Bridging analog and digital expertise: Cross-domain collaboration and boundary-spanning tools in the creation of digital innovation

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\begin{abstract}
Expertise in digital technologies is necessary, but rarely sufficient to generate digital innovation. The purpose of this paper is to explore how specialists rooted in digital and analog knowledge domains engage in cross-domain collaboration to jointly create digital innovation. Our analysis cross-examines the literature on knowledge integration and coordination by examining the role of boundary-spanning tools in fusing divergent types of knowledge. The empirical setting for our study is the development of digital serious games, a novel breed of digital learning products whose creation involves a wide range of gaming/digital and learning/analog expertise. Drawing on an in-depth qualitative study, we find that boundary-spanning tools such as prototypes, mockups, and whiteboards serve as important knowledge bridges buttressing the overall innovation process, enabling diverse experts to increasingly align and integrate their divergent thought worlds and knowledge domains. Furthermore, we find that the alternative interplay among digital and non-digital tools supports the gradual transformation of digital and analog expertise into a novel digital format. Taken together, our results explicate how boundary-spanning tools facilitate collaborative work among specialists rooted in diverse digital and non-digital knowledge domains. Our findings contribute to the literature on knowledge integration and coordination in cross-domain collaboration and digital innovation.
\end{abstract}

\section{Introduction}

Collaborating across established professional, cognitive, technological and social boundaries and integrating diverse streams of knowledge is challenging, but it is often a prerequisite for the development of innovative products and services (Leonard, 1995; Carlile, 2004). This notion seems particularly true for digital innovation. Over the past decades, the pervasive use of digital technologies and progressive efforts at digitization have sparked a novel generation of products, services, and platforms. Digital innovation has started to permeate all spheres of social and economic life, ranging from sports watches that track activity levels (e.g., Fitbit Smartwatch), to retail and entertainment platforms (e.g., Amazon, Netflix, Spotify), to online health and transportation services (e.g., IBM Watson Health, Uber). While “digital technologies and associated digitizing processes form an innate part” (Nambsian et al., 2017, p. 224) of digital innovation, the increasingly digitized world poses novel challenges for understanding how to organize for innovation (Yoo et al., 2012). Both organizational innovation processes, as well as outcomes, have become less bounded, more permeable, and more complex as they cut across traditional industry boundaries, blur knowledge domains, and involve heterogeneous actors with diverse goals, capabilities, and expertise (Dougherty and Dunne, 2012; Nambsian, 2017; Porter and Heppelmann, 2014). In fact, to develop digital innovations, digital expertise is important; however, the integration of digital expertise with a set of analog (i.e., non-digital) areas of specialized knowledge is necessary. This may include business and market knowledge, expertise from science and engineering, medicine, psychology, architecture, culture, music, and the arts, as well as many other domains of knowledge. Hence, the development of digital innovation consequently involves cross-domain collaboration, that is, collaborative work among people of differential domains of expertise with the goal of aligning and integrating their specialized contributions to jointly accomplish a novel task (Bruns, 2013).
In this paper, we explore how specialists rooted in digital and analog\(^1\) knowledge domains engage in cross-domain collaboration to jointly create digital innovation. First, the integration of diverse domains of knowledge is highly challenging. Independent of the contexts studied, researchers have reported challenges and conflicts as experts from various knowledge domains try to work together, including hindered communication, competition over resources, power struggles, and disproportionate focus on own areas of expertise and priorities (e.g., Bechky, 2003a; Siedlok and Hibbert, 2014). The underlying reason for such tensions is rooted in the divergent “thought worlds”, shared cognitive models and understandings that are deeply intertwined with a specific knowledge domain and that define experts’ schemes of interpretation, how to filter incoming information, and engage in methods, practices, and work approaches (Dougherty, 1992; Fay et al., 2006). Second, digital innovation is not only highly complex in nature, it also rapidly influences our social and professional lives. Research has yet to illuminate the extensive, collaborative efforts that generate their making.

Theoretically, our analysis builds on and extends the literature on knowledge integration and coordination. Common to the innovation management literature is the concept of knowledge integration (Tell et al., 2017). The principal issue addressed in this literature is the integration of differential and specialized knowledge to realize a collective performance. Concerned with the same topic, organizational scholars refer to the concept of coordination (Okhuysen and Bechky, 2009; Faraj and Xiao, 2006). Despite the common emphasis, work in the tradition of knowledge integration has largely focused on the managerial and planned efforts and activities in processes of knowledge integration, such as how management can reduce the challenges involved in handling diversity in teams (Carlile, 2004; Siedlok et al., 2015). In contrast, the literature on coordination explores the everyday practices and tools that emerge “on the ground” and are employed by practitioners to accomplish collective and interdependent work. Specifically, existing research has highlighted that technological and material artifacts are important tools of coordination and boundary-spanning that require further unpacking (Bechky, 2003b; Nicolini et al., 2012; Star and Griesemer, 1989).

Much of the literature on boundary-spanning tools has studied one particular object or artifact, often in the context of science (e.g., Bruns, 2013; Dougherty and Dunne, 2012; Kaplan et al., 2017). We thus have a limited understanding of the assembly as well as interplay of different types of boundary-spanning tools that help practitioners overcome challenges related to divergent thought worlds and fusing differential domains of knowledge into a joint outcome. Such a focus seems critical because simply “putting people together” does not automatically generate productive outcomes and innovative accomplishments. Hence, we ask the following questions: How do diverse specialists engage in collaborative work and combine their digital and non-digital knowledge domains to jointly create digital innovation? What are the boundary-spanning tools they mobilize to overcome cognitive differences, and how do these tools interplay across an unfolding innovation process?

We examine these questions by drawing on a nested case study of the product development of digital serious games. Serious games are a new breed of digital learning products that are applied in settings such as healthcare, school and university education, and corporate training. Designing serious games involves the integration of a wide range of digital (game design, programming, graphics, etc.) and non-digital expertise (education, learning assessment, business development).

