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Drawing Snow White and Animating Buzz Lightyear: Technological Toolkit Characteristics and Creativity in Cross-Disciplinary Teams

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Abstract. The use of technological tools to execute creative tasks is pervasive within cross-disciplinary teams, yet little attention has been paid to their role in influencing team creativity. In particular, no research has focused on how the characteristics of a team's technological toolkit—the set of technological tools a team can draw upon to construct its actions—can affect team creativity. I propose that considering the toolkit, rather than just isolated tools, and the multiple functions played by tools is critical to understanding how technology characteristics influence team creativity. I hypothesize that creativity in cross-disciplinary teams is influenced by the size and field diffusion of the team toolkit, with size having a curvilinear relationship with creativity, and diffusion having a positive relationship. Moreover, I hypothesize that these effects will be attenuated when the number of team members who are experts with the focal tool is high. I test and find support for these hypotheses in a study set in the context of the Hollywood animation industry, a knowledge-intensive industry characterized by the presence of cross-disciplinary teams using a variety of technological tools. Theoretical and practical implications of the results are discussed.

Keywords: team creativity • toolkits • technology • cross-disciplinary teams • knowledge

Introduction

In 1981, Ed Catmull and Alvy Ray Smith, heads of Lucasfilm Computer Division, were struggling in their attempt to use computer graphics to realize animated movies. In particular, they seemed unable to overcome the "coldness" and lack of expressiveness of computer-animated characters, which resulted in the field rejecting projects realized with computer graphics, judging them as weird, rather than creative (Price 2009). In the same years, Walt Disney Animation, the uncontested leader of the sector for decades, was suffering from a creative drought and seemed no longer able to apply its "classic" hand-drawn animation tool to the realization of creative movies (Bendazzi 2016). In 1983, Catmull and Smith brought in John Lasseter, a young animator formerly working at Disney with a strong grounding in hand-drawn animation. Lasseter and members of Lucasfilm Computer Division combined their technological tools to create a short movie called *The Adventures of André and Wally B.* (Catmull and Wallace 2014, Price 2009). The new toolkit allowed the Lucasfilm team to overcome both the field diffidence about computer graphics and the "creative exhaustion" of classic animation, creating something entirely new that was received by the field as groundbreaking work (Price 2009). This movie became the first step of the company that would create the most creative animated movies of the last 20 years (Rodowick 2008): Pixar Animation Studios.

The preceding passage highlights a potentially powerful antecedent of creativity in cross-disciplinary teams: the combination of technological tools in toolkits, and the characteristics of the resulting combination. While existing research has thoroughly explored the role of technology in cross-disciplinary teamwork (e.g., Bechky 2003, Boland et al. 2007, Leonardi 2011), the topic of how technology characteristics might influence team creativity is still relatively understudied. However, understanding the role of technology in shaping creativity is particularly relevant, given the rising infusion of technical content and technology use in knowledge-intensive work (Barley 1986). This is especially true in those contexts where creativity and innovation constitute the main activity and work is conducted in cross-disciplinary teams (Boland et al. 2007, Carlile 2002, Orlikowski 1992).

Research on technological tools and creativity, however, is still in its infancy (Argote and Miron-Spektor 2011). In particular, extant research has not yet considered how technological tools are combined within a team (Argote and Miron-Spektor 2011). Cross-disciplinary teams do not use technological tools in isolation, but combine them in a toolkit to execute their tasks (DeSanctis and Poole 1994, von Hippel and Katz

2002, Seidel and O'Mahony 2014). For example, Boland et al. (2007) describe how Gehry Partners combined physical models and digital 3-D representations to realize the fish sculpture hosted on the Barcelona 1992 Olympic Grounds. Since differences between toolkits explain why different groups behave differently in similar situations (DiBenigno and Kellogg 2014, Kellogg 2011, Swidler 1986), teams owning toolkits with different characteristics are likely to differ in their ability to be creative. Despite this evidence, creativity literature has largely ignored how toolkits and, most importantly, toolkit characteristics can affect creativity (see Seidel and O'Mahony 2014 for a relevant exception).

