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Contextual Priming and the Design of 3D Virtual Environments to Improve Group Ideation

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Abstract. Three-dimensional (3D) virtual environments (VEs) are collaboration platforms where group members are represented as avatars and interact in a customizable simulated world. Research from cognitive psychology has shown that it is possible to manipulate nonconscious cognition and behavior through "priming," a well-known phenomenon in which words and images are used to activate desired concepts in participants' minds. Our goal in this was to investigate whether priming during the task execution (called contextual priming) using 3D objects in the VE can improve brainstorming performance. To investigate this, we conducted two studies. The first used priming objects specifically related to the task topic and the second used priming objects related to creativity, in general. Compared to VEs without 3D priming objects, our results show that when groups brainstormed in the VEs designed with 3D priming objects, they generated better quality ideas as well as a greater breadth and depth of ideas. Thus, the 3D priming stimuli incorporated in a VE enhances brainstorming, which indicates that the design of VE has a direct effect on team brainstorming performance. Our results also show that target concept activation and task absorption act as the underlying mechanisms, partially mediating the relationship between the design of the VE (i.e., the presence or absence of priming objects) and performance outcomes.

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Keywords: virtual environments • group collaboration • groups • priming • electronic brainstorming • idea generation

Introduction

Organizations are exploring platforms that facilitate the brainstorming process in ways that can improve creativity and keep group members engaged (Gilson et al. 2015). Our interest lies in one such platform—3D virtual environments (VEs). In a VE, participants interact within a simulated space consisting of 3D objects and users (represented as avatars). Compared to earlier computer-mediated tools, VEs offer more realistic spaces that mimic the real world (Bainbridge 2007). Enabled by these simulation technologies, a VE provides a locus for virtual group interaction (Montoya et al. 2011). VE platforms such as *Active Worlds*, *Open Wonderland*, and *Entropia* offer interactive spaces that can support collaborative business applications. Recently, head-mounted devices have been introduced, bringing VEs into the mainstream (e.g., Microsoft HoloLens, Oculus Rift, and Samsung Gear VR). As the sophistication of the technology continues to improve, it is important to understand factors that could improve the performance of teams that would potentially use VEs for brainstorming tasks.

In this paper, we investigate whether the design of VEs can influence the performance of groups engaged in brainstorming. Drawing from research on priming and nonconscious cognition (Bargh and Chartrand 1999, Bargh et al. 2001), we examine whether the inclusion of design elements (i.e., three-dimensional (3D) priming objects) can improve group performance (i.e., quantity and quality of ideas as well as their depth and breadth). Priming is induced by presenting stimuli to an individual to activate representations of certain target concepts in working memory that, in turn, subtly influence behavior, usually without the individuals being aware of their altered behavior (Bargh and Chartrand 1999, 2000). Traditionally, priming stimuli are delivered *prior* to the task of interest (e.g., using a game, movie, or warm-up task), which is why it is called priming. VEs allow for *contextual priming* with relevant stimuli delivered in the environment during the execution of the brainstorming task. We use contextual priming by imbedding 3D priming objects in the VE itself so that they are visible to individuals as they work on the task. Thus, contextual priming works as real-time priming, alongside the task, to affect individual behavior during task execution. We expect contextual priming to work like a priori priming, in that the concept being primed will result in an increased performance during the brainstorming task.

We conducted two experimental studies to examine whether the inclusion of 3D priming objects in VEs can improve brainstorming performance. In our first experiment, we compare two simulated workspaces—a standard "generic" VE versus a "topic-specific" VE. The topic-specific VE incorporated 3D objects directly related to the topic of the idea generation task. In our second experiment, we compare the generic VE to an "enriched" VE. The enriched VE was designed with 3D objects intended to (more broadly) induce creativity and improve performance. In both studies, the 3D objects were visible during task execution and relevant to the goal of brainstorming, thus making this a form of contextual priming. We used four key dimensions to assess brainstorming performance: number of ideas, breadth of ideas (number of topic themes), depth of ideas (number of ideas within the topic themes), and idea quality. We also investigated two key theoretical mechanisms by which contextual priming leads to improved performance (target concept activation and task absorption).

The results of our experiments show that when groups brainstormed in the VEs designed with 3D priming objects, they generated better quality ideas (as well as greater breadth and depth of ideas) compared to when they brainstormed in VEs without the objects. Thus, the 3D priming stimuli incorporated in a VE enhances brainstorming. Overall, this indicates that the design of VEs has direct implications for team performance. Our results also show that target concept activation and task absorption are underlying mechanisms through which priming works. Both target concept activation and task absorption partially mediated the relationship between the design of the VE (i.e., the presence or absence of priming objects) and performance outcomes. In the following sections, we first discuss prior research. We then develop our hypotheses and describe our methodological approach, including analyses and results. We conclude with a discussion of our findings and implications for research and practice.

Prior Research and Theory

Electronic Brainstorming

Brainstorming in VEs is a relatively new research area, but its roots go back more than 50 years to both verbal and electronic brainstorming. Brainstorming is the process of combining existing and new information in an effort to generate original ideas to solve a problem (Amabile 1983, Osborn 1953). Research has shown that electronic brainstorming (EBS) is often more effective than verbal brainstorming (Gallupe et al. 1992, Nunamaker et al. 1996). EBS involves use of technology such as email, text-based chat, and group support systems and/or vendor specific tools to support the brainstorming process (Nijstad et al. 2003). EBS incorporates the best features of verbal brainstorming by facilitating idea exchanges and allowing members to build on each other's ideas. EBS has been used for more than two decades as an effective technique for improving brainstorming performance (Gallupe et al. 1992, Nunamaker et al. 1996).

One useful theoretical model for understanding idea generation is the Search for Ideas in Associative Memory (SIAM) model (Nijstad and Stroebe 2006). SIAM argues that memory is divided into two components. The first is long-term memory, which stores an individual's fundamental knowledge organized into central concepts that have features and linkages to related concepts. There is often a considerable overlap between concepts and the boundaries are fuzzy, especially for concepts that share a lot of similar linkages to each other and to other concepts. An individual's long-term memory has an unlimited capacity and is permanent, although it can degrade with aging. The second component is working memory, which has a limited capacity and is only capable of storing information for a finite time. Deliberate conscious cognition takes place in working memory, as knowledge from long-term memory is fetched and placed in working memory for consideration.

Under the SIAM model, idea generation is a two-step process (Nijstad and Stroebe 2006). First, an individual activates knowledge concepts in long-term memory, loading them into working memory. Second, working memory is examined as the individual tries to generate a new idea by combining concepts, making new connections or applying the knowledge to a new domain. These two processes are iterative in that the output from one influences the other. Ideas produced in step two serve as cues to knowledge activation in step one. As an individual generates an idea, it influences what knowledge is further activated in long-term memory and brought into working memory for use in generating more ideas. For this reason, generated ideas may exhibit cognitive inertia as an individual explores the same solution space in greater depth, overlooking other portions of the space (Dennis and Valacich 1999).

The shortcomings of individual idea generation may be mitigated when idea generation occurs in groups. Building on the SIAM model, researchers suggested a dual pathway model of creativity that argues that there are two routes to a creative set of ideas: breadth and depth (De Dreu et al. 2008, Paulus and Brown 2007, Nijstad et al. 2010). Breadth refers to the search for different categories or themes within the solution space, while depth refers to the pursuit of ideas within one category (De Dreu et al. 2008, Paulus and Brown 2007, Nijstad et al. 2010). Breadth improves brainstorming performance by increasing the number of cues that can be used to produce ideas (Nijstad et al. 2010). Depth improves performance when a group perseveres and thinks deeply about the dimensions of one category to develop more ideas (De Dreu et al. 2008).

