and consultants engaged on digital innovation projects (see Appendix A for more details of the workshop). The purpose of the workshop was to determine if professionals found the categories in KIM understandable, whether they could place innovation vignettes into the correct quadrant of KIM, and whether they believed such a categorization device could be useful in planning for digital innovation. Results showed that the categories were understandable and 70 % of the vignettes of innovation cases presented were classified in the quadrant regarded as the *best fit* by the experimenters. Where the cases were placed differently, the participants showed they had considered their choices and in many cases gave reasons for their placement.

A post-workshop survey showed that all respondents agreed that the workshop was useful and that it would change the way they thought about performing innovation in the future. Their comments indicated ways they believed they could use the KIM framework for defining entrepreneurial strategies in their organizations. For example, participants said that KIM concepts would help: 1) *As a way of understanding where innovation fits,* 2) *for setting a focus across all 4 quadrants,* 3) *for categorizing ideas in a more structured way,* and 4) *for designing solutions for the analysis of the problem and for prioritizing innovation projects.* To highlight the comments of one participant: "*KIM to me is a tool with great potential. It deals directly with the issue of how to use knowledge, essentially via a categorization, 'Knowledge in a build/delivery context'. This kind of says it is an agnostic tool.*" This comment shows recognition that the KIM framework is not approaching innovation in one specific way, but shows different strategic pathways to entrepreneurial activities.

8. A DSR-DI process model for digital innovation

Our proposed conceptual model for the process integration of DSR with digital innovation is grounded by the effectuation theories of entrepreneurship with the extant design science research process models and innovation concepts from the knowledge innovation matrix (KIM). The DSR-DI process model shown in Fig. 3 draws its environmental context from the current problem space and appropriates existing knowledge from the extant knowledge bases. The purpose of the new process model is to provide a sense-making device showing how different entrepreneurial roles and strategies guide the selection and application of different KIM design practices in rapid digital innovation cycles.

In the remainder of this section, we briefly describe the innovation activities found in the six stages of the DSR-DI cycle of Fig. 3. We highlight differences and commonalities between this new model and prior process models for DSR. There is an emphasis on the first three stages of the DI cycle, which correspond to the front-end of innovation (FEI). FEI encompasses the essential activities in the innovation process in which ideas are generated and evaluated before one or more selected ideas or prototypes continue on to the comparatively well-structured new product and process development (NPPD) activities.