I define a team technological toolkit as the set of technological tools that team members can draw upon to construct their actions. I propose that the characteristics of a team technological toolkit affect the team's ability to generate outcomes that are evaluated as creative by the field, and that this happens because tools can serve multiple functions. On one side, tools can act as knowledge repositories, where knowledge is stocked and can be accessed through use (Argote and Ingram 2000, Argote and Miron-Spektor 2011, McGrath and Argote 2001). On the other, they can be used as boundary objects, artifacts that are shared across different disciplines and thus allow interdisciplinary communication and collaboration (Bechky 2003; Cacciatori 2008; Carlile 2002, 2004; Star 1989). While extant literature has focused only on one function at a time, doing so can result in a limited understanding of the way they affect team efforts in general (Nicolini et al. 2012), and team creativity in particular.

In this study, I focus on two characteristics of a team toolkit, namely, its size (i.e., the number of tools that the team can use to execute creative work) and diffusion (i.e., the degree to which the toolkit of the team is diffused in the industry). I hypothesize that team toolkit size has a curvilinear effect on team creativity, while diffusion has a positive effect. Moreover, I hypothesize that when many team members are experts in the use of the tool that is most relevant to their task (i.e., the focal tool), they will be more focused on that tool and thus less able to use the toolkit in its entirety. Thus, the effect of toolkit size and diffusion will be attenuated when the number of team members who are experts with the focal tool is high. I test these hypotheses in a context where creative work is in the hands of cross-disciplinary teams using a variety of technological tools: the Hollywood animation industry.

This study stands to make a number of potential contributions. First, it introduces a focus on technology into research on team creativity. By considering the different functions played by technological tools and their combination in team toolkits, I provide a theoretical explanation and empirical test of how toolkit characteristics affect team creativity as judged by field members. Second, my findings show that the relationship between uniqueness and creativity is more complex than what is usually theorized, with uniqueness potentially hindering interpretability and, thus, the recognition of creativity by the field. Finally, I extend research on toolkits by showing how different characteristics of the toolkit can affect its effectiveness in shaping team outcomes, and by identifying the number of experts in the team as a key boundary condition for toolkit effectiveness.

Theory and Hypotheses

The basic elements of organizations are members, tools, and tasks (Arrow et al. 2000, McGrath and Argote 2001). These elements, and the way they are connected to each other, constitute the primary mechanisms through which knowledge is managed in organizations. Scholars have thoroughly investigated how creativity is affected by the knowledge acquired through social interaction processes (e.g., Hargadon and Bechky 2006, Perry-Smith and Shalley 2014) and teams' engagement with their tasks (e.g., Gino et al. 2010). Research on how technological tools affect creativity, on the other side, has so far focused only on how the introduction of information technologies facilitates creativity (e.g., Boland et al. 1994, Ashworth et al. 2004). Technology has been treated as a structural "background" element whose characteristics affect creativity only when they are used to enable the internal exchange of information (Argote and Miron-Spektor 2011). However, technology has an active role in shaping human agency (Giddens 1979, Orlikowski 2002), and could thus affect creative action much more significantly than currently theorized. In particular, the role of technological toolkits is likely to be relevant.

From Technological Tools to Technological Toolkits

When cross-disciplinary work is involved, teams are drawing "on a shared set of resources, as well as on additional resources that are not shared equally" by all team members (Leonardi 2011, p. 348). This means that teams do not use technological tools in isolation, but draw on a multiplicity of tools to construct their actions. While scholars have already described the combination of technological tools in a team toolkit (e.g., Boland et al. 2007, Carlile and Lakhani 2012, DeSanctis and Poole 1994), they have not explicitly defined what a technological toolkit is and how its characteristics affect creativity. The concept of toolkit was first introduced by Swidler (1986), and is defined as the set of objects, skills, or resources available to members of a social group. Scholars have looked at toolkits encompassing different types of tools, such as prototypes, metaphors, design tools, and human resource systems (e.g., DiBenigno and Kellogg 2014, Kellogg 2011, Seidel and O'Mahony 2014, von Hippel and Katz 2002). Each team member comes with his or her set of tools that he or she uses to execute tasks.

These tools might have different meanings for different members, but they possess some common structural features that make them understandable to other members across different disciplines (Carlile 2002, 2004; Nicolini et al. 2012; Star 1989).

Because of these common features, teams have the tendency to find connections between the tools previously used by their members (Carlile and Rebentisch 2003, DeSanctis and Poole 1994). They thus combine them to create a common pool of tools each member can draw from to execute their tasks. A team technological toolkit is thus defined as the set of technological tools that team members can draw upon to construct their actions. The toolkit is the sum of the different tools previously used by team members and represents the team's technological repertoire. Not all the tools included in a toolkit are necessarily used by the team in any given situation: they are *available* to be used, but it is up to the team to decide whether or not to use them (Swidler 1986).