Electronic brainstorming may improve idea breadth. Since every individual may have a different store of knowledge in long-term memory, a group can activate a more diverse knowledge (i.e., alternate categories in the solution space). This can lead to the generation of an initial set of ideas that is more cognitively diverse than any individual acting alone. As such, cognitive flexibility is higher (Dennis and Valacich 1993, De Dreu et al. 2008, Paulus and Brown 2007, Nijstad et al. 2010). In fact, when generated ideas are shared, they become cues—reflecting more diverse categories—for all group members. An individual can use these cues to activate a more diverse knowledge from her own long-term memory; thus, in turn, leading to the generation of more ideas. This is one of the reasons why electronic brainstorming groups generate more ideas than the same number of individuals working separately, particularly for larger groups possessing more diverse knowledge (Dennis and Valacich 1999).

Electronic brainstorming may also improve depth, the second pathway to performance. Social comparison is a phenomenon where members of a group match their efforts to the efforts of other group members (Shepherd et al. 1995). It is common for brainstorming to begin with a flood of ideas within a certain category or theme of ideas at the start of the task, eventually waning as individuals run out of initial ideas for that idea category (Richins 1991, Shepherd et al. 1995). Group members might then move to another idea category and keep working on that idea category for some time. If some group members persist in contributing ideas, their behavior will induce other members to continue as well, leading to the generation of more ideas within the idea category (Richins 1991).

External factors can influence the breadth and depth of ideas produced. For example, when more diverse cues are present in the task description, groups generate ideas across a wider variety of categories (i.e., breadth) (Nijstad and Stroebe 2006). Research also shows that it is possible to manipulate social comparison processes via software to induce group members to persist longer (Jung et al. 2005, Shepherd et al. 1995).

3D Virtual Environments and Workspace Design

VEs are computer-generated 3D spaces in which users interact through "avatars"—a digital representation of one's self that can be controlled in appearance and behavior (Saunders et al. 2011). For example, avatars can be designed to do animated gestures that mimic nonverbal interactions (Moore et al. 2006), which are often essential to collaboration. VEs can be designed to contain elements such as topography, landscapes, buildings, and objects such as tables or chairs. The ability of VEs to offer an awareness of space, distance, and the coexistence of other participants make them attractive for collaboration (Montoya et al. 2011).

VEs enable participants to communicate through text chat, gestures, and voice. They not only provide a visual representation of artifacts and users but they also offer a convergence of media that incorporates multiple communication channels (i.e., text, audio, and visual based) (Moore et al. 2006). Some VEs also offer special-purpose tools to support group collaboration. For example, *Open Wonderland*, an open source toolkit for creating collaborative 3D virtual worlds, offers users a 3D notepad to communicate and exchange information in the same way they could use a whiteboard in the physical world. VEs such as *ProtoSphere* and *Second Life* also integrate web applications such as social networks, blogs, and Microsoft Office applications. Thus, VEs offer a richer communication than commonly used tools like email and instant messaging (Montoya et al. 2011).

Since VEs replicate and often go beyond the possibilities of physical workspaces, it is important to consider research that examines design of physical spaces and creativity. Organizations invest a lot of money in building physical facilities to encourage creativity and innovation, especially meeting rooms where groups collaborate on knowledge intensive and creative tasks (Lewis and Moultrie 2005, Hemlin et al. 2008). The design of physical workspaces in the real world and their impact on creativity has been a topic of interest in several disciplines including environmental psychology, sociology, architecture, and management (Elsbach and Pratt 2007, Haner 2005, Lewis and Moultrie 2005, McCoy and Evans 2002). Research has studied the importance of workspace design, the objects they incorporate, and their impact on outcomes (Haner 2005, Kent 2007). Experimental studies show that certain features in a physical workspace directly influence creativity. As examples, the presence of natural objects such as plants and flowers (Shibata and Suzuki 2002, 2004), window views or an open sky (Stone and Irvine 1994), and bright light (versus a darker ambience) (Alencar and Bruno-Faria 1997, Knez 1995) have all been shown to help improve groups' creativity. Individuals associate these visuals with attributes such as creativity, innovation, and achievements (Ridoutt et al. 2002). Similarly, certain bright colors (e.g., red, orange, or purple) are expected to positively influence a person's mood, and a positive mood has been associated with creativity (Dul et al. 2011).

Overall, while research suggests the importance of workspace design for creativity, the understanding of the relationship is still in its early stages (Dul et al. 2011, Hemlin et al. 2008). A major constraint is the time and financial resources required to design a new physical workspace or redesign an existing one (Hemlin et al. 2008). By contrast, VEs can be (re)designed more quickly and with fewer resources. They can place participants in a variety of spaces (from offices to forests), a significant departure from the one-size-fits-all approach of physical workspaces.

Development of Hypotheses

When individuals see an object, *automatic cognition* is triggered as the brain strives to understand the meaning of the object (Karremans et al. 2006, Lau and Passingham 2007). This cognition activates knowledge from long-term memory and places related knowledge concepts in working memory, whether desired or not (Lau and Passingham 2007). Of course, as an individual sees new objects or changes the focus of her attention in the VE, other concepts may also automatically enter working memory. Since working memory is limited in its capacity, as new concepts enter, older concepts drop out (Nijstad and Stroebe 2006).

Priming research has deliberately attempted to manipulate the concepts in working memory to influence behavior (Bargh and Chartrand 2000). Priming is often done prior to a task by having participants focus their attention on stimuli such as objects, words, or pictures so that the concepts associated with the stimuli become active in working memory. Priming affects a wide variety of subsequent behavior (Bargh et al. 1996, Bargh and Chartrand 2000), including electronic brainstorming. For example, priming individuals with words associated with achievement prior to text-based electronic brainstorming has been shown to increase the number of ideas generated and overall idea quality (Dennis et al. 2013). However, prior research has treated priming in an a priori fashion—prime the individual first and then turn their attention to the brainstorming task. Therefore, a priori priming is limited in its ability because it uses an artificial priming session prior to the task of interest. In addition, the effects of a priori priming dissipate over time, influenced by factors such as duration of the priming session and stimuli used (DeCoster and Claypool 2004). Thus, the efficacy of priming stimuli delivered prior to a task is strongest at the beginning of a task and diminishes as time from priming elapses. Consequently, traditional priming is limited in its effectiveness because the priming effect is most needed in latter stages of the task when the group begins to run out of ideas.

VEs offer the possibility of avoiding the decay effect by exposing participants to the prime during task execution. In VEs, 3D objects or pictures (visual stimuli) are used instead of words, which are known to be as effective as words in eliciting priming effects (Carr et al. 1982, Giner-Sorolla et al. 1999). Visual stimuli activate semantic networks in a similar way to priming with words by eliciting semantic interpretations of the pictures (Giner-Sorolla et al. 1999). This type of priming, which we label contextual priming, works like a priori priming in that the stimuli cause the target concept(s) to be automatically brought from long-term memory into working memory. Once there, they influence behavior, including potentially increasing performance. Thus, contextual priming (exposure of relevant priming stimuli for the entire electronic brainstorming session) is appropriate for use in VEs.