Drawing on a rich set of qualitative data, we find that working across and integrating these two broad knowledge domains and associated thought worlds results in tensions that become particularly visible in conflicting product concepts. To cope with these challenges, the digital/gaming and non-digital/learning experts follow an iterative innovation process consisting of several activities, including ideation, prototyping, and testing that lend a certain routine to the collective endeavor. Along this process, the various participants share and develop a set of boundary-spanning tools consisting of digital (e.g., mockups, wireframes, game design documentation) and non-digital tools (e.g., paper prototypes, whiteboards, clay sculptures). We find that these tools serve as knowledge bridges buttressing the overall innovation process. First, the tools mediate the various design activities and enable their joint enactment. Second, they serve as temporary knowledge storage as they become critical intermediary products themselves, enabling the various experts to increasingly balance and fuse their divergent contributions into a final product. We also observe an alternating interplay between digital and non-digital tools along the overall innovation process that supports, as we argue, the gradual transformation of digital and analog expertise into a novel digital format. While analog tools enable more open-ended innovation activities, digital tools are tools of convergence supporting the unfolding transition of an emerging game idea into its digital format.

Our results make important contributions to the literature. First, by introducing the concept of knowledge bridges to the literature on knowledge integration and coordination, our study can be considered an important step towards reconciling the two literatures, responding to recent quests to develop “a more general theory of coordination/integration within and between organizations” (Grant, 2017, p. 8). Second, by accounting for both the assemblage and interplay of diverse boundary-spanning tools in cross-domain collaboration, we specifically offer a dynamic and relational approach to the literature on coordination (Nicolini et al., 2012). Last, by unpacking the boundary-spanning tools that assist in the synthesis of digital and analog expertise in the context of digital serious games, we contribute to the emerging literature on digital innovation by providing further evidence of the dynamic and interdependent nature of innovation processes and outcomes in the digital era.

2. Theoretical Orientation

2.1. Cross-domain collaboration: innovation potential and challenges

Research on innovation highlights that novelty often occurs at the boundaries between divergent social, cognitive, technological and professional domains. Creatively combining and recombinining diverse sets of knowledge can prompt the emergence of novel ideas, services, and products. From the earliest studies of innovation, the ability to combine and connect different but complementary knowledge has been considered a key driver of innovation. In the literature, this widespread phenomenon is discussed referring to concepts such as recombiniation (Schumpeter, 1939) and convergence (Lee and Olson, 2016) highlighting the great potential for innovation being catalyzed at the interfaces of distinct knowledge domains. Examples include the convergence of construction and information technology resulting in the creation of intelligent buildings (Hacklin, 2007), functional food developed through recombination from the life sciences and food production (Hacklin, 2007), and autonomous vehicles emerging at the intersection of cutting-edge sensor technology and automobile manufacturing.

While the literature on recombination and convergence aims to explain why innovation is likely to arise at the intersection of divergent knowledge domains, the literature on cross-domain collaboration, with similar emphasis on the fruitfulness of blending different domains of expertise, focuses on the organizational and team level dynamics involved in such processes. Specifically, research on cross-domain collaboration highlights the difficulties and tensions involved in collaborating across diverse knowledge domains (i.e., area of specialized

\(1\) We refer to analog knowledge domains as a digital expertise counterpart. Analog expertise relates to expertise that does not involve the use of computer or digital technology. We use the terms ‘analog’ and ‘non-digital’ interchangeably.
expertise) (Okhuysen and Eisenhardt, 2002; Majchrzak et al., 2012; Mengis et al., 2018).

One major problem is that specialists possess complex, ambiguous and tacit knowledge, which cannot simply be transmitted. Rather, integrating knowledge across divergent boundaries requires the development of mutual understanding. Such a process not only involves knowledge transfer but also knowledge translation and transformation (Carlile, 2004). However, experts tend to incarnate distinct systems of meanings and beliefs, values, and prescriptions related to their professional community. Each knowledge domain comprises certain career paths and a specific system of professional recognition (Kaplan et al., 2017), which directly links experts’ self-esteem and identity to their professional work (Kellogg, 2014). This renders communication and collaborative efforts highly challenging among multiple specialists possessing distinct domains of knowledge.

Dougherty (1992) attributes this phenomenon to differences in “thought worlds” defined as “a community of persons engaged in a certain domain of activity who have a shared understanding about that activity” (p. 182). While a thought world relating to a certain area of specialty is internally coherent, differences among various thought worlds create a lack of common ground and further the cognitive gap and knowledge fault lines between distinct groups of specialists who “not only know different things but also know things differently” (Dougherty and Dunne, 2012, p. 1470). Indeed, differences in mental models imply selective filtering of incoming information, diverse views and schemes of interpretation, incompatible methods and work practices, and unique approaches to product design (Fay et al., 2006; Dougherty, 1992). When experts from distinct knowledge domains collaborate, they often judge the ideas of one another as less valuable, or try to reconfigure and discard them, even though these ideas might be crucial for successful task accomplishment (Dougherty, 1992). Conflicting goals and priorities, competition over resources and responsibilities, and lack of motivation for cooperation are issues that reflect differences in thought worlds (Holland et al., 2000). Moreover, professionals tend to develop their own specialized language and vocabulary, making it difficult for others to decipher (Edmondson and Nembhard, 2009).

2.2. Knowledge integration and coordination across knowledge domains

Handling such challenges is key for cross-domain collaboration. A rich body of literature rooted in multiple theoretical strands addresses how people navigate across domains to integrate specialized and diverse knowledge, resulting in various definitions, concepts and labels as well as theoretical foci and empirical applications. Scholars of innovation and management, as well as organizational sociologists, have produced a vibrant literature. Common to the innovation management literature is the concept of knowledge integration, rooted in the knowledge-based theory of the firm (Grant, 1996a). The principal issue addressed by this body of literature is the integration of differential and specialized knowledge to perform a novel productive task. Okhuysen and Eisenhardt (2002) define the process of knowledge integration as the sharing and combining of individual expertise within a group to create new knowledge (p. 371). Differently labeled, organizational sociologists join the scholarly conversation by referring to the concept of coordination, the integration of a set of interdependent and specialized tasks to realize a collective performance (Okhuysen and Bechky, 2009; Faraj and Xiao, 2006).