FEI is receiving increased attention because of a perception that

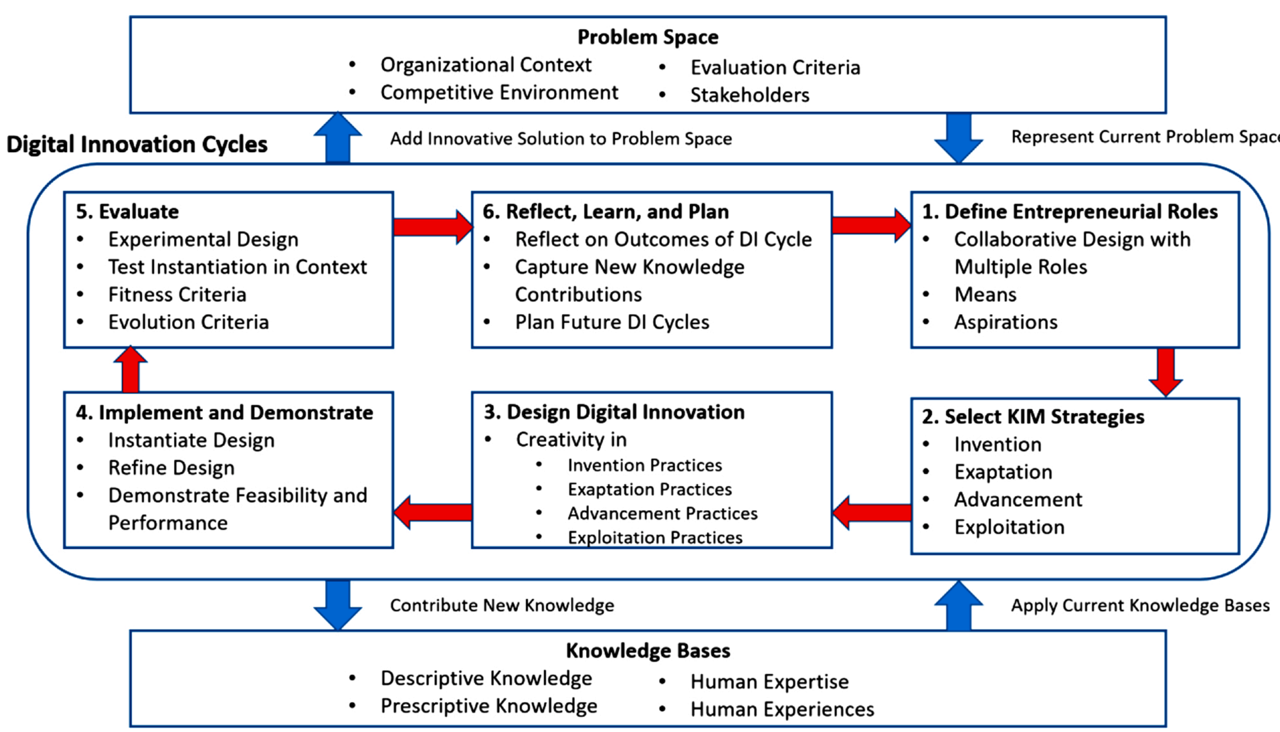

Fig. 3. The DSR-DI Process Model with KIM Strategies and Entrepreneurial Roles.

there is a lack of high-profit ideas entering NPPD [49,89]. Noting the lack of research into the FEI and believing that the FEI is not as mysterious as it has been portrayed; Koen et al. [90] developed a model for the FEI based on best practices in eight companies. However, the FEI is hardly studied at all in connection with DI. In addition, the FEI is comparatively atheoretical [91,92] and current innovation process models are not linked to the insights that can be gleaned from relevant underlying theories, including germane theories of creativity, knowledge, entrepreneurship, and design science research.

The activities of the six DSR-DI stages are briefly described as follows:

8.1. Define entrepreneurial roles

The starting point of an innovation cycle brings together the key entrepreneurial stakeholders with a recognition of the various stakeholder roles. The goal is to form a collaborative, high functioning entrepreneurial team with a full understanding of the means, aspirations, and capabilities that each role brings to the project. An innovation project *team* is "collaborative, diversely skilled, and idea-focused" [78]. Teams are more creative when the elements of cohesiveness and diversity among members are effectively balanced [93]. Entrepreneur roles involved in an innovation project will include application domain specialists, software engineers, data scientists, business managers, economists, venture capitalists, entrepreneurs, and various user groups, amongst others as co-designers.

The central research challenge regarding collaborative innovation and co-design is to understand how to assemble and support teams that interact effectively with one another to produce novel ideas and designs. To meet this challenge we must study how entrepreneurial minds work alone and together as they solve complex problems in creative ways with appropriate controls. Such research requires methods that reveal individual cognitions (e.g. neuroscience); the knowledge, skills and abilities that each individual brings to the team (e.g. survey measures); team interactions and representations (e.g. video and audio recordings of interactions, collection of models and other external representations); as well as ideation and design outcomes (e.g. design artifacts). This multilevel and multi-method approach has the potential to open up the black box on individual cognition along with the more traditional ways of investigating collaboration to draw a more complete picture of collaborative design [94].

Drawing from the theory of effectuation, the beginning of the innovation cycle will collectively assemble the means (resources) brought to the project by the involved entrepreneurial roles as well as the aspirations (desired results). The resources will allow detailed project planning activities to be performed for budgeting, staffing, and scheduling purposes for the current cycle. The collective aspirations will provide the material for the activities of project goal-setting in which criteria can be established for the evaluation of the ideas generated and innovation implementations produced later in the cycle. Risk assessments can be performed at this initial stage to determine if the project goals are appropriately matched by the project means to achieve those goals.