A VE can be designed in a variety of ways to facilitate contextual priming. Most priming research begins by first identifying a concept that should influence the task and then designing stimuli to activate that concept in long-term memory so that it influences behavior (Bargh et al. 1996, Bargh and Chartrand 2000). Thus, one way is to include 3D objects to activate knowledge directly related to a specific task-topic. For example, if the task were to generate ideas to improve sales, objects associated with selling products, customers, and so on could be included in the workspace to provide cues to activate knowledge related to sales in long-term memory. These cues serve as stimuli to trigger the activation of more useful task concepts in long-term memory during the first stage of the SIAM model. Then, in the second step of the model, participants can more readily access concepts suitable for the generation of ideas. When the VE includes specific stimuli, the number of ideas generated will be increased.

The risk with this method is that the selection of objects with a narrow focus may constrain the way participants think about the problem, locking them into one approach (Bradley et al. 1996, Cuthbert et al. 2000). The solution is to offer a variety of different types of topic-specific stimuli to stimulate participants to take a broader view of the solution space (Schupp et al. 2000). In other words, provide objects that are deliberately designed to provide stimuli that approach the problem from distinctly different conceptual directions. This approach will help trigger activation of concepts in long-term memory that are drawn from different parts of the problem space.

While designing a VE with stimuli directly related to the task-topic may be effective, doing this for every new task-topic may be challenging because of time or other resource constraints. One alternative is to design a VE to improve creativity in general, regardless of the task-topic. In addition to activating concepts in long-term memory, stimuli can also trigger different levels of emotional arousal, which can lead to changes in behavior, especially motivation and persistence (De Dreu et al. 2008). Emotional arousal has been shown to lead to a greater motivation and absorption in cognitive tasks (Dul et al. 2011, McCoy and Evans 2002, Alencar and Bruno-Faria 1997, Knez 1995, Ceylan et al. 2008). For example, the priming concept of achievement has been shown to increase motivation and persistence and induce groups to generate more ideas (Dennis et al. 2013).

Prior research on the design of physical workspaces may inform this alternative. For example, physical objects such as race cars and aircraft often trigger the broader concept of achievement and their presence may increase brainstorming performance (Kristensen 2004, Ceylan et al. 2008). Likewise, prior research suggests creativity can be improved when workspaces are designed with natural materials such as wood, offer a variety of textures, and/or include natural objects like flowers or plants (or even wall décor or wallpaper with natural objects) (Ceylan et al. 2008, Ridoutt et al. 2002). Research has shown that individuals associate these design features with creativity, innovation, and achievement (Ridoutt et al. 2002; Shibata and Suzuki 2002, 2004). Also, prior research examining the use of abstract shapes in physical workspaces shows they too can trigger associations in memory[1] (Chapman and Chapman 1982). Bright colored objects in workspaces, as well as illuminance and spectral distribution, have been shown to lead to a more positive mood and emotional arousal (Knez and Kers 2000, Steidle and Werth 2014). In addition, high visual complexity (i.e., the presence of many and different objects) can motivate attention and stimulate emotional arousal (Ceylan et al. 2008, De Dreu et al. 2008). Prior research also suggests that a work environment containing different objects can better trigger creativity compared to a "barren" environment without visual stimuli (Amabile 1983, Becker and Steele 1995, McCoy 2005). Prior research has shown that greater task absorption leads to improved performance across a wide variety of tasks (Slater et al. 1996, Kerr and Tindale 2004).

To summarize, we suggest two VE design approaches for contextual priming: include 3D objects related to the task-topic to activate specific concepts in memory; or, include objects intended to universally improve creativity by increasing motivation and task absorption. Given all this, we hypothesize that VE workspaces designed with 3D objects to prime group members will increase the number of ideas produced. Stated formally, we have the following:

Hypothesis 1 (H1). *Groups will produce more unique ideas when they work in a VE designed for contextual priming using 3D priming objects than one without 3D priming objects.*

De Dreu et al. (2008) suggest that there are two pathways to brainstorming performance—breadth of ideas and depth of ideas. Examining these pathways can lead to a more comprehensive understanding of a group's brainstorming performance (Diehl and Stroebe 1987, Paulus and Nijstad 2003, Nijstad et al. 2010). The objects in the VE can serve as cues that activate knowledge in long-term memory, which may affect both breadth and depth (Nijstad and Stroebe 2006). Idea breadth is manifested in the form of different idea categories (Amabile 1983, Diehl and Stroebe 1987, Paulus and Nijstad 2003). Nijstad et al. (2010) suggest that generating ideas across many different categories reflects a cognitive process where uncommon and disparate associations are considered, leading to more (and likely better) ideas. Essentially, idea breadth helps groups overcome cognitive inertia. We posit that 3D priming objects will help groups overcome cognitive inertia as concepts are activated across multiple categories. Since memory is associative in nature, groups will start generating ideas that are related to each other in solving the stated brainstorming problem (Paulus and Brown 2007). Constantly visible, the 3D objects will act as stimuli during task execution, helping individuals think beyond a limited set of idea categories, thus improving the breadth of ideas.

Complementing breadth, depth measures the ideational fluency of groups within a single idea category (De Dreu et al. 2008). While breadth of ideas is important for thinking across categories, it is also important for groups to ideate deeply within the same category (Nijstad et al. 2010). Depth measures the exploration within a category and indicates that the group has considered multiple possible elements within a category (Diehl and Stroebe 1987, Paulus and Nijstad 2003). As noted earlier, VEs facilitate contextual priming through the use of the 3D priming objects that are always visible. The objects will help group members think more deeply about related concepts. Also, working in a group provides exposure to ideas that others in the group have generated, which will allow an individual to think more deeply on those existing ideas and improve them further (Smith 2003). This will improve the depth of ideas generated. Stated formally, we have the following:

Hypothesis 2 (H2). *Groups will generate ideas of* (a) *more breadth and* (b) *more depth when they work in a VE designed for contextual priming using 3D priming objects than one without 3D priming objects.*

The quality of ideas is also an important measure of brainstorming performance (Dean et al. 2006, Diehl and Stroebe 1987, Osborn 1953), because, depending on the context, organizations may prefer a group to generate a large quantity of ideas or a few high-quality ideas (Gallupe et al. 1992). There are many ways to assess idea quality, but the best approach is to count the number of "good" ideas (i.e., the number of ideas that meet some basic quality threshold) (Diehl and Stroebe 1987). The number of good quality ideas is highly related to the overall number of ideas (Diehl and Stroebe 1987), because as Osborn (1953, p. 131) put it, "It is almost axiomatic that quantity breeds quality . . . the more ideas we produce, the more likely we are to think up some that are good." A group with a perfect ability would produce only good ideas, so that quantity and quality would be the same, but most groups are not perfect, so the two can differ (Briggs and Reinig 2010).

Based on a review of prior research, Dean et al. (2006) conclude that there are distinct but related dimensions of idea quality: novelty, workability, and relevancy. Relevancy addresses how clearly the idea relates to and/or solves all or part of the problem. Given that Dean et al. (2006) suggest that relevancy is closely related to workability, we conceptualize the idea quality using novelty and workability.

Novelty addresses originality (the degree to which the idea is imaginative) and paradigm relatedness (the ability of the idea to change the way a problem is viewed). A VE with priming objects is more likely to stimulate participants to generate more ideas that are novel because the priming objects are not narrowly coupled to the problem. The objects offer different perspectives that can be used to generate ideas that are imaginative and approach the problem from a different paradigm.