Regarding the common concern of how diverse experts can pull their specializations together to accomplish a collective task, the two literatures focus on different aspects of this issue. Work in the tradition of knowledge integration and innovation management has largely focused on the organizational and managerial aspects that are related to how specialized and dispersed knowledge can be fused to successfully innovate (Tell et al., 2017). Efficient knowledge integration across boundaries is considered crucial in providing the organization with a competitive advantage in the development of new products, services, and systems (Grant, 1996b). For instance, research has investigated the management practices and formal organizational structures and strategies that can be planned and designed to manage the problem of knowledge integration in cross-domain collaboration. Considerable work has focused on governance structures and managerial practices, roles, rules, and responsibilities that assist in bridging knowledge across boundaries (e.g., Grant, 1996a; Ravasi and Verona, 2001). Others have studied structural organizational support mechanisms, ranging from the setup of cross-functional teams (Nonaka, 1994) to supporting tasks and activities, including formal meetings and prototyping (Clark et al., 1991).

While this body of literature has attended to management and how to foster “effective” knowledge integration, it largely fails to account for the more unconscious aspects involved in processes of knowledge integration. In contrast, the literature on coordination pays closer attention to such micro dynamics of organizing. The bulk of this literature has investigated the emergent practices and forms of interaction among the experts themselves as they attempt to pull together their diverse contributions (Okhuysen and Bechky, 2009). Inspired by ethnographic and science studies, work in this tradition has highlighted the important role of objects as well as technological and material devices in facilitating collaboration on the ground (Bechky, 2003b; Nicolini et al., 2008; Star and Griesemer, 1989).

Research in the context of scientific and technical collaborations has demonstrated that specialists rely on ‘boundary’ or ‘epistemic’ objects serving as bridges across intersecting social and professional worlds. Such objects take different forms; they may be material or immaterial. For instance, in their study of the development of a zoology museum, Star and Griesemer (1989) cast light on the role of methods standardization as boundary objects in enabling collaboration between two different social worlds, amateurs and professionals, by being flexible enough to align divergent interests. Investigating a semiconductor equipment manufacturing company, Bechky (2003b) shows how engineering drawings and machines were used to share knowledge and transgress divergent occupational communities. Other examples include telescope (Knorr Cetina, 1997) and bioreactor (Nicolini et al., 2008; Mengis et al., 2018). Taken together, these studies suggest that different types of artifacts can be mobilized as boundary-spanning tools to bridge analog and digital knowledge in collaborative work across distinct knowledge domains and thought worlds.

We aim at to advance research on cross-domain collaboration in the context of digital innovation by cross-examining the literature on knowledge integration and coordination. We do so by examining the role of boundary-spanning tools as knowledge bridges integrating analog and digital domains of expertise (Cohen and Tripsas, 2018) during the joint development of innovation. Much of the literature on boundary-spanning tools has focused on collaborative work, particularly in the context of science (Brus, 2013; Dougherty and Dunne, 2012; Kaplan et al., 2017; Knorr Cetina, 1997) and narrowly centered on a particular tool. However, recent literature has emphasized a more holistic approach accounting for the role of different types of tools in supporting innovation efforts (Nicolini et al., 2012). We seek to advance current theorizing by focusing on both the assemblage as well as interplay of different types of boundary-spanning tools that are being mobilized along a collaborative innovation process. Such a focus is particularly relevant in the context of digital innovation as increased digitization is not only radically enhancing the complexity of the available products and services but also poses new challenges for collaborative work among specialists rooted in digital and analog strands of knowledge (Dougherty and Dunne, 2012; Lyttinen et al., 2016; Yoo et al., 2012).
3. Methodology

3.1. Empirical setting

Serious games are a new breed of digital learning products seeking to educate through digital entertainment by transforming “intellectual hard work” into play (Graesser et al., 2009, p. 83). The wave of development of digital serious games began to take shape in 2002, when the U.S. Army published the serious game “America’s Army” to train strategic communication and recruitment (Djaouti et al., 2011). The market for serious games is growing rapidly, with estimations to reach around USD 5,500 million by 2020 (Jaramillo-Alcázar and Luján-Mora, 2017). While IBM and Microsoft are among the biggest producers, most serious games are being developed by startups and young project-organizations.

Investigating the development of serious games provides us with an ideal setting. First, serious games are complex digital innovations whose creation takes months and involves intense collaboration among experts from digital and non-digital knowledge domains. The digital experts include game designers, programmers, digital artists and graphic designers, and non-digital expertise is represented by educators and subject matter experts (like math, history, languages), specialists in learning assessment, and marketing and business developers. Second, the involvement of both digital and non-digital experts implies the presence of cognitive differences. This conflict becomes highly evident in the early product development phase, in which the main struggle is to conceptualize a product that is simultaneously an entertaining digital game and an effective learning tool – two agendas that often clash among the involved experts given their respective expertise and thought worlds.

The literature on serious games underscores this discrepancy by presenting the development of serious games as the fusion of two divergent agendas. For instance, Lelardeux et al. (2013, p. 24) suggest the following “formula” for serious games: “Utilitarian scenario + gaming scenario = > serious game”. While the latter implies entertainment, pleasure, and fun for the consumer – the fulfillment of the digital gaming agenda – the former encompasses more utilitarian goals such as the adequate transfer of learning content, proper learning assessment of predefined learning outcomes, and business development (Michael and Chen, 2005). Widespread discussions on how to best integrate the knowledge of the involved digital and non-digital experts are especially palpable at the early stage of game development when the concept of the game is being shaped, a phase usually referred to as “greenlighting”. Therefore, our analysis predominantly concentrates on this stage in the development of games.