At this initial stage, a primary difference between the new DSR-DI model and existing process models for DSR is obvious. Prior models such as that of Peffers et al. [20] have "Identify Problem and Motivate" and "Define Objectives of a Solution" as their first activities, including possibly the definition of meta-requirements for a solution. The new model recognizes, drawing on effectuation logic, that entrepreneurial innovation can begin with the identification of possibilities and opportunities (the solution space), rather than focusing on identifying problems (the problem space). It frees up a team to envisage different ways of achieving innovation rather than tying them prematurely to a set of requirements that reflect a single view of a problem space.

8.2. Select KIM strategies

Once the entrepreneurial roles have been melded into a collaborative team with an understanding of project means and aspirations, the next stage of the DSR-DI process model involves representing the problem and solution spaces sufficiently to be able to select the most appropriate KIM entrepreneurial strategy. The team must represent the complex problem or opportunity in a format that can be understood and manipulated. Drawing from ideas of problem structuring and complexity, two categories of problem uncertainty can be identified:

- *Reducible Uncertainty* – The problem can be decomposed into subproblems that can be addressed independently via control techniques of learning, bounded scope, abstraction, rapid stakeholder feedback, and composition of solutions.
- *Irreducible Uncertainty* – The problem has no obvious decomposition and must be solved as a whole via control techniques like scenario generation, simulation, and risk reduction. However, big problems are often perceived to be irreducible because they are not well understood. The solution approach then must first attempt to gather more facts in order to better understand and represent the problem in a way to support decomposition.

Thus, the innovation team may react to complexity in the problem space in different ways. They may choose to decompose the system into subsystems, each of which then becomes the basis of its own innovation project. They may choose to approach the problem iteratively, using the repetitive innovation cycles that are typical of agile methods in software development. They may choose to reframe the problem entirely, perhaps using analogy to look at the problem space in an entirely different way. They may even simplify the whole problem by choosing to imitate another design.

Once a deep understanding of the problem is achieved, the team will select an entrepreneurial strategy based on the matrix quadrants. As discussed previously, the maturity of the problem space as captured in the problem representation will be matched with the maturity of potential solution options to identify which of the four matrix strategies will be most effectively applied in this innovation cycle. Here, again, the new model diverges from prior DSR process models that do not show a branch point where alternative design and development paths are envisaged, perhaps in tandem, from an early point in the process.

8.3. Design digital innovation

The execution of the selected entrepreneurial strategy is the stage of creating novel ideas and of reasoning in the choice of the best idea to move forward to implementation. According to Burkus [95, p. 15], "creativity is the starting point for all innovation" where creativity is defined as "the process of developing ideas that are both novel and useful" [96,97,78] posits that four components are necessary for a creative response:

- Domain-relevant skills include intelligence, expertise, knowledge, technical skills, and talent in the particular domain in which the innovator is working;
- Creativity-relevant processes include personality and cognitive characteristics that lend themselves to taking new perspectives on problems, such as independence, risk taking, self-discipline in generating ideas, and a tolerance for ambiguity.
- Intrinsic task motivation is seen as a central tenet. "People are most creative when they feel motivated primarily by the interest, enjoyment, satisfaction and challenge of the work itself – and not by extrinsic motivators."
- The social environment, the only external component, addresses the working conditions that support creative activity. Negative organizational settings harshly criticize new ideas, emphasize political

problems, stress the status quo, impose excessive time pressures, and support low-risk attitudes of top management. While positive organizational settings stimulate creativity with clear and compelling management visions, work teams with diverse skills working collaboratively, freedom to investigate ideas, and mechanisms for developing new ideas and norms of sharing ideas.