Workability reflects acceptability (the level to which an idea does not violate known constraints) and implementability (the ease with which the idea solves the problem). As noted earlier, the 3D objects in a VE trigger concepts in the working memory. The triggered concepts would, in turn, enable the participants to think about ideas that are within the known constraints of the brainstorming topic. As the 3D objects are constantly visible, they could induce participants to examine more ideas within the problem space, resulting in more workable ideas (Briggs and Reinig 2010). Consequently, the 3D priming objects provide cognitive stimuli for the participants, resulting in a greater number of workable ideas. In summary, a VE with priming objects is more likely to stimulate participants to generate more workable ideas because the priming objects will provide participants more stimuli to use in thinking about their brainstorming topic. Stated formally, these arguments produce a two-part hypothesis:

Hypothesis 3 (H3). *Groups will produce higher quality ideas when they work in a VE designed for contextual priming using* 3D *priming objects than one without* 3D *priming objects.*

Next, we hypothesize two theoretical mechanisms, target concept activation and task absorption, by which priming objects will influence brainstorming performance. These mechanisms help further understand how the 3D priming objects trigger cognition around concepts related to the brainstorming and help individuals focus on their work. First, the 3D priming objects could serve as cues that activate certain concepts in long-term memory, causing them to be brought into working memory and used during idea generation (Nijstad and Stroebe 2006). Specifically, 3D priming objects may trigger cognition about *target concepts* related to the objects. As objects are seen in the VE, group members will strive to understand the object and any associated meaning (Lau and Passingham 2007). As described earlier, this automatic cognition is placed in working memory, helping members generate ideas related to the concepts activated by the priming objects. Since memory is associative in nature, the groups will start generating ideas related to the target concepts, eventually forming an idea cluster associated with the target concepts (Paulus and Brown 2007). This will help them increase the number of ideas and generate more ideas within the same category (depth). For an individual, working in a group also allows for exposure to ideas beyond one's own ideas. Prior research suggests that while such exposure can be distracting, it does allow an individual to think more broadly (breadth) and improve their own suggestions of ideas (Smith 2003).

We also posit that target concept activation will improve the idea quality. As group members see various 3D objects, concepts related to each of those objects are activated (Nijstad and Stroebe 2006). This will help individuals think of imaginative ideas related to the associated concepts for the 3D objects, thus improving the novelty of ideas. With more concepts related to the 3D objects activated in the working memory, members would be able to think of ideas around the known constraints of the brainstorming topic. This will lead to ideas that fit within the parameters of an acceptable solution, leading to higher workability of the generated ideas.

Hypothesis 4 (H4). *The effects of a VE designed for contextual priming using* 3D *priming objects on brainstorming performance* (*idea quantity, idea quality, depth of ideas, and breadth of ideas*) *will be mediated by target concept activation.*

The second theoretical mechanism that may help explain how performance will be influenced by 3D priming objects is task absorption. Task absorption measures the extent of engagement experienced by an individual while working on a task (Agarwal and Karahanna 2000, Finneran and Zhang 2005). As noted earlier, prior research suggests that high visual complexity (i.e., the presence of many and different objects) can stimulate arousal, leading to greater absorption in the task (Ceylan et al. 2008, De Dreu et al. 2008). Having just one stimulus is not sufficient as it leads to boredom and eventual distraction from the task (Finneran and Zhang 2005). Consequently, a VE that consists of multiple 3D objects would provide greater stimulation, leading to a greater sense of absorption during task execution.

Prior research has shown that greater task absorption leads to improved performance across a wide range of task types (Ceylan et al. 2008, Agarwal and Karahanna 2000). In this regard, VEs designed to include multiple and varied priming 3D objects provide the stimuli that can help improve individual task absorption. With many objects incorporated into the VE, individuals can remain more absorbed on the task at hand, leading to an improved brainstorming performance. The 3D objects would act as a contextual priming mechanism, intrinsically motivating the individual to generate more ideas (Cury et al. 2002).

We also posit that task absorption would lead to a better quality of ideas. A higher sense of task absorption implies that the individual has focused attention on the 3D objects (Manmiller et al. 2005). Prior research in psychology suggests that focused attention helps stabilize thinking (Bowers 1978, Lynn and Rhue 1986) and focus on individual prior experiences related to the object of attention (Martin and Jackson 2008, Lippelt et al. 2014, Manmiller et al. 2005). In this case, with the object of attention being the 3D priming object, it is likely that focused attention would help the individual think of ideas based on experiences with what that 3D priming object depicts within the boundaries of the brainstorming task. This could help the individual think of original ideas possibly related to the object. Since there are multiple objects in the VE, the individual can stay focused on one object at a time and think of ideas in the context of the task based on their experience with what the 3D objects depict. It can be expected that what an individual experiences based on what the 3D objects depict would vary (Lippelt et al. 2014, Martin and Jackson 2008), thus leading to a greater number of novel ideas within the team. With a higher sense of task absorption, individuals can remain focused on the goal of the brainstorming task, which is to generate ideas that can solve the stated problem. Consequently, the individual would generate more ideas that are easily implementable, thus generating more workable ideas.

Hypothesis 5 (H5). *The effects of a VE designed for contextual priming using 3D priming objects on brainstorming performance (idea quantity, idea quality, depth of ideas, and breadth of ideas) will be mediated by task absorption.*

Methods

To test our hypotheses, we conducted two experiments using *Open Wonderland*, a Java-based open source platform and toolkit for creating 3D collaborative environments. A generic conference hall (generic VE), provided in *Open Wonderland*, served as the basis for our design and comparisons in both experiments. In Study 1, we added 3D priming objects to the generic VE, creating a VE designed with objects directly related to the topic of the task (topic-specific VE). In Study 2, we investigated whether we could design a more universal VE to improve brainstorming performance. We added topic independent 3D priming objects to the generic VE, creating a VE designed to generally induce creativity (enriched VE). Our designs were informed by prior research on physical workspace design and creativity, discussed earlier. Further design details are provided below. Studies 1 and 2 are essentially the same, but differ in terms of the VEs compared (generic versus topic specific; generic versus enriched), and the number of groups studied.

Participants. In both studies, sophomores and juniors were drawn from various business school courses and received extra credit. In Study 1, 168 participants were randomly assigned to four person groups (42 groups). Their average age was 19.8 years and 58% were male. In Study 2, 80 participants were similarly assigned (20 groups). Their average age was 19.1 years and 62% were male. Age and socioeconomic status are generally considered to be the key difference between students and organizational populations (Compeau et al. 2012); here, neither is theorized to interact with the experimental conditions. Undergraduate students are also representative of future employees, since they will join organizations within a span of two to three years.

Our goal is to provide an initial test of our theory, not to generalize the theory to a specific setting. Lee and Baskerville (2003) note that we never generalize from the behavior observed in one setting (e.g., a research lab) to behavior in a different setting (e.g., a specific organization), because no two settings are ever truly the same (not even within the same organization). Instead, when we do experimental research, we first generalize from theory to behavior in the lab (does the theory apply to the lab setting) and then apply the empirical results in the lab setting back to the theory (do the results disconfirm the theory); second, we generalize from the theory to behavior in field settings (i.e., does this theory apply to this specific setting) (Lee and Baskerville 2003). Therefore, the key question is *not* whether students are appropriate surrogates for organizational employees, but rather whether the theory should apply to the lab setting (Lee and Baskerville 2003). We believe that the theory applies to our lab setting. Once we take the results of the lab back to the theory, we can then move to the second step and ask ourselves to what field settings is this theory likely to apply (i.e., what are the boundary conditions of the *theory*, not the empirical results).