3.2. Research design, data collection and analysis

Given our research questions that focus on how diverse specialists collaborate and integrate knowledge to develop innovative products and the tools they mobilize to accomplish this task, we chose a qualitative research design. Specifically, we used a nested case study approach (Thomas, 2011), in which findings that emerge from several units are integrated and made sense of in a holistic manner. The case we chose to study is the development of serious games, seen through the eyes of the game developers involved in such processes.

The nested case study approach differs from a comparative case study, for which the aim is to compare across multiple units, to shed light on key similarities and differences and to generate theory (Yin, 2009; Eisenhardt and Graebner, 2007). It also differs from a process-oriented case study, in which critical events are identified and analyzed over time (Poole et al., 2000). Our goal was to compare neither how different serious game organizations work nor how the game development process evolves over time. Rather, our aim was to develop comprehensive empirical insights about the collaborative practices and challenges surrounding the creation of serious games, which required data and insights from multiple organizations and game development processes.

To achieve a thorough understanding of the development of serious games, we collected data both at the industry level and from a set of serious games producers. Table 1 provides an overview of the data set, which we collected between 2016 and 2018.

To collect the data, we first familiarized ourselves with important industry developments and trends by reviewing the expert literature on serious games. During this phase, we identified a set of leading organizations involved in the development of serious games globally, conducted interviews with industry experts, researchers, and organizational representatives, and visited relevant companies and research institutions.

Based on this industry level information, we selected a target group of dedicated serious games producers on which we collected rich primary data about game development at the team level. We focused on producers developing games for schools, universities, and professional training programs, as these application areas seem to be most prominent in the serious games industry. Some examples of games produced by the organizations in our sample include games teaching primary and secondary students math and physics concepts (e.g., ratios, energy, and forces) and games training new recruits and old employees to excel at
their jobs (e.g., sales personnel, nurses). We limited our sample to award-winning organizations to preclude the risk of collecting data from less innovative or simply not functional product development efforts. In total, we sampled nine organizations located in the US, France, Denmark, and Norway having at least one serious game in their product portfolio. The companies were founded in the year 2000 or later.

We identified informants within these organizations (managers, designers, software engineers, educators, etc.) who had recently been or currently involved in the development of a serious game and could therefore be suitable to interview. Interviews were conducted with at least two key informants per organization representing digital/game design and non-digital/learning domains of expertise. It was important that our informants had worked together as a team on at least one project. On average, the interviews lasted 80 minutes and were conducted mostly in person (some via Skype or phone). Table 2 provides an overview of the selected organizations and our key informants.

An important step to prepare for the data collection was to analyze some of the serious games that the teams worked on. To do so, we played the games, wrote a summary of each game and our impression of it, and took notes on game particularities. The concrete production of each game was later discussed during the interviews. This provided us with illustrative material during the conversation and allowed us to obtain a deeper understanding of the concrete challenges the various participants faced during the development process and how they had worked to solve them.

In addition to the interviews, several of the sampled organizations were visited (organizations C, D, F, and G; see Table 2). These visits triggered multiple informal interviews with various experts, who demonstrated some of the tools they worked with (e.g., software, prototypes) and the games they created. These visits also enabled us to gain a better understanding of the environment in which the games were being designed. It was possible to observe the office layout, the artifacts inhabiting the space and the use of these artifacts, as well as communication among experts, and, in some cases, between experts and customers.

Finally, additional data were collected to triangulate and nuance the findings obtained through our analysis and to discuss the representativeness and validity of the findings for the serious games industry in a wider sense. This was done by revisiting available documentation and industry literature, as well as by conducting additional interviews with industry experts and company representatives outside our target group of organizations.

Following recommendations on conducting qualitative research (Miles et al., 2014; Silverman, 2013), data collection and analysis were concurrent. This helped us to “kick-start” the analysis and adjust our semi-structured interview guideline over time. At the beginning, the interview questions were mostly guided by insights from the literature, eventually, the more we became familiar with the industry and the more we learned from our informants, the more targeted our questions became. As described above, since we familiarized ourselves with the actual games and game documentation, we were able to ask very concrete questions, and we got our informants to explain and illustrate how they had accomplished specific tasks and to discuss the tools they had used throughout this process.

The primary data collected through interviews (27 interviews) and observations (field-visits, informal talks, etc.) were transcribed verbatim or otherwise documented (audio recorded, photos, summaries of meetings, field notes) shortly after collection. The final dataset prepared for the analysis encompassed interview transcripts, field notes, summaries, and game-related data. We applied thematic analysis to reveal common patterns, relationships, and emerging themes related to our research questions (Maguire and Delahunt, 2017). After we entered all collected data into a database, we read and reread it carefully, took notes on our early impressions, and discussed common concepts and ideas that emerged in our data. We sifted, sorted, and regrouped the data several times to detect patterns, common concepts and their relationships, which we then grouped into higher-level themes related to our research focus. In doing so, we became aware of the fundamental divide between digital and analog domains of expertise resulting in distinct challenges of cross-domain collaboration in serious games development, as well as the pronounced role of digital and analog boundary-spanning tools in bridging this divide. In a last step, we condensed these themes into more general theoretical concepts (Miles and Huberman, 1994). Multiple tables, graphs, and figures helped us to organize and display the data as well as the emerging conceptual insights; some of them are presented in this paper. Fig. 1 presents the logic behind our analytical process.

As is customary in qualitative analysis, we moved between the theoretical concerns and interest and the empirical data – an iterative process aimed at building empirically founded but theoretically motivated insights of the collective creation of digital innovation. As our analysis advanced and the level of abstraction rose, we repeatedly went back to the original interview transcripts and notes to ensure consistency with the original data. As explained above, we did not pay attention to critical events and compared organizations to develop or test theory that can account for variance. Rather, we drew on the data collected from multiple sites to develop a holistic story of game development.