As they interact, teams develop a shared understanding of each other's competences (Bechky 2003, Boland et al. 2007, Seidel and O'Mahony 2014), thus becoming more and more knowledgeable about which tools are present in the toolkit and who masters them (DiBenigno and Kellogg 2014). In other words, teams develop a transactive memory system (Wegner 1987; for a review, see Ren and Argote 2011) that allows team members to know who is knowledgeable about a specific tool and to retrieve the tools they deem more appropriate for each task. The presence of a transactive memory system means that the tool is not necessarily used by the team member who deems it appropriate for the task at hand: if he or she does not know how to use it, he or she can call upon another team member who is knowledgeable about it and ask him or her to use it. For example, Baker and Nelson (2005) describe how a group of repairers led by a guy named Roscoe was able to draw on tools included in a team toolkit thanks to their transactive memory system. Roscoe thought about realizing a product aimed at troubleshooting underground power lines in coal mines. The realization of the product required the use of a welding machine, something Roscoe was not proficient with. He thus involved one of his partners, who knew how to use the tool, in the project. Kamoche and Cunha (2001) and Peplowski (1998) describe a similar phenomenon in jazz ensembles. When they come together for the first time, ensemble members know little about others' preferences in terms of instruments, cords, and patterns. As they play together, members acquire an increasing "understanding of the role and contribution of other instruments, other than one's preferred one" (Kamoche and Cunha 2001, p. 748).

This suggests that team members need to be knowledgeable about, but not experts on, the tools in the toolkit. Tools carry details that can be understood by all team members, but only those using them are required to understand the full context of use (Carlile 2002, 2004; Nicolini et al. 2012). For example, at Gehry Partners, each team member learned the basic principles of 3-D design, even if they were not using it, to be able to communicate with other team members and external contractors and partners (Boland et al. 2007). Similarly, bioengineers in a high-tech project explicitly stated that they needed to understand only basic principles of how certain tools (e.g., sensors) can be used. In the words of one of them: "I don't need to understand how sensors work. I need to know very little about them, for example, whether they are working or not and how I can tell" (Nicolini et al. 2012, p. 617). Finally, Lucasfilm members were not proficient in classic animation, but they learned its basic principles to better understand Lasseter's and other animators' requirements (Price 2009). In the same fashion, Lasseter was not an expert of computer graphics, but learned the basics of Lucasfilm's animation software (Price 2009).

In all the instances described above, the formation and use of a technological toolkit helped the team to generate creative outcomes. This is consistent with the fact that teams involved in creative work often develop a collective mind that enables them to see similarities in their disparate perspectives on which they build to achieve creative synthesis (Hargadon and Bechky 2006, Harvey 2014, Lingo and O'Mahony 2010). The formation and use of a common toolkit is thus at the heart of creative work, and its characteristics are likely to have a relevant effect on the generation of creative outcomes. First, because tools can act as knowledge repositories, the composition of the team toolkit affects the common knowledge base the team can draw upon. As the knowledge base has been recognized as a relevant creativity antecedent in cross-disciplinary teams (e.g., Hargadon and Bechky 2006, Taylor and Greve 2006), the way it is composed is going to affect the team's ability to be creative. Second, technological toolkit characteristics can affect the effectiveness of the team's internal and external knowledge processes. Tools help to establish a shared language for representing knowledge, thus favoring its transfer, translation, and transformation across different disciplines (Argote and Ingram 2000; Carlile 2002, 2004; Carlile and Rebentisch 2003; Dougherty 1992). The composition of a team's technological toolkit is thus likely to influence how many disciplines team members can effectively exchange knowledge with. In particular, toolkit characteristics should affect the internal cross-disciplinary transfer of knowledge, as well as the type and amount of external knowledge the team is able to access. This, in turn, will affect the team's ability to generate novel and useful ideas. Toolkit characteristics can also affect the team's ability to create a shared understanding around their outcomes and, consequently, the likelihood that these outcomes are judged to be creative by the field. Many researchers have emphasized the importance of interpretability to ensure that an outcome is assessed as creative (e.g., Boudreau et al. 2012, Fleming et al. 2007, Laudel 2006, Perry-Smith and Mannucci 2017). Toolkit characteristics can impact the field's ability to understand the outcome generated through toolkit use and, consequently, its perceived creativity.