Task Topics. Participants performed two different 15-minute idea generation tasks in a repeated measures experimental design. The tasks were drawn from prior research (Dennis et al. 2013); one asked participants to generate ideas to increase tourism in our state and

Figure 1. (Color online) Generic VE

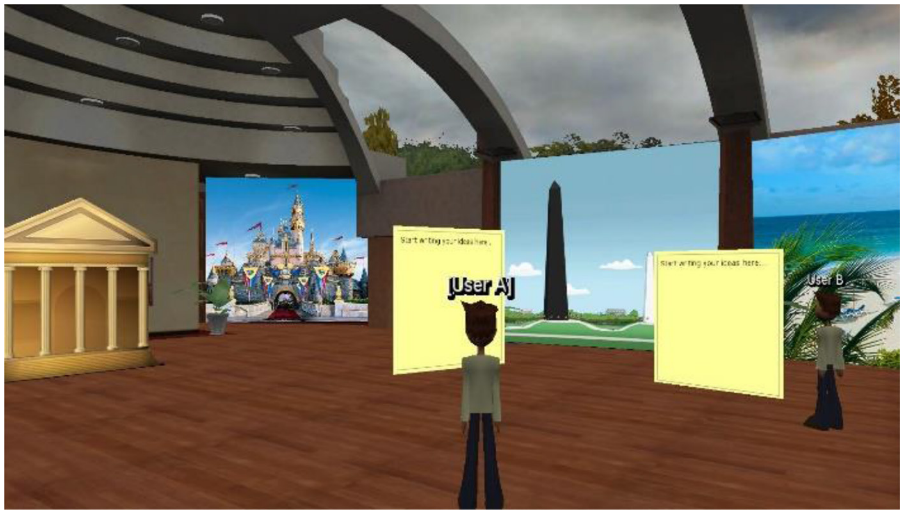
the other on reducing air, water, and land pollution. Participants were instructed to generate as many ideas as possible and build off the ideas of others in their group.

Treatments and Procedures. Study 1 compared the generic VE to a topic-specific VE. Study 2 compared the same generic VE to an enriched VE. In both studies, we used a repeated measures design so all groups participated in both VEs and idea generation tasks, with the order randomly assigned. The generic VE simulates a nonspecific conference hall. We added a set of five virtual notepads (which mimic whiteboards in a physical workspace) as the means by which group members would record the ideas they generated. The session moderator instructed participants to move (using their avatar) to a new notepad on their right side in the VE every three minutes. Participants were told to build on the ideas that were written on the notepad, if possible. The approach of one notepad more than the number of participants and moving participants to notepads is similar to the design of the EBS tool provided in the GroupSystems software (Nunamaker et al. 1991). Apart from notepads, no other objects were added to the generic VE (see Figure 1).

In Study 1, because we use two task topics (tourism and pollution), we designed two topic-specific VEs, one for each. We used the generic VE as the base design and then added 3D priming objects. For the pollution topic-specific VE, we added objects such as a trash can, windmill, etc. (see Figure 2). For the tourism topic-specific VE, objects included a theme park, popular tourist attractions (e.g., Washington Monument), etc. (see Figure 3). The 3D priming objects were obtained from the Google 3D Warehouse, an open

Figure 2. (Color online) Topic-Specific VE: Pollution Reduction

Figure 3. (Color online) Topic-Specific VE: Tourism



source website for 3D objects, and were customized to fit in the topic-specific VEs.

To design the enriched VE for Study 2, the generic VE was again used as the base VE design. We added 3D priming objects intended to enhance creativity, but not directly related to the task topic. Drawing from the literature on physical workspace design, discussed earlier, we incorporated 3D objects such as aircraft, cars, abstract shapes, and brightly-colored objects (see Figure 4). These objects were selected, modified, and arranged based on our theoretical understanding of how and what workspace elements improve creativity.

Apart from the 3D priming objects, all VEs were identical. The notepads used to generate ideas were identical in functionality and were placed in the same place. The ambient lighting was bright and sunny (i.e., daylight) as prior research has shown that evening or bluish ambient lighting negatively affects brainstorming performance (Alencar and Bruno-Faria 1997, Ceylan et al. 2008).

During the session, participants were seated in separate office spaces and provided with a headset (no microphone) to listen to instructions from the study administrator. The chat window was made unavailable during brainstorming. Participants were assigned a generic avatar (based on their gender—male or female) and received training on *Open Wonderland* including navigation of the avatar and the use of notepads. After the training, they were provided details on the task (tourism or pollution). They were asked to generate as many ideas as possible and build off the ideas of others. They worked for 15 minutes with their group members on one of the VEs (Study 1: generic *or* topic-specific; Study 2: generic *or* enriched) to generate ideas.

Figure 4. (Color online) Enriched VE

During the session, every three minutes, they were instructed to move from one notepad to the next by the administrator. After moving, participants could read through the ideas written by other group members on the virtual notepads so that they could build on each other's ideas, when possible. When time elapsed, they completed a survey consisting of demographic and task absorption items. Participants then continued on to the second task and alternate VE, following the same procedures. After 15 minutes, participants again answered questions related to task absorption items and were debriefed.

Measures. The primary dependent measure was brainstorming performance, measured in four ways (number of unique ideas, breadth and depth of ideas, and idea quality). The number of unique ideas (i.e., counting duplicate ideas only once) was independently assessed by two raters who analyzed the ideas on the virtual notepads. Interrater reliability for the two studies, calculated as the number of ideas on which the raters agreed, divided by the total number of ideas, was 92.8% and 96.7%, respectively.

Following the guidelines of Dean et al. (2006) to measure idea quality, ideas generated on all of the virtual notepads were transferred to a master idea list to avoid any repetition. Each idea was analyzed along the two subdimensions of novelty (originality and paradigm relatedness) and two subdimensions of workability (acceptability and implementability) (Dean et al. 2006). The quality of each idea was rated by one rater using the four-point scales of Dean et al. (2006). To ensure reliability, a second rater independently scored all four dimensions for the first 25 ideas from both the tourism and pollution reduction master idea list, resulting in 150 ratings for each task topic. Interrater reliability was 91.2% and 94.6% for Studies 1 and 2, respectively. Cronbach's alphas were obtained for each of the three dimensions based on their two subdimensions. Novelty was comprised of originality and paradigm relatedness ($\alpha = 0.84$) and workability was comprised of acceptability and implementability ($\alpha = 0.82$). We used the number of ideas with a mean of 3 or higher as the number of novel and workable ideas.

Drawing from De Dreu et al. (2008) and Nijstad et al. (2010), the breadth of ideas was measured as the number of distinct categories generated by groups for each task topic. Two raters independently examined and sorted the ideas into categories for each topic. Examples of the categories for the pollution reduction task included green energy, garbage reduction, and pollution generated by vehicles. For tourism, categories included parks, advertisement, and monuments. Interrater reliability, calculated as the number of topic categories for which the raters agreed, divided by the total number of categories, was 84.8% for tourism and 87.2% for pollution reduction. To measure depth, we calculated the average of the number of ideas generated by the groups per topic category. Table 1 shows the summary of the measures used to evaluate team performance and their definitions.