4. Findings

4.1. Collaboration among digital and analog experts in the greenlighting phase

The term “greenlighting” is commonly associated with the early creation phase of creative and cultural goods. In our setting, it refers to the conceptual phase of game development. The greenlighting phase is characterized by an intense collaboration among digital and non-digital experts. Game designers, learning designers, subject matter experts, artists, programmers and others work side by side attempting to fuse their divergent pieces of knowledge to jointly develop a new product concept. In most cases, at the very beginning, the largest share of work rests on the shoulders of game and learning designers, who jointly work
on the core of a serious game – its gameplay. Here, subject matter experts, behavior analysts, or assessment specialists might also be involved, depending on the goals of the game and the size of the organization. As the core of the game concept evolves, artists start developing the overall style and concept art, character design and game components, while the software engineers begin writing codes.
Eventually, the final serious game is a single, complex system in which learning, entertainment, design aesthetics, and digital technology become highly interdependent elements. Changing one element often entails changing others; hence, constant input and communication across the two groups of digital/gaming and analog/learning experts is needed.

As confirmed by many of our informants, challenges occurred during the greenlighting phase. Arising challenges and tensions are rooted in divergent cognitive worlds and the lack of mutual understanding of the respective, and at times perceived as incompatible, knowledge domains. This results in divergent product goals and makes the development of serious games an intricate balancing act. For example, one of our informants stated:

“As a game designer it’s [designing a serious game] almost harder than making an entertainment focused game because there are more processes involved... it’s more or less trying to strike the balance between teaching the players what needs to be taught, but also making it fun. Not only that, but most of the time you make games about things you necessarily don’t know a lot about...”.

We learned that the differential thought worlds among digital and analog experts manifest in divergent perceptions about a game, which, in turn and often subconsciously, guide gaming and learning experts in divergent directions in regard to interpreting and approaching tasks, what to prioritize and which methods to use. In fact, the biggest concern expressed by the various experts was not being able to achieve the deep integration between learning and gaming and end up with a “chocolate covered broccoli” – a rather boring game with the entertaining part being superficial and layered on top of learning. Learning experts typically view a serious game primarily as a learning tool while game designers accentuate the gaming part, and business developers the goods that need to be sold, leading to severe issues of coordination and knowledge integration. For instance, game designers tend to offer ideas and solutions that do not treat the educational part very vigorously, while learning designers often prioritize assessment and learning outcomes over the gaming experience. As a game design leader shared:

“Individual expertise brings different criteria that are often subconscious in their minds – the problems that they are trying to solve. So, finding the solution that meets the criteria of every discipline is basically impossible, you constantly have to compromise, especially if you are trying to deal with something very innovative.”

A game designer who participated in the production of multiple games for preschoolers described these challenges associated with collaborative work in serious games using the following metaphor: “It is like a circus tent that is held by multiple poles where each pole is a person, and the tent is the project. So, everyone is important but also if someone pulls it too hard on his side, the whole thing breaks.” In other words, conceptualizing a serious game requires careful synthesis of various knowledge domains. This is not only the case for the design of the overall game concept but also an issue for individual design elements (e.g., the quality of digital art and graphics, audio, the nature of rewards, the design of separate game components).

Divergent thought worlds also impede communication resulting in difficulties of sharing domain-specific knowledge among the various experts. This partly stems from cognitive barriers, and partly from the use of field-specific jargon that create a lack of mutual understanding. For instance, while in digital game design, expressions like “level and mode”, “gameplay and game mechanics”, “shooters and platforms” belong to the standard vocabulary of everyday work, “affirmation and abstracting”, “causal mapping and cognitive maps”, and “deductive inquiry and learning logs” are common to the world of learning and education. An expert in software development mentioned to us that “non-technical people” rarely realize how much work it takes to build a game. To explain the amount of work needed to implement changes suggested by his analog colleagues, he used the following analogy: “it is like tearing the newly built single story house to the ground and rebuilding it anew but with five floors and using a completely different blueprint.”

For these reasons, the process of creating digital serious games is a challenging endeavor, undergirded by the need to coordinate and integrate knowledge of all involved participants so that the final output is coherent and well-balanced, that is, a serious game that provides both entertainment and robust learning. While the exact number of involved experts differs from case to case depending on a game’s specific learning goals and target group, we found that all organizations in our sample share a high degree of communality in their overall design approach, as well as the boundary-spanning tools that the various experts employ to cope with these difficulties.

Specifically, we find that the digital/gaming and non-digital/learning experts follow an overarching innovation process consisting of several predefined activities lending a certain routine and structure to the collective endeavor. Along this process, the various participants share and develop both digital (e.g., mockups, wireframes, game design documentation (GDD)) and analog-boundary-spanning tools (e.g., paper prototypes, whiteboards, clay sculptures) to overcome tensions associated with divergent knowledge domains and thought worlds. Our analysis revealed that these tools serve as important knowledge bridges buttressing the overall innovation process, a finding we now explicate in detail.

4.2. Boundary-spanning tools as knowledge bridges in cross-domain collaboration

Across our sample, the creators of serious games relied on an iterative design process comprising the following activities: ideation, creation/refinement of game documentation, prototyping, user testing, and analysis. These activities represent major tasks in the creation of digital games and are typically repeated more than once. At each step of the process, gaming becomes increasingly integrated with learning content and educational objectives, altogether moving the evolving game design closer to fusing digital and non-digital expert knowledge into a coherent innovative output. When unraveled, the innovation process can be depicted as a spiral, with the number of turns growing depending on the complexity of the game (Fig. 2).

In the development of serious games, there are no ready-made templates for their creators to rely on. For each game, unique learning content and goals need to be jointly developed and matched with a fitting gameplay. One of our informants, a learning designer, shared with us: “If you can take a game [already existing] and change the content [to integrate learning material], but the gameplay remains the same – it is not a good game... Making it more fun by adding things on top is not a good approach either. If developers ask ‘how can we make it more fun’ – the whole approach is wrong”.

Having to constantly exercise creative and innovative thinking, digital and learning experts typically fail and learn from each other multiple times before arriving at a product design that offers a balanced account of learning and entertainment. The iterative innovation process offers a routinized approach at experimental innovation, which fosters trial (ideation & prototyping), allows for failure (testing), and supports mutual understanding (analyzing). The following excerpt illustrates this point, echoing many of our interview partners: “First designs and prototypes are never final. There are many changes in the process. We have to experiment with both the graphics and game mechanics, run user tests... it is a highly iterative process.”