It is important to note that Amabile's work is based on two important assumptions. First, there is a continuum from relatively low, everyday levels of adaptive creativity to the higher levels of creativity found in significant inventions and scientific discoveries. Second, there are degrees of creativity exhibited in the work of any single individual at different points of time and circumstances [78].

Effective digital innovation requires more than just the generation of many creative ideas. Many creative individuals waste time, energy, and resources chasing infeasible and unprofitable hunches into blind alleys.[6] Successful innovation also requires the intellectual control to refine creative thinking into practical IT solutions. Such control is dependent on the cognitive skills of reason and judgment. Human reason reflects thinking in which plans are made, hypotheses are formed, and conclusions are drawn on the basis of evidence in the form of data, past experience, or knowledge [98]. While creativity often calls for divergent thinking to break out of mindsets; reason calls for convergent thinking to refine ideas into practical artifacts and actions. Moving design ideas from 'blue sky' to artifact instantiations requires goal setting. The goal setting activity in the initial stage of the DSR-DI process now comes into play as the criteria for ranking the creative ideas produced to address the problem into one design candidate to move forward into the implementation and evaluations stages.

The entrepreneurial practices for each of the KIM strategies, as presented previously, are drawn from theory and our observations of cases (e.g. [75]). With all innovations the individual characteristics and organizational conditions that allow human creativity and reason will be important for success. In particular to DI, access to pertinent technical domain knowledge bases and the latest technology trends along with free flow of knowledge among collaborators will also be important across all quadrants. This stage for the new DSR-DI model differs from comparable stages in prior models of DSR in its emphasis on creativity: for example in comparison with Peffers et al. [20] who place more emphasis on "knowledge of theory that can be brought to bear on a solution" (p. 55) and do not explicitly mention creativity.

8.4. Implement and demonstrate DI

The results of the previous three FEI stages produce candidate design artifacts as innovative IT solutions for the target problem space. The next DSR-DI stage instantiates and refines the design in order to address the following fundamental questions:

- *Can the design be demonstrated and is it feasible?* - Can the proposed design be implemented and does the proposed design provide a feasible problem solution?
- *Does the design have value?* - Does the design offer benefits unmatched by competing candidate designs?
- *How can the design be most effectively represented and communicated?* – How can we best communicate the intricacies of the design to collaborators, implementers (e.g., architects, programmers), and other stakeholders?
- *How best to construct the actual use artifacts?* How do we guide the construction and operation of the use artifact in the problem space?
- *How can we demonstrate the utility of the design artifact before its implementation into the problem space?* Can we model the problem context adequately in order to demonstrate that the innovative solution will work in the real application context?

The initial implementation and demonstration of the chosen design could be performed in a controlled 'lab' environment. Such formative experiments will provide answers to the above questions. During these rapid build and evaluate cycles, the design will be refined in preparation for more extensive testing in the problem space environment. This stage of the DSR-DI model does not differ markedly from DSR models that see a variety of means for demonstrating an idea works; for example, experimentation, simulation, case study, or proof.

8.5. Evaluate DI

The evaluation of the DI design in the actual problem application context is a critical stage. The in situ evaluations provide crucial evidence that an important impact will be made from the intervention of the DI design into the problem space with clear evidence generated to determine the success or failure of the entrepreneurial project. We note that not all projects have the opportunity to test the new design artifacts in realistic environments. In those cases, opportunities for extensive evaluations in artificial environments should be considered (e.g. simulation) [99].

We propose that two distinct types of design fitness evaluations should be performed in an entrepreneurial project. These two forms of summative evaluation will demand a focus on very different measures of goodness as discussed in Gill and Hevner [100].

- *Fitness for Use* evaluation assesses the ability of the design artifact to perform in the current application context with the current set of goals in the problem space. This is the most common type of summative DI evaluation.
- *Fitness for Evolution* evaluation assesses the ability of the DI design artifact to adapt to changes in the problem space over time. This type of evaluation is critical for application environments in which rapid technology or human interaction changes are inevitable and the design artifact must evolve successfully.