For the first mediator, target concept activation, we determined the extent to which the ideas generated by each group were related to target concepts activated by the 3D priming objects. Recall that we posit that 3D objects activate concepts in long-term memory, which, in turn, are brought into working memory, from which ideas are generated. The actual concepts activated in the long-term memory will differ from person to person depending on prior experiences. Table 2 lists the 3D objects and associated target concepts activated for Studies 1 and 2, respectively. We coded each generated idea as "related" or "unrelated" to the target concepts and used the number of related ideas as the measure of the target concept activation mediator.

Our second mediator, task absorption, was measured on a postsession questionnaire using three items (seven-point Likert scale, with 1 = Strongly Disagree to 7 = Strongly Agree) adapted from prior research (Agarwal and Karahanna 2000, Finneran and Zhang 2005): I was deeply engrossed in the task; The task was

Table 1. Measures and Definitions

Measure	Source	Definition
Idea quantity	Dean et al. (2006)	The number of unique ideas generated by the group
Idea quality—Novelty	Dean et al. (2006)	The number of rare or uncommon ideas in comparison to other ideas generated by the group
Idea quality—Workability	Dean et al. (2006)	The number of ideas that can be easily implemented and that do not violate the known constraints of the problem space under consideration
Breadth of ideas	De Dreu et al. (2008); Nijstad et al. (2010)	The number of distinct idea categories generated by the group
Depth of ideas	De Dreu et al. (2008); Nijstad et al. (2010)	The average number of ideas generated by the group per idea category

Table 2. 3D Priming Objects and Target Concepts

VEs	3D priming object	Activated target concepts
Generic VE	Not included	
Topic-specific VEs		
Pollution reduction	Windmill	Energy, green energy, wind, farm
	Solar panel	Energy, green energy, sun, nature
	Plants	Nature, environment, life, green
	Trash can	Garbage, clean, home, office
	Garden	Nature, environment, life, fresh, colors
	Factory	Smoke, fumes, industry
	Car	Transportation, smoke, commute, travel
	Bus	Public transportation, smoke, commute, travel
Tourism	Beach	Nature, relaxation, travel
	Disneyland	Fun, excitement, children, family
	Washington Monument	History, monuments, war, nation
	White House	Monument, history, president, nation
	Mountain	Nature, adventure, excitement, snow
	Resort	Fun, relaxation, family
	Boat	Adventure, fun, water, vehicles
	Race car	Sports, events, celebrities
Enriched VE	Angry bird	Games, mobile apps, software, enjoyment, excitement, fun, fantasy, animals, flying, space
	Airplane	Flying, vehicles, transportation
	Plants	Nature, environment, life, relaxation
	Chairs	Sitting, comfort, collaboration, work, relaxation, metal
	Guitar	Music, harmony, relaxation, hobby, concerts, shows
	Multicolored dice	Games, fun, excitement
	Spikes	Excitement, danger
	Orange colored jack	Games, fun, excitement

interesting; and, I was absorbed intensely in the task. Alphas were 0.89 and 0.91 for Studies 1 and 2, indicating adequate reliability.

Results

Study 1: Generic VE vs. Topic-Specific VE. All statistical analyses for H1–H3 were completed in SPSS PASW Statistics 22.0. A repeated-measures GLM ANOVA was used. The results are provided in Table 3. For all hypotheses testing in Studies 1 and 2, the treatment order and task-topic order were not significant. In topic-specific VEs, groups produced significantly more unique ideas than in the generic VE ($F(1,39) = 13.15$, $p < 0.001$). The effect size was large (Cohen's $d = 0.79$). Thus, H1 is supported. Groups also generated ideas across more categories (breadth) in topic-specific VEs than in the generic VE ($F(1,39) = 8.53$, $p < 0.01$). The effect size was medium (Cohen's $d = 0.48$). Groups also produced greater depth of ideas when working in the topic-specific VE ($F(1,39) = 5.76$, $p < 0.05$). The effect size was medium (Cohen's $d = 0.44$). Therefore, H2(a) and H2(b) are supported. Regarding quality, significantly more novel ($F(1,39) = 5.89$, $p < 0.05$) and workable ($F(1,39) = 10.77$, $p < 0.01$) ideas were produced in the topic-specific VEs. The effect sizes were all large (Cohen's $d = 0.53$ and 0.72, respectively). H3 is supported.

To test H4 and H5, the underlying process by which 3D priming objects (present or absent in VE design) influence performance, we used the Preacher and Hayes (2008) bootstrapping method with 5,000 iterations in SPSS 22.0. The method offers several advantages that makes it particularly well suited for our studies: (a) the method can estimate an indirect effect for each mediator while accounting for covariance between mediators, (b) the method does not require large sample sizes since it involves bootstrapping, and (c) since indirect effect estimation involves the product of terms, they have a skewed sampling distribution and so confidence intervals (CI) computed using bootstrapping are suitable for such distributions (Preacher and Hayes 2008).

Table 4 shows the results of the multiple mediators test. Coefficient estimates of indirect effects are statistically significant from 0 when the CI does not include 0. H4 is supported since the indirect effect of the target concept activation is significant for the number of ideas (0.24, bias corrected CI: 0.04 to 0.50), quality of ideas (0.17, bias corrected CI: 0.01 to 0.29), breadth (0.20, bias corrected CI: 0.03 to 0.37), and depth (0.19, bias corrected CI: 0.01 to 0.35). Similarly, H5 is supported since the indirect effect of task absorption is significant for the number of ideas (0.14, bias corrected CI: 0.03 to

Table 3. Results of Studies 1 and 2

	Study 1: Topic-specific vs. generic VE (N = 42 groups)					Study 2: Enriched vs. generic VE (N = 20 groups)				
	Topic-specific		Generic			Enriched		Generic		
Measures	Mean	SD	Mean	SD	F	Mean	SD	Mean	SD	F
Number of ideas	52.94	8.016	47.31	5.38	13.15***	48.20	10.17	42.25	9.25	12.80**
Breadth of ideas	10.26	1.02	8.89	0.87	8.53**	7.23	1.12	5.31	0.84	8.93**
Depth of ideas	5.39	1.13	4.32	1.02	5.76*	6.67	1.82	6.95	0.71	4.02
Novel ideas	11.70	2.29	10.42	2.63	5.89*	11.30	2.49	8.52	2.99	10.28**
Workable ideas	34.03	7.78	29.16	5.54	10.77**	29.80	9.14	24.95	4.52	7.78*

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 4. Results Using Preacher and Hayes (2008) Bootstrapping Method for Study 1: Topic-Specific VE

Independent variable	Mediator	Indirect effect on DVs	Bias corrected 95% CI for indirect effect
Treatment	Target concept activation	Number of ideas: 0.24 (0.06)	0.04 to 0.50
		Quality of ideas: 0.17 (0.04)	0.01 to 0.29
		Breadth: 0.20 (0.06)	0.03 to 0.37
		Depth: 0.19 (0.05)	0.01 to 0.35
Treatment	Task absorption	Number of ideas: 0.14 (0.02)	0.03 to 0.43
		Quality of ideas: 0.13 (0.04)	0.01 to 0.36
		Breadth: 0.11 (0.02)	0.02 to 0.34
		Depth: 0.14 (0.06)	0.03 to 0.38

0.43), quality of ideas (0.13, bias corrected CI: 0.01 to 0.36), breadth (0.11, bias corrected CI: 0.02 to 0.34), and depth (0.14, bias corrected CI: 0.03 to 0.38). Note that, when working in the topic-specific VE, groups generated significantly more ideas related to the target concepts (Table 2) than in the generic VE ($\bar{x} = 40.23$ versus 33.12, $F(1,39) = 13.69$, $p < 0.001$) and comparatively significantly fewer unrelated ideas ($\bar{x} = 12.51$ versus 30.19, $F(1,39) = 7.98$, $p < 0.05$). Also, participants reported higher task absorption in the topic-specific VE than in the generic VE ($F(1,39) = 8.29$, $p = 0.037$. We conclude that the 3D priming objects were working as intended.