However, identifying these central innovation activities did not help us to fully reveal how collaborative work across domains was successfully performed ‘on the ground’. What surprised us during our analysis and observations was the pronounced use of not only digital boundary-spanning tools such as digital prototypes and GDD, but the wide array of analog tools, including whiteboard and paper prototypes in our setting of developing digital products.

Indeed, we found that the various experts made use of a set of boundary-spanning tools serving both as outcomes and mediators of the various innovation activities that together comprise the overarching
innovation process. The tools acted as knowledge bridges by orchestrating the various activities of the design process into a cyclic and routinized pattern. They enabled the joint enactment of the various innovation activities, supported mutual understanding, and served as tools of knowledge storage at each stage of the innovation process, altogether fostering knowledge synthesis among digital and analog domains of expertise towards a single product concept. Fig. 3 illustrates this finding.

As illustrated in Fig. 3, the multiple tools formed a chain of orchestration by tying the various activities of the iterative innovation process together. For instance, whiteboard prototypes (initial design ideas sketched on a whiteboard) typically provide the starting point for documenting the emerging game concept, an activity resulting in the GDD, which, in turn, provides the basis for subsequent prototyping. Along the way, the tools act as knowledge bridges as they mediate between both the collaborating experts and the various innovation activities, a finding we explicate next.

4.3. Boundary-spanning tools mediating between collaborating experts and innovation activities

The whiteboard, often occupying a central position in the office space, is one of the first key tools used. As described by a product designer:

“Most of our design, brainstorming, and communication was mediated by whiteboards… Most of our design work really was that whiteboard, so we would take photographs of the whiteboard and dropped those into a shared folder that people would reference… I can’t really imagine a digital device that would have the same affordances as a whiteboard. With a whiteboard you have large physical space and then you can gesture and move around.”

Whiteboards are large and versatile and allow the visual presentation of multiple thought worlds and product goals simultaneously, namely, pedagogical content, as well as gameplay and game story. The following was shared by a specialist of learning assessment:

“We draw on it, add text, and images and everything relevant for different parts of the game – those relevant for assessment to those relevant for gaming – game story next to pedagogical story. It provides a visual registry for the things we want to talk about.”

Analog tools such as whiteboards serve as important repositories as they allow to make both gaming and pedagogical content tangible and visible, enabling fruitful discussions. The involved participants can express their ideas verbally and visually in a way that is most convenient given their own, respective thought worlds, and start developing linkages between their divergent agendas and knowledge domains.

Whiteboards are mainly used to develop initial thoughts and first game design ideas, working as first rudimentary prototypes of the emerging game concept, including game characters and a gameplay. These rudimentary prototypes are typically the starting point for the creation of the GDD, in which the prototypes and ideas sketched on the whiteboard are moved into the digital realm.

The GDD, a living digital document that is jointly created and being constantly updated, is a highly critical boundary-spanning tool common in the development of new computer games (Scarbrough et al., 2015). In the context of serious games, it enables bridging learning and gaming expertise by supporting intensified efforts at developing a common game vision and concretizing the game development. By collectively creating the document, the GDD, also referred to as the “bible”, becomes an important knowledge bridge by facilitating touchpoints between the involved experts, further fusing their various expertise and storing the jointly developed intermediate and evolving outcome. Multiple informants mentioned its critical role: “After the brainstorming session, they start working on a design document to make sure that everyone is on the same page…They use lots of sketches, wireframes that go back and forth between the specialists…Through this process they put together the game design document”.

Ultimately, the GDD describes the game concept in detail providing an important input to prototyping, the next step in the innovation process. The following excerpt from a conversation with a CEO and a game designer of a company producing games within the natural
sciences illustrates this process: “We create a document that is relevant for all stakeholders. For instance, for [name of the] game, on the art side, it was the art slam that helped us create the looks the kids would love... We then developed the prototypes, which we sent to the audience: to schools – urban, suburban and other areas. In that case, the prototypes were printed art… The feedback we got influenced the final design of the game.”

While the whiteboard can be regarded as a first non-digital rudimentary prototype as the game is being pushed through the various steps of the iterative innovation process, the prototypes are becoming increasingly elaborate. In our fieldwork, we were surprised by the frequent and prominent use of non-digital prototypes, for instance, in drafting user experience or selecting a digital game character (for an example, see Fig. 4). Both gaming and learning experts explained us that paper prototypes “are very flexible and everyone in the team can do it”, and, at the same time, they “serve the main purpose – it gives the opportunity to test and change things quickly.”

Paper prototypes seem to be a highly important boundary-spanning tool as their flexible nature enables the various specialists to instantly share and collectively experiment with new ideas in search of a novel and balanced design configuration. They provide room for joint creativity and co-creation, are mobile and accessible, as they do not require any special technical knowledge or digital platform to run on. Another example is clay sculptures. Clay sculptures are jointly created to visualize and refine design ideas, before 3D game characters are being digitally modeled.

As the gameplay is being tested and refined, the evolving game idea typically takes a more advanced and digital shape. Common digital prototypes are wireframes and mockups incarnating dynamic representations of the structure and functionality of an evolving game. In this sense, digital prototypes function as temporary knowledge storage on the way to the final digital product. They are used to playtest interactive components, to test the user interface and to assess and refine the overall gaming and learning experience before being taken further.

Similarly, we found that various digital and non-digital reference material are critical boundary-spanning tools facilitating cross-domain collaboration. For instance, digital images, screenshots and video clips from existing digital and board games, or specialized learning equipment were used to overcome communication issues among the experts and to illustrate ideas. More importantly, these tools as well as the activities involving them (e.g., playing board or card games) motivate the experts to gradually build a basic understanding of one another’s knowledge domain, which ultimately helps in developing the links

Fig. 3. Boundary-spanning tools as knowledge bridges buttressing the innovation process.
between the gaming and learning domains of expertise. One of the learning experts shared with us: “I wasn’t speaking the same language as the team. To convey those ideas, I had to use images as well. Same for a game designer, when you talk game mechanics, level design, you need concrete material references during the course of conversation. These material resources become very important in these conversations”.