Size of the Toolkit

Teams with large toolkits should display an increased ability to generate new recombinations of existing knowledge that result in creative outcomes. This should happen for three reasons. First, each tool embeds knowledge about its use and possible applications (Orlikowski 2000). Every time teams use a tool, they can access the knowledge embedded in that tool: the higher the number of tools in the toolkit, the broader the pool of knowledge a team can access. Possessing a broad knowledge pool fosters the team's ability to come up with new ways of recombining existing knowledge, which is likely to lead to higher levels of creativity (Hargadon and Bechky 2006, Taylor and Greve 2006). Second, possessing a large technological toolkit increases the team's ability to access and acquire diverse knowledge from outside the team. As mentioned, tools can function as a shared language that allows translating and interpreting knowledge embedded in different social worlds (Carlile 2002, 2004; Orlikowski 2002; Star 1989). Owning a large toolkit should thus enable teams to "speak the language" of a larger number of other social groups, allowing them to access distant knowledge that would otherwise be difficult to acquire, thus increasing their likelihood to generate creative ideas. Finally, the ability to switch from one tool to another indicates cognitive adaptation and flexibility across knowledge domains (Weick 1996). Teams with a large toolkit must switch between a variety of domains, and thus have to think and act flexibly to effectively use them to address the task at hand (Orlikowski 2000, Swidler 1986). Teams whose members are cognitively flexible enjoy a creative advantage (Pirola-Merlo and Mann 2004, Taggar 2002), as cognitively flexible members are more likely to recombine and integrate existing knowledge into novel and useful ideas (Amabile 1983, Mednick 1962, Simonton 2003). Moreover, teams that possess a large toolkit are also more likely to display a more flexible collective cognition (Weick and Roberts 1993), enabling team members to mindfully consider each other's contributions, change frames, and consider the task from a different angle. This increases the likelihood that the team successfully recombines members' knowledge into novel and useful outcomes (Hargadon and Bechky 2006).

The advantages of having a large toolkit are not limited to those deriving from increased knowledge breadth, but include also improved coordination. Possessing a plurality of tools leads to a better understanding of objectives and goals, thus fostering coordination (Seidel and O'Mahony 2014). Moreover, the tangible nature of tools "makes it possible not only to uncover different meanings and perspectives, but also to understand the concrete implications of these differences" (Nicolini et al. 2012, p. 616). Possessing a large toolkit enhances the number of "translation devices" the team has at its disposal, thus fostering their ability to effectively coordinate work across different disciplinary boundaries. In other words, a team with a large toolkit has a higher likelihood of retrieving and using the tool that is most appropriate given the task at hand and the social worlds involved. For example, in Bechky's (2003) study of semiconductor chip designs, teams whose toolkits included both prototypes and drawings were better able to coordinate interdependent work than those whose toolkits included only one of the two. This happened because different disciplines had diverging preferences in terms of which tool to use: engineers preferred to work with prototypes, while designers preferred to work with drawings. Owning both tools allowed coordinating efforts with both disciplines, fostering the creation of a shared understanding and coordination efficiency. Since effective coordination is a fundamental precursor of team creativity (Hargadon and Bechky 2006, Harrison and Rouse 2014, Lingo and O'Mahony 2010), teams with large toolkits should display higher creativity.

Although toolkit size may facilitate team creativity, excessively large toolkits can become constraining. Extreme toolkit size might result in a reduced ability to achieve creative integration. In recent years, research has started to acknowledge that extreme levels of diversity can have disruptive effects on creativity (for a review, see Kannan et al. 2016). In particular, in a series of experiments, Harvey (2013) showed that when diversity is moderate, it fosters divergent thinking. However, when it becomes too high, it starts to engender negative effects on the team's ability to converge on a specific creative idea. Consequently, when toolkit size becomes too high, the recombination advantage is likely to be counterbalanced by a decrease in the ability to integrate different perspectives, a vital part of team creativity (Hargadon and Bechky 2006, Lingo and O'Mahony 2010). In addition, owning a toolkit that is too large can result in a decrease in coordination. Teams using an excessive number of tools might become unable to reach a shared understanding and align objectives because of the excessive number of representations (Leonardi 2011, Seidel and O'Mahony 2014). Instead of helping to bridge disciplinary boundaries, an excessively large toolkit can create new dividing lines within the group, fostering perceived diversity within the team and creating subgroups of "tool specialists" (Carlile and Rebentisch 2003). This in turn will hamper internal communication and coordination (Dougherty 1992, Hinds 1999, Polzer et al. 2002). As effective internal communication and coordination have been shown to be important predictors of team creativity (e.g., Harrison and Rouse 2014, Vera and Crossan 2005), teams with excessively large toolkits could be impaired in their creativity.