We note that existing models of DSR show a range of means for evaluation, as in Peffers et al. [20]. However, the DSR-DI process explicitly requires the researchers to develop evaluation methods for the specific matrix quadrant of the digital innovation.

8.6. Reflect, learn, and plan

The final stage of the DSR-DI process is the team's activities to reflect on the completed innovation cycle, to capture lessons learned, and to plan for future digital innovation cycles. In line with the goals of DSR, and as shown in other DSR models (e.g. [20,101]), this is the stage in which new knowledge contributions are made to the prescriptive and descriptive knowledge bases of the project and the broader knowledge bases of the scientific communities [21]. Finally, the entrepreneurial team will decide if further DI cycles are needed; either to complete the goals of the current project or to follow up the success (or failure) of the current cycle with new entrepreneurial goals.

9. Discussion and conclusions

This research essay provides several important contributions to a clearer understanding of digital innovation (DI) and the use of ambidextrous entrepreneurship in organizational DI portfolios. To begin, we position DI appropriately as a result of design science research (DSR) in information systems. This positioning addresses an important gap in understanding the relationship between DI and DSR in the IS field [16].

[6] A student once asked Linus Pauling, "Dr. Pauling, how does one go about having good ideas?" He replied, "You have lots of ideas and throw away the bad ones." ([79], p. 116).

We then draw from the entrepreneurial theory of effectuation [42] to ground the emergent development of DI artifacts to design and build sociotechnical systems [18,19] for the solution of complex and interesting problems.

The knowledge innovation matrix (KIM) from DSR provides a novel approach for identifying richer categories of DI ambidextrous entrepreneurship. The four entrepreneurial strategies of (1) invention; (2) exaptation; (3) advancement; and (4) exploitation support richer opportunities for organizational DI. Corresponding practices for each of these strategies are described and analyzed. Finally, a novel DSR-DI process model is proposed. The model includes the phases of: (1) define entrepreneurial roles; (2) select KIM strategies; (3) design digital innovation; (4) implement and demonstrate; (5) evaluate; and (6) reflect, learn, and plan.

The DSR-DI process model shows that, although some design activities such as ideation occur across all quadrants, some activities are more likely to be associated with one entrepreneurial strategy in the knowledge-innovation matrix than others. Thus, we advance the following conjectures:

- Innovations in the *invention* quadrant will be associated with creative processes within an individual or group that are facilitated by conditions such as free time for thinking, tinkering and experimenting outside normal duties, deep knowledge of new technologies, and opportunities to pursue bold ideas in R&D.
- Innovations in the *exaptation* quadrant will be associated with design activities that allow the identification of new user needs that can be met by an existing technology, such as collaborative design and design thinking that involve end users as well as designers. Interdisciplinary collaborative teams provide diverse backgrounds and views in this quadrant. These activities may occur in relatively short cycles.
- Innovations in the *advancement* quadrant require individuals with in-depth expertise related to the problem area, knowledge of novel technology advances, and experience with traditional R&D-type activities.
- Innovations in the *exploitation* quadrant require recognition that existing technologies could be adopted or appropriated with some redesign by an organization or individual. Scanning and benchmarking activities are useful.

The research essay has theoretical significance as it adds to theory on portfolio approaches to digital innovation, building on foundations in design science research (e.g. KIM), prior exploratory studies of design activities (e.g. [29]), entrepreneurial effectuation theory (e.g. [42]), and creativity theories (e.g. [92]).

The practical significance of the research arises as the new DSR-DI process model provides a common 'language' or viewpoint for entrepreneurial stakeholders from diverse backgrounds, as demonstrated in the workshop results in the understanding of the KIM quadrants. The entrepreneurial strategies provide actionable practice guidelines that can be implemented in innovation projects. As with any set of general guidelines, however, we note that the differing innovation strategies in the model should not be expected to hold too strictly. Any specific innovation project is likely to involve a number of DSR-DI cycles of creative insight, application discovery, problem solving, and artifact appropriation. Thus, the project may move among different strategies over time. What the practice guidelines illustrate is what is expected at a general level, showing archetypes of behavior for the different strategies. In fact, the 'menu' of innovation activities that are depicted may suggest possibilities to project leaders, rather than blindly following familiar patterns, such as brainstorming or benchmarking. DI leaders can map innovation practice in their organization and see if there are gaps and opportunities for doing things differently.