Study 2: Generic VE vs. Enriched VE. We used the same analytical approach for Study 2 as in Study 1. Table 3 summarizes the results for H1–H3. Compared to the generic VE, groups in the enriched VE produced significantly more unique ideas ($F(1,17) = 12.802$, $p < 0.01$). The effect size was large (Cohen's $d = 0.54$). H1 is supported. Regarding breadth of ideas, groups demonstrated more breadth in the enriched VE ($F(1,17) = 8.93$, $p = 0.009$). The effect size was large (Cohen's $d = 0.69$). By contrast to the result in Study 1, for depth of ideas, the difference was not significant ($F(1,17) = 4.02$, $p = 0.067$). Thus, H2(a) is supported, but H2(b) is not. Groups also produced significantly more novel ($F(1,17) = 10.28$, $p < 0.01$) and workable ideas ($F(1,17) = 7.78$, $p < 0.05$). The effect sizes were large (Cohen's $d = 1.00$ and $d = 0.67$, respectively). Thus, H3 is supported.

For H4 and H5, we used the Preacher and Hayes (2008) bootstrapping method. Table 5 presents the

Table 5. Results Using Preacher and Hayes (2008) Bootstrapping Method for Study 2: Enriched VE

Independent variable	Mediator	Indirect effect on DVs	Bias corrected 95% CI for indirect effect
Treatment	Target concept activation	Number of ideas: 0.23 (0.04)	0.04 to 0.46
		Quality of ideas: 0.19 (0.03)	0.01 to 0.31
		Breadth: 0.18 (0.06)	0.01 to 0.36
		Depth: 0.20 (0.03)	0.02 to 0.39
Treatment	Task absorption	Number of ideas: 0.12 (0.06)	0.03 to 0.37
		Quality of ideas: 0.09 (0.02)	0.01 to 0.29
		Breadth: 0.13 (0.04)	0.02 to 0.37
		Depth: 0.12 (0.03)	0.03 to 0.35

results for Study 2. H4 is supported since the indirect effect of target concept activation is significant for the number of ideas (0.23, bias corrected CI: 0.01 to 0.44), quality of ideas (0.19, bias corrected CI: 0.01 to 0.31), breadth (0.18, bias corrected CI: 0.01 to 0.36), and depth (0.20, bias corrected CI: 0.02 to 0.39). Similarly, H5 is supported since the indirect effect of task absorption is significant for the number of ideas (0.12, bias corrected CI: 0.03 to 0.37), quality of ideas (0.09, bias corrected CI: 0.01 to 0.29), breadth (0.13, bias corrected CI: 0.02 to 0.37), and depth (0.12, bias corrected CI: 0.03 to 0.35). Compared to the generic VE, groups in the enriched VE generated significantly more ideas related to the target concepts (Table 2) ($\bar{x} = 22.27$ versus 12.41, $F(1, 17) = 14.69$, $p = 0.002$) and significantly fewer unrelated ideas ($\bar{x} = 25.93$ versus 29.84, $F(1, 17) = 8.34$, $p = 0.041$). Participants reported higher task absorption in the enriched VE ($F(1, 17) = 7.79$, $p = 0.04$).

Discussion

While VEs may address some of the shortcomings of earlier two-dimensional technologies, there has been limited research on whether the design of the VE itself influences group outcomes. Given their relatively recent emergence, understanding this relationship takes on a heightened importance and may be essential to demonstrating business value. Our results offer evidence that the intentional design of a VE can positively influence brainstorming. Drawing from a body of research across multiple disciplines, we proposed two alternative ways to design VEs to improve brainstorming: (1) include 3D objects directly related to the task topic (Study 1: topic-specific VE); or, (2) include objects independent of the topic, but intended to enrich creativity in general (Study 2: enriched VE). Our results showed that groups produced more unique and better quality ideas when they worked in either the topic-specific or enriched VE as compared to the generic VE. Both the topic-specific and enriched VE induced groups to generate ideas across more categories (breadth), but only the topic-specific VE induced greater category depth.

Our research makes four contributions. First, our research shows that designing a VE for contextual priming using 3D priming objects has significant and meaningful effects on group performance. The effect sizes were large, similar to those found in prior research comparing EBS to verbal brainstorming (Gallupe et al. 1992). In other words, the design of VEs is as important to performance as the choice to use electronic rather than verbal brainstorming in the first place. It is important to note that these effects are *not* due to any functionality differences; it is purely the visual appearance of the workspace that leads to differences. In Study 1, we deliberately designed two VEs, each related to the topic of the brainstorming task. In Study 2, we designed the enriched VE with the goal of improving creativity in general. This differentiates our studies from traditional brainstorming research since we specifically connect the design of the VE to the goal of the brainstorming task. We also note that contextual priming led to a higher level of task absorption and production of more ideas related to the target concepts. As a result, we suggest contextual priming using 3D objects as an appropriate way to implement priming in VEs as compared to traditional priming methods used in research (Bargh and Chartrand 2000, DeCoster and Claypool 2004).

Second, drawing from the dual pathway model (De Dreu et al. 2008, Paulus and Brown 2007, Nijstad et al. 2010) and the SIAM model (Nijstad and Stroebe 2006), we offered two underlying theoretical mechanisms to explain how the presence of 3D priming objects in VEs influences performance: by increasing the number of ideas related to the target concepts and by increasing task absorption. Our results suggest that both mechanisms partially mediate the relationship between the VE design and performance. Regarding target concept activation, results show that the VEs with 3D priming objects induced more ideas related to the target concepts, thus providing support for the theoretical linkage. In fact, in both the topic-specific and enriched VEs, the effect of target concept activation was so strong that it reduced the number of unrelated ideas, i.e., the priming objects cause participants to focus on certain concepts, which, when brought into working memory, were used to generate more related ideas. In both studies, the VEs with 3D priming objects offered greater visual complexity and stimuli that significantly increased task absorption.

Finally, we offer two distinct theory-based approaches to the design of VE workspaces to improve creativity: by adding objects related to the specific topic, and by adding topics related to more universal creativity themes. We build on and extend research in environment psychology that discusses specific components of a workspace that influence cognition and emotions (Haner 2005, Lewis and Moultrie 2005, McCoy and Evans 2002). Rather than just focusing on the components that comprise a workspace, we focus on relevant concepts that could be activated by incorporating objects that lead to performance improvements. VEs offer malleability in that multiple workspaces can be designed (and redesigned) to suit different group configurations, tasks, and topics. Building VEs is significantly cheaper than building physical workspaces. By using theoretical concepts from prior research on brainstorming and priming, our results offer a scientifically grounded methodology for the design of VE workspaces. The provision of design insights and our findings on the link between VE design and outcomes may also help in demonstrating the business value of the technology, which is a key challenge in the IS field.