Altogether, these arguments suggest that toolkit size should facilitate team creativity, unless size is so high that coordination and integration problems become overwhelming and thus constrain creativity. I thus expect the relationship between toolkit size and team creativity to be quadratic, with teams with moderate toolkit size exhibiting the highest levels of creativity.

Hypothesis 1. *The size of a team's technological toolkit has an inverted-U-shaped relationship with team creativity.*

Field Diffusion of the Toolkit

As mentioned, each team assembles its own toolkit. However, some (if not all) of the tools it includes are likely to be used also by other teams. In other words, teams do not have full control of how many other teams use the same toolkit and, consequently, on the diffusion of the toolkit in the field. Albeit not entirely dependent on team agency, toolkit diffusion can have relevant effects on teams' external knowledge exchange. Teams with a highly diffused toolkit can enjoy advantages in terms of their ability to transfer and translate knowledge from outside the team. Having a toolkit that is highly diffused in the field means being able to use tools used by many other teams, and thus being able to effectively communicate with these teams. This will happen regardless of the internal diffusion of the tool within the team: even if just one team member uses a specific tool, this should enable the team to communicate and work successfully with other teams whose toolkits include the same tool. Research has in fact shown that teams can derive creative benefits from the boundary spanning activities of individual team members (Lingo and O'Mahony 2010, Perry-Smith and Shalley 2014). In particular, two teams from different disciplines can be bridged even if just one person in each team shares a common feature (in this case, the tool) that enables communication (DiBenigno and Kellogg 2014). Overall, this suggests that teams with a highly diffused toolkit should have access to and be able to effectively use a wider pool of knowledge than those using a "unique" toolkit, thus exhibiting higher creativity (Taylor and Greve 2006, Uzzi and Spiro 2005).

Using a diffused toolkit may also improve the likelihood that the outcomes produced by the team are recognized as novel and creative by the field. Creativity is a social product, generated not just by individuals' efforts, but also by the existence of a social system making judgments about these efforts (Cattani and Ferriani 2008, Csikszentmihályi 1999, Perry-Smith and Shalley 2003). To be creative, an outcome has to be judged as such by relevant audiences (Amabile 1996, Csikszentmihályi 1988). While creativity is commonly conceptualized as mainly driven by novelty and uniqueness, research shows that products that are too novel are actually at risk of being judged as less creative (Boudreau et al. 2012, Criscuolo et al. 2017, Uzzi et al. 2013). Excessively novel products can be difficult to interpret and understand, leading field members to judge the outcome as "weird," rather than novel, or to judge it as not appropriate or useful, resulting in a lower creativity assessment. This penalty is particularly strong when the audience is not very familiar with the methods and theories underpinning the creative contribution (Laudel 2006, Uzzi et al. 2013). As technological tools are characterized by a high level of knowledge tacitness and specificity (Orlikowski 2002), a team using a diffused toolkit should face a lower risk of having its outcomes judged as noncreative: the higher the number of people who can understand one's work, the higher the likelihood of it being recognized as creative.

On the other side, if the team uses a less diffused, more unique toolkit, only a few people in the field will be able to interpret and appreciate the novelty of the team's creative work. As an example, consider the introduction of computer graphics into the animation industry. Creators in the field considered the new technique unsuitable for animation, as it lacked vitality and expressiveness: objects and characters had a mechanic look that was totally unappealing. Field members were thus initially unable to understand the revolutionary creative potential of the new technique. As such, they discarded animated products realized with computer graphics as "odd" and strange, rather than creative. In an interview, John Lasseter recalled his and other people's reaction when they first saw an example of computer graphic animation, in 1980:

> Walt Disney had always tried to get more dimension in his animation and when I saw these tapes, I thought, this is it! This is what Walt was waiting for! But when I looked around, nobody at the studio at the time was even halfway interested in it. . . . I remember the head of the studio had only one question: "How much is this going to cost? . . . I'm only interested in computer animation if it saves money or saves time." (Schlender and Tkaczyk 2006, p. 66)

Because of the fact that few people understood its characteristics and features, computer graphics remained for many years a niche technique, used only for experimental short films. It took almost 15 years before the animation field recognized its creative potential thanks to Pixar's intuition of combining computer graphics with tips and principles from cel animation.

By doing so, Pixar formed a toolkit whose combination of the new tool with an established, diffused one made the final outcome more understandable by the field.