As future research, we suggest deeper investigations into the different entrepreneurial roles for key DI stakeholders. In particular, a better understanding of how government, industry, and academia interact in the *triple helix* model of economic and social innovations [102]. Approximately two-thirds of leading innovations in recent years are estimated to have come from collaborative partnerships involving academia, business, and government, including government funded labs and university research [103,104]. Governmental actions, such as providing funding for academic research or industrial innovations (e.g. clean energy), have the goal of encouraging and enabling a dynamic innovation culture and economy [105]. These collaborative research ventures should yield dual outcomes, with both: (1) digital innovations in terms of products and processes with real-world impacts outside the development environment; and (2) formal knowledge production for future evolution in the innovation field. In this way, we extend the insights of Stokes [106] for basic science and technological innovation.

Our current study has limitations. We recognize that the landscape of digital innovation is huge and there are other entrepreneurial roles and strategies that we have not been able to cover adequately in this essay. The results of our experimental workshop provides only an initial 'proof of concept' of the four entrepreneurial strategies. We expect future DI case studies will expand the boundaries of our initial directions as presented here.

In conclusion, the new DSR-DI process model provides exciting opportunities for much future study. The potential impacts of the multiple entrepreneurial roles and strategies can be tested empirically in business and industry DI case studies and the theoretical DSR-DI model expanded to encompass additional roles and strategies. Work can also be done to investigate how organizations can use the DSR-DI model so as to behave ambidextrously, being involved in all four entrepreneurial strategies - invention, exaptation, advancement, and exploitation - at the same time. It has been shown that firms that can balance these activities well are nine times more likely to achieve breakthrough products and processes than others, even while sustaining their existing business [25].

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Alan Hevner: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration. **Shirley Gregor:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration.

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Appendix A

KIM evaluation with innovation practitioners

A proof of concept experiment on identifying the four entrepreneurial strategies is provided by a recent workshop, where the topic chosen as a focus of DI was the design of 'nudges' as practiced in behavioral insight teams in government. A nudge is a method for predictably altering behavior without restricting consumer choice options or significantly changing incentives. Nudges work by leveraging human biases and default human behaviors such as the tendency to take the path of least resistance [107]. The design and development of digital nudges in government applications is a good example of a situation where people with many different backgrounds need to engage in entrepreneurial endeavors. The concept of nudges arise in behavioral economics [108]. Behavioral insight teams in government include DI stakeholders with backgrounds in economics, government, psychology, and information technology, amongst others.

Participants

There were 11 participants in the workshop, all of whom had some exposure to the use of nudges either through their employment in a government department, consultancy employed by government, or as a research topic. Demographic information provided in the pre-workshop survey was as follows: gender (7 male, 4 female); sector (7 private sector, 3 public sector, 1 academic); and work roles (2 management, 1 analyst, 1 administration, 2 R&D, 1 management consulting, 1 strategy, 1 product development, 1 sales, 1 solutions). All participants responded that innovation was an important part of their role. When questioned whether they had used any type of innovation tool before to assist in designing nudges, nine responded in the negative and two said they had used 'design thinking.'

Procedure

After an introduction to the KIM typology and an overview of digital and non-digital nudges, participants were coached through a series of exercises and activities using KIM as an entrepreneurial framework for the design of behavioral nudges. The workshop was facilitated by a consultant qualified in using design thinking techniques and took approximately two hours for the activities described here. Participants were asked to fill in a pre-workshop questionnaire asking for demographic data and a post-workshop questionnaire asking for evaluative responses.