As the development of the game progresses, new and more representative tools are required. For instance, while at the beginning of concept development for a “teaching children science” game, images and screenshots were sufficient to explain the basics behind the physical forces, the digital specialists (designers, artists and programmers) needed a more advanced reference tool to be able to authentically depict the concept of wave motions in the game. This was solved by purchasing an actual “mini” wave unit and using it as learning equipment to be able to more accurately digitize the physical force in action.

4.4. Transformative interplay between digital and non-digital boundary-spanning tools

While analyzing these various tools and their use by the experts, we also detected an interesting alternating interplay between digital and non-digital tools underlying the overall innovation process of serious games. Based on our analysis, we suggest that this alternation played a critical role in the integration and gradual transformation of digital and non-digital expertise into a novel digital format. In other words, while serious games are digital outputs, an emerging game idea passes through several material and digital incarnations before a new digital serious game becomes realized. Fig. 5 visualizes this finding.

As mentioned earlier, while unpacking the creation of serious games, we were surprised by the repeated use of non-digital tools, such as whiteboards, paper sketches, and paper prototypes. Further analyzing the interplay of analog and digital tools, we found that the analog tools were mobilized to enable more open-ended innovation activities among the educators and digital experts, such as brainstorming and creative sessions, alternated with digital tools as tools of convergence, supporting the unfolding transformation of an emerging game idea towards a final digital output.

Fig. 5 illustrates these insights by depicting how the development of the overall game concept typically begins on the whiteboard – an analog tool that allows all involved gaming and learning experts to participate in the brainstorming and enables first linkages and negotiations. These first game design ideas conceived on the whiteboard are then moved to the digital realm where they are being converged and further developed, for example, through the digital GDD. The multimedia nature of digital tools enables both the digital and learning experts to generate more concrete examples of desirable graphics and work in more detail on the dynamic interaction between the various game components and gaming characters – design developments that analog tools lack given their simpler nature of visualization. This is often followed by the creation of a non-digital (paper) prototype to further develop and test the emerging gameplay.

The accessibility of non-digital tools encourages experts without specialized digital knowledge to participate in the game creation and allows them to do so on equal terms with more digitally skilled participants. These analog tools are, thus, central in helping to overcome cognitive differences and construct a fruitful environment for cross-domain collaboration. They trigger discussions and negotiations and propel collective ideation processes. Digital tools, however, are usually more technically advanced (e.g., specialized software for wireframing or graphic design). They contribute more expressly to building the final (digital) substance of the product. For instance, digital prototypes such as wireframes model dynamic interactions between game elements. In
other words, digital tools are a first attempt to try a new digital “skin” on the jointly developed ideas and thus converge non-digital and digital expertise.

To summarize our findings, Table 3 provides an overview of the specific capabilities of the various digital, non-digital and linguistic tools we detected in facilitating knowledge integration and coordination in cross-domain collaboration among gaming and learning experts in the design of serious games. Overall, these capabilities suggest that both analog and digital boundary-spanning tools are important knowledge bridges synthesizing digital and analog expertise.

5. Discussion and conclusion

This paper was motivated by the goal to better understand how specialists rooted in digital and analog knowledge domains engage in cross-domain collaboration to jointly create digital innovation. Reporting on our qualitative study of the development of serious games, our findings contribute to the literature on knowledge integration and coordination, and digital innovation in several ways.

5.1. Knowledge integration and coordination in cross-domain collaboration

While cross-domain collaboration is considered a fruitful setting for the creation of innovation, how to combine divergent knowledge domains is a core concern to both innovation and organization scholars. The literature on knowledge integration highlights that collaborative efforts involving multiple specialists are essential for a firm’s innovation capacity but are difficult to achieve given the challenge of translating knowledge across domains to create joint innovation (Carlile, 2004; Grant, 1996a,b). This literature has emphasized the role of managerial practices and organizational processes in facilitating knowledge integration across boundaries. Scholars of organization theory and sociology have noted that experts rooted in divergent knowledge domains struggle to collaborate given their different beliefs, values, and norms (Dougherty, 1992). Rooted in the literature on coordination (Okhuysen and Bechky, 2009), much work has pointed to the role of boundary objects in mitigating coordination challenges ‘on the ground’.

Our major contribution is that we cross-fertilize and reconcile these two lines of research by unpacking the role of boundary-spanning tools in knowledge integration. Responding to recent quests to develop “a more general theory of coordination/integration within and between organizations” (Grant, 2017, p. 8), our study can be considered an important step towards an integrative theoretical perspective. We focused on both the assembly as well as interplay of different types of boundary-spanning tools that are being mobilized by the experts to increasingly integrate their knowledge along an unfolding innovation journey. Our main finding is that boundary-spanning tools act as important knowledge bridges integrating analog and digital expertise. They mediate between the collaborating experts by helping to create shared understandings and assist the enactment of routinized innovation activities.

By introducing the concept of knowledge bridges to the literature on knowledge integration and coordination, we build on recent work by Cohen and Tripsas (2018). In a study of photography incumbents attempting to transition from analog to the novel domain of digital technologies, the authors use the concept of knowledge bridges to refer to spanning old and new generations of knowledge. We extend their insights in three important ways. First, we show that knowledge bridges come into play not only when moving between generations of knowledge domains but also when integrating divergent domains of knowledge regardless of generational or transitional aspects of knowledge. This is a critical extension because in order to innovate, not all firms may need to transition away from their existing knowledge base. In other words, while intergenerational knowledge bridges may be particularly relevant in the context of established firms helping to integrate old/analog and new/digital knowledge in order to enable transition, our findings suggest the concept of intragenerational knowledge bridges as critical in integrating contemporary analog with digital expertise. Based on our insights, we believe that intragenerational knowledge bridges may frequently play an important role in digital innovation as its development often involves cutting across and recombining a variety of existing digital and analog knowledge domains (Dougherty and Dunne, 2012; Nambisan, 2017; Porter and Heppelmann, 2014).