Implications for Future Research

In this section, we discuss the implications for future research based on our findings and research contributions. First, VEs offer the ability to enact insights from the design of physical workspaces, including the use of light, colors, and textures, as well as the shape and organization of objects (Ceylan et al. 2008, McCoy 2005, Steidle and Werth 2014). Yet, there is limited existing research that examines whether or how VE design affects outcomes. Our results suggest that if we know what and how objects contribute to successful performance (as well as other visual and audible workspace features), we may be better able to fit the workspace to the work and workers. More research is needed on VE design, its elements, and impact on performance. For example, future research could focus on elements such as ambient light to understand its effects and whether our understanding of physical workspaces always translates to virtual spaces. Also, future research is needed on the relationship between the nature of topic and the choice of objects in design. For example, we deployed two topics, the first of which (increasing tourism) might be perceived as a "positive" topic, while the second (decreasing pollution) might be perceived as somewhat negative. Beyond the related topics, it would be interesting to investigate other object characteristics (e.g., degree of positivity) that influence outcomes.

Second, as noted earlier, we investigated two mediating mechanisms (target concept activation and task absorption) that explain how 3D priming objects influence brainstorming performance. Our results provide evidence that the performance effects of these objects in both the topic-specific and enriched VEs were partially mediated by both mechanisms. One might argue that it is important to separate the two mediating mechanisms, but this will prove challenging. VEs are visually complex and thus engaging, and the introduction of 3D priming objects makes them more so. It is human nature to ascribe meaning to abstract objects; even seemingly meaningless objects will activate concepts in long-term memory. For example, whether objects as simple as grass or palm trees activate concepts in long-term memory likely depends on the individual's conceptual schema (e.g., consider the schema about grass and palm trees that individuals from Arizona versus Vermont likely have). Likewise, the mere presence of objects will increase visual complexity and have the potential to increase task absorption. Yet, whether any given object is engaging may vary by the individual. Rather than attempting to disaggregate the separate effects of task absorption and target concept activation (which may be virtually impossible), future research can devote attention to better understand how the two mechanisms work together and can be jointly used to design better VEs. One intriguing finding is that the two mediating mechanisms *partly* mediated the effects of the 3D priming objects; this means that these two mechanisms are important mediators, but that some other theoretical mechanism(s) are also at work. We need more research to better understand what these other mechanism(s) might be.

Finally, an important aspect about VEs is that they are persistent (i.e., the environments exist even after the conclusion of the brainstorming activity). Future research can look at ways to leverage this characteristic of the VE to create avenues for asynchronous brainstorming. Asynchronous brainstorming could help group members be more productive since they can return to the environment and tools used (such as the notepads in this study) whenever they wish. For example, using a persistent VE, group members can return to the space, access ideas generated by others, and build on them to generate more ideas.

Limitations

This research suffers from the usual limitations of laboratory research: we studied student participants who worked on artificial short-duration tasks that had no intrinsic value to them. Thus, there is a need for field research involving groups in organizations working on longer duration tasks. As discussed earlier, given the aims and context of our study, the use of a laboratory experiment with student subjects was appropriate for testing the theory, given the control that laboratory experiments provide (Compeau et al. 2012, Lee and Baskerville 2003). Participants used a technology that was novel to them, which is common in laboratory experiments. As prior experience with any technology often influences performance, this could impact our results. We attempted to mitigate this by using a repeated measures design. Nonetheless, this remains a limitation. Last, we note the gender skew (60–40 male) and differences in background of subjects as limitations of this study. Individual interpretations of a 3D priming object might differ from person to person based on life experiences and men might interpret objects differently than women (Ceario 2014). Future research should explore how these and other demographics interact with VE design.

Implications for Practice

Despite these limitations, we conclude that workspace design matters. Recent practitioner literature has focused on the role of physical workspace design to keep employees engaged (Augustin 2014, Waber et al. 2014). Organizations that focus on workspace design can expect their employees to feel psychologically uplifted (Augustin 2014). We believe keeping employees engaged and feeling good about their employer and environment extends to virtual spaces. Our research contributes to addressing these needs as organizations can leverage the flexibility offered by VEs in designing spaces that cater to employees. One implication is that organizations should hire (or train) technology designers who understand and can enact VE design features to influence processes and outcomes.

Extending general insights from physical workspace design (e.g., lighting, colors) into VE design is a first step. As with physical workspaces, when a VE meets the needs of employees as they work, not only will they perform better but they also feel more positive about their organization. Beyond general guidelines, a second step is to include design elements to intentionally influence work processes and outcomes. While we used visual 3D objects as priming stimuli, organizations should consider other ways of creating stimuli that leverages the visualization capabilities of VEs. For example, one avenue to explore is avatar design. How avatars appear (human versus nonhuman, professional versus casual, etc.) to others and in different situations may, in fact, engender different reactions. For example, what is amusing in one culture may activate very different reactions from other cultures. Similarly, design of a virtual brainstorming tool itself could be manipulated to induce a specific type of priming.

Organizations are rapidly moving toward a structure where most of the employees work virtually, at least part of the time. In such organizational structures, the work environment is of more concern than the physical location of the employee. Microsoft HoloLens, Oculus Rift, and Samsung Gear VR provide consumer grade virtual reality equipment. While consumer markets may lead organizational work adoption, the introduction of these devices and further advances in VEs as collaboration platforms will likely fuel organizational interest. A key advantage of using VEs that this study highlights is the ease in design and redesign. As organizations explore the efficacy of VEs for collaborative work, our efforts may help guide the design and exploration of these visual workspaces for not only brainstorming, but other tasks such as decision making or planning. Just as in a physical location, we can envision a VE consisting of multiple different workspaces, each designed to support different types of groups, tasks, and topics.

Finally, our research has implications for design thinking, which is a collaborative process. Visualization methods are used in nearly every stage of this process, from making sense of observations during problem/opportunity identification, to the generation of innovative ideas in response, and on through the creation of prototypes for idea testing (Gassmann and Zeschky 2008, Gilhooly et al. 2010). Our results suggest that contextual priming may help design thinking, particularly during the "what if" or ideation phase. During this phase design, criteria shapes idea generation and concept development. Our results suggest topic or criteria relevant visual stimuli may help collaborators think more broadly and deeply about ideas during this phase.

Conclusion

We contribute to bodies of literatures in multiple areas, including electronic brainstorming, cognitive priming, and workspace design. The challenging question of how and under what conditions VEs enhance collaborative work is essential to demonstrating value. Our research efforts are one step toward addressing this challenge. Overall, our results highlight that the design of a VE matters to performance. Specifically, we show that the inclusion of 3D priming objects, acting as stimuli, enhance brainstorming. Our findings also suggest that target concept activation and task absorption act as the underlying mechanisms through which priming works. The study opens many avenues for future research on VE design and the relationship between diverse types of primes and the tasks. While much work remains, we hope that the results of this research note provide the impetus for further exploration.

Endnote

[1] One example of the link between abstract shapes and memory is the Rorschach test, a projective psychological test used to examine personality characteristics and emotional functioning. Analyses of subjects' perceptions of ambiguous inkblots suggests that an individual perceives external stimuli based on prior real-life experiences; that is, prior meaning schemas are activated in memory (Urist 1977).

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