Two primary exercises were undertaken by participants: a sorting exercise in which they were asked to classify 6 cases of nudges as entrepreneurial strategies and an ideation exercise in which they explored ways that the KIM matrix could be used further in nudge design innovation. The sorting exercise followed a procedure similar to the closed card sorting method used in human-computer interaction [109]. Participants were given a short written description of six case studies and were asked to classify each one in turn in terms of the KIM quadrants, writing their responses on a personal answer sheet. They could discuss each case with others in their small group and could write clarifying information following their own answer. They were told that there were no right or wrong answers. The cases were selected for realism and to stimulate ideas. The participants were aware that not all cases fitted unambiguously into a specific quadrant.

Materials

The six cases provided, in random order, were:

Case 1:(Invention) Visualizing data with the first coxcomb diagrams[7]

Case 2:(Exaptation) SMS reminders for income reporting[8] ;

Case 3:(Exaptation) Suicide deterrence through use of blister packs for paracetemol[9]

Case 4:(Advancement) Simplified form of energy fact sheets to help consumers make better choices[10] .

Case 5:(Advancement) Investigating drivers' understanding of transport infrastructure concepts with a driving simulator in road infrastructure design[11]

Case 6:(Exploitation) UK adoption of plain tobacco packaging laws after successful use in Australia[12] .

Case 3 is presented as an example at the end of this appendix.

Results

For the categorization exercise, 70 % of cases were classified in the quadrant regarded as the *best fit* by the experimenters. Where the cases were placed differently, the participants showed they had considered the choices and in many cases gave reasons for their placement. For example, the tobacco plain packaging was classed by the experimenters to be 'exploitation', but one respondent classed it as 'advancement'; commenting on "iterative advancement in disincentivising customers from purchasing cigarettes." Following Case 3 below are participants' reasoning for the categorization for Case 3 as 'exaptation'.

The post- workshop survey showed that all respondents agreed that the workshop was useful and that it would change the way they thought about performing innovation in the future. Their comments indicated ways they believed they could use the KIM framework for entrepreneurial strategies. Consider the following comments:

- *As a way of understanding where innovation fits*
- *Challenge the fundamentals of nudge by setting a focus across all 4 quadrants*
- *Significant and desirable tool in application of strategy*
- *By categorizing ideas in a more structured way*
- *Perhaps in designing solutions rather than nudges. Analysis of the problem and category/classification of priority of works.*

One participant commented: The KIM to me is a tool with great potential. It deals directly with the issue of how to use knowledge, essentially via a categorization, 'Knowledge in a build/delivery context'. This kind of says it is an agnostic tool. This comment shows recognition that the KIM framework is not approaching innovation in one specific way, but shows different strategic pathways to entrepreneurial activities.

Example: Case 3 - Small Barriers to Deter Suicide[13] .

Case description supplied to workshop participants.

Background

Paracetamol overdose is a common method of suicide and non-fatal self-harm worldwide. Suicidal behavior is often impulsive and people tend to use drugs already available in their homes. People are also more likely to consume more than 25 tablets, the amount associated with acute liver dysfunction, when they are in a loose pack instead of a blister pack.

The project

In 1998, the UK changed the laws on paracetamol packaging so that the drug could not be sold loose in large containers. The packs were restricted to blister packs with a maximum of 32 tablets in pharmacies and 16 tablets elsewhere. In addition, multiple packs could not be bought at the same shop. The change in legislation presented only a small barrier because people could still buy packs at multiple outlets if they wanted to.