Second, while the authors propose three types of knowledge bridges (inventor bridges, technology bridges, and product bridges), we present another type of knowledge bridge. Our findings suggest that knowledge bridges also occur ‘on the ground’, incarnated by tangible and intangible boundary-spanning tools such as whiteboards and prototypes
that store and fuse elements of divergent knowledge. Third, we suggest an evolving and dynamic understanding of knowledge bridges. Our study of the development of serious games indicates a gradual transformation of digital and non-digital expertise into a novel, coherent whole, a process that is buttressed by the interplay of various knowledge bridges. This insight might provide an interesting feedback to the investigation of intergenerational knowledge bridges. Technological transitions are a gradual process, and firms may face divergent stages of technological transitions. Understanding how the interplay of the diverse types of intragenerational knowledge bridges differs among firms at heterogeneous transitioning stages is an important avenue for future research.

We also make specific contributions to the literature on coordination, which has placed the roles of different types of artifacts and boundary objects in accomplishing collaborative work in the foreground by offering a dynamic and relational view of boundary-spanning tools. By studying the assemblage as well as interplay of different types of tools in supporting collaborative efforts, first, we add to recent research that has started to promote a relational view of objects in cross-domain collaboration (Scarborough et al., 2015; Nicolini et al., 2012). Our study provides additional evidence that not only a single artifact or tool is decisive in supporting joint innovation, but it is the ensemble of various tools and their relationality that facilitate collaborative work. We show how boundary-spanning tools have relational capacity by mediating between both experts as well as tasks during collaborative innovation. We also add to a dynamic understanding of objects used in cross-domain collaboration by showing how divergent experts collaborate through an interplay of digital and analog tools that enables ongoing revision and alignment (Kellogg et al., 2006). This alternating interplay supports the progressive assembly of the diverse contributions into a balanced collage that eventually represents the final product. The various boundary-spanning tools relate to one another in a dynamic way; they are being revised and modified as people work with and through them, incarnating intermediate developments before a final output is reached. This is an important contribution to the existing literature that has studied single boundary objects, often in the context of science, conceptualizing them as relatively static devices that make differences more obvious and enable communication and discussions across pre-existing boundaries of expertise (Star and Griesemer, 1989).

Future research could build on our insights by studying knowledge integration through boundary-spanning tools in interorganizational settings and novel organizational forms such as open innovation. The literature on open innovation suggests that firms gain from integrating knowledge provided by specialists outside of the organizational boundaries (Chesbrough et al., 2006). Taking a microlens on open innovation by studying the role of boundary-spanning tools used could provide an important opportunity for future research. Another important extension of our study could be to compare success and failure cases of cross-domain collaboration. Indeed, exploring failure cases would be a highly important research avenue. Future research could also be enriched by studying the use of boundary-spanning tools in integrating highly distant vs. more proximate knowledge domains as the ability of experts to collaborate across knowledge boundaries might be crucially influenced by whether highly proximate or distant domains are to be combined. Last, as we collected cross-sectional data, future research could build on our findings and explicitly take a process approach to better understand the dynamic and evolving role of boundary-spanning tools across time.

5.2. Digital innovation

Our findings also hold contributions to the emerging literature on digital innovation. First, since digital technologies and processes of digitization are transforming the lives of individuals, organizations, and societies (Kagermann, 2015), much research has emphasized the disruptive nature of digitization and efforts associated with pivoting away from analog towards digital expertise (Cohen and Tripsas, 2018; Lucas and Goh, 2009; Hampel et al., 2019). Instead, we emphasize the importance of synthesis of digital and analog expertise. This may not only be relevant for the development of digital products such as serious games but may also apply to a range of other products and industries ranging from automobile to architecture. In all these settings, the ability to bridge digital and analog knowledge seems to become increasingly important to leverage innovation in the digital era.

Second, as the literature on digital innovation is emerging, there is still an abundance of unanswered questions revolving around the creation of digital innovation (Nambisan, 2013; Lyytinen et al., 2016). For instance, recent studies suggest that the traditional segregation between innovation processes and innovation outcomes becomes outdated in the age of digitization, highlighting the need for more research on the dynamic relationship between the two (Nambisan et al., 2017). Our study lends further evidence to the dynamic and interdependent nature of innovation processes and outcomes in the digital era by demonstrating how digital tools and technologies such as mockups and wireframes are indeed not only an outcome but an integral part to the innovation process.

Third, our findings add to research concerned with sociomateriality in the context of digital innovation (Nambisan, 2017; Holmström, 2018). We show that not only digital tools and technologies are key to the collective development of digital innovation. The development of serious games also critically depends on their interplay with analog tools, such as paper prototypes, clay sculptures, and whiteboards. These analog tools supported more open-ended innovation activities, such as brainstorming and ideation sessions, while the digital tools pre-dominantly became means of knowledge convergence, an interplay that progressively resulted in the fusion of digital and non-digital expertise into a novel digital format. These insights indicate the importance for future research to further unpack the affordances of seemingly mundane ‘analog’ devices in the context of digital innovation.

5.3. Policy implications

Our insights imply that cross-domain education and interdisciplinary training are increasingly important in the digital era. Digital innovation occurs at the intersection between various sources of knowledge, thus, fostering the integration of digital expertise with other domains of knowledge is of interest to researchers and practitioners alike. Innovative solutions to grand challenges such as access to education are often at least partly based on digital technologies in combination with domain specific knowledge (Kagermann, 2015), and improving our understanding of how knowledge integration may result in digital innovation, therefore, seems highly critical. Next, our study has demonstrated the critical role of analog tools for collaborative, digital innovation. The generation currently growing up can, for the most part, be characterized as ‘digital natives’, which implies a more developed and natural understanding of digital technologies. Governments could thus strengthen a balanced integration of digital, as well as analog tools, in educational programs across all levels of education and professional trainings.

Declaration of Competing Interest

The authors declare no conflict of interest.

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