Results

These small barriers ('friction costs') led to an estimated 43 percent

7 Lienhard, J. https://www.uh.edu/engines/epi1712.htm

8 https://www.pmc.gov.au/domestic-policy/behavioural-economics/effective-use-sms-encourage-timely-reporting-behaviour-using-digital-channels

9 Hallsworth et al. (2016). Applying Behavioural Insights Simple Ways to Improve Health Outcome. https://www.imperial.ac.uk/media/imperial-college/institute-of-global-health_innovation/Behavioral_Insights_Report-(1).pdf

10 https://www.pmc.gov.au/domestic-policy/behavioural-economics/simplifying-energy-fact-sheets-improve-consumer-understanding

11 Lourenco, J. et al. (2016). Behavioural insights applied to policy. European Report. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/behavioural-insights-applied-policy-european-report-2016

12 Gallopel-Morvan, K. http://www.fctc.org/fca-media/opinion-pieces/1409-studies-show-that-plain-packaging-of-tobacco-works

13 Hallsworth et al. (2016). Applying Behavioural Insights Simple Ways to Improve Health Outcome. https://www.imperial.ac.uk/media/imperial-college/institute-of-global-health-innovation/Behavioral_Insights_Report-(1).pdf

reduction in suicides in the 11 years following the legislation – that's 765 fewer deaths; 990 including accidental poisonings. There was also a 61 percent reduction in registrations for liver transplants caused by paracetamol poisoning.

Conclusion

Decreasing ease of access to large amounts of painkillers may be a successful way to decrease suicide rates. Evidence suggests that people do not find another route for suicide when faced with these kind of costs, but rather discontinue the attempt altogether.

Outcome of classification exercise

Ten of eleven (91 %) respondents classified this case as "exaptation", which was the expected response. Comments provided were:

- *Blister packs already invented - not invention then*
- *Re-purpose delivery mechanism. A known problem/ a solution that has been repurposed.*
- *Taking a solution that was already in place and realizing that its use in another way can have an impact elsewhere.*
- *Good example of extended use of an existing product.*
- *Known solution applied for a new purpose.*
- *The packaging might be in use for other medicine and then adopted to make it harder in this case.*

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Alan R. Hevner (ahevner@usf.edu) is a Distinguished University Professor and Eminent Scholar in the School of Information Systems and Management in the Muma College of Business at the University of South Florida. He holds the Citigroup/Hidden River Chair of Distributed Technology. Dr. Hevner's areas of research interest include design science research, information systems development, software engineering, distributed database systems, healthcare systems, and Internet of Things computing. He has published over 250 research papers on these topics and has consulted for a number of Fortune 500 companies. Dr. Hevner received a pH.D. in Computer Science from Purdue University. He has held faculty positions at the University of Maryland and the University of Minnesota. Dr. Hevner is a Fellow of the American Association for the Advancement of Science (AAAS), a Fellow of the Association for Information Systems (AIS), and a Fellow of IEEE. He is a member of ACM and INFORMS. Additional honors include selection as a Parnas Fellow at Lero, the Irish software research center, a Schoeller Senior Fellow at Friedrich Alexander University in Germany, and a recipient of the Design Science Research Lifetime Achievement Award. From 2006–2009, he served as a program manager at the U.S. National Science Foundation (NSF) in the Computer and Information Science and Engineering (CISE) Directorate.

Shirley Gregor (shirley.gregor@anu.edu.au) is a professor of Information Systems in the College of Business and Economics (CBE) at the Australian National University and a director of the National Centre for Information Systems Research. Her current research interests include intelligent systems, human-computer interaction, the innovative and strategic use of information and communications technologies, and the philosophy of science and technology. Dr Gregor has led several large applied research projects funded by bodies including the Australian Research Council and AusAID. She has published in outlets such as *MIS Quarterly, Journal of Management Information Systems, Journal of the Association of Information Systems, European Journal of Information Systems* and *Information Technology & People*. She was a senior editor for *MIS Quarterly* 2008–2010 and was editor in chief for the *Journal of the Association of Information Systems* from 2010 to 2013. Professor Gregor was made an officer of the Order of Australia in June 2005. She is a fellow of the Australian Computer Society and a fellow of the Association for Information Systems. In 2014 she was awarded a Schöller Senior Fellowship at the Friedrich Alexander University of Erlangen-Nurenberg and in 2017 she received the Design Science Research Lifetime Achievement Award.