Hypothesis 2. *The diffusion of a team's toolkit within the field has a positive relationship with team creativity.*

Moderation of the Number of Experts with the Focal Tool

As mentioned above, team members have to be knowledgeable about each tool in the toolkit, but are not required to be experts. On the contrary, literature seems to suggest that having a high number of experts with the focal tool (i.e., the tool that is more relevant for task execution) might hinder the team's ability to use the toolkit in its entirety. Consequently, the effect of toolkit characteristics on creativity is likely to be stronger when the number of experts with the focal tool is not high.

The presence of many experts with a specific tool makes the risk of individual fixation and functional fixedness more widespread, reducing the likelihood of identifying connections between different tools (Haas and Ham 2015). Moreover, experts tend to steer their team's attention toward their area of expertise (Thomas-Hunt et al. 2003). Teams with a high number of experts with a specific tool are thus less likely to attend to other tools, and will tend to use only that tool for any given task (Kaplan 1964, Leonardi 2011, Weick 1996). This is what (Kaplan 1964, p. 28), calls the "law of the instrument": "A scientist formulates problems in a way which requires for their solution just those techniques in which he himself is especially skilled." On the other side, teams with a low number of experts with a specific tool display greater adaptability and ability to select the most appropriate tool given the circumstances (Weick and Roberts 1993). For example, during the fish project, the fact that long-time employees at Gehry's were not expert with low expertise with 2-D computer-aided design tools enabled the team to adapt more easily to the use of digital 3-D and to combine it with physical models (Boland et al. 2007).

While teams are likely to use a plurality of tools to execute a task, there will always be a focal tool. For example, while Pixar success originated from the combination of computer graphics and classic animation, computer graphics was the "signature tool" of the company, the one that was more relevant for the creation of their movies. The negative effect of a high number of experts within a domain on the likelihood of identifying connections between domains is particularly pronounced when the domain of expertise is "core," i.e., it is the most relevant to the task (for a review, see Haas and Ham 2015). Similarly, having a high number of experts with the focal tool might be particularly detrimental for seeing connections between tools and using the toolkit in its entirety. On the other side, teams where the number of experts with the focal tool is not high should be able to see potential interconnections and to successfully integrate the tools to execute creative tasks. For example, Pixar's team presented a mix of experts with hand-drawn animation, experts with computer graphics, and novices (Catmull and Wallace 2014, Price 2009). This team configuration allowed them to understand when using one or the other tool was more appropriate given the task at hand, and to integrate their features in a creative way. A high number of experts with the focal tool can even lead team members to not even perceive the existence of other tools in the toolkits (Dane 2010, Kaplan 1964). Their overlapping familiarity with the focal tool is likely to engender a common knowledge effect, leading team members to discuss only ideas on how to apply that tool to the creative task (Gigone and Hastie 1993, Stasser et al. 2000). Overall, this will result in lower toolkit integration, with the team possessing a multiplicity of tools but using only one of them. This will make the presence of other tools in the toolkit close to irrelevant, as team members will not even consider them regardless of the task, thus reducing the strength of the effect of toolkit characteristics.

More specifically, the presence of a high number of experts with the focal tool should reduce the coordination and flexibility benefits of a moderate toolkit size. Possessing a plurality of tools leads to better coordination only when there is a collective scrutiny of different perspectives (Seidel and O'Mahony 2014). Teams with many experts with the focal tool will be less likely to consider different perspectives and ways of doing things (Dane 2010, Kaplan 1964, Weick and Roberts 1993), with toolkit size resulting in less, rather than more, effective coordination (Seidel and O'Mahony 2014). Moreover, a high number of experts is likely to reduce also the creative benefits of moderate toolkit size in terms of external knowledge transfer, as specializing in one tool limits the exchange of knowledge with other social groups (Carlile 2002, Dougherty 1992). Consequently, the effect of toolkit size will become less strong.

For similar reasons, teams that include many experts with the focal tool might be unable to fully exploit the creative benefits of toolkit diffusion, reducing both the actual and the perceived creativity of their outcomes. As mentioned, the presence of a high number of experts should reduce the likelihood that team members communicate and discuss with other teams using different tools. This, in turn, will hinder the team's ability to access diverse knowledge, thus stifling their recombination ability (Taylor and Greve 2006). Moreover, having a high number of experts might reduce the benefits of toolkit diffusion for novelty recognition. If a team uses just the focal tool to execute a creative task, only audiences that are familiar with that tool will be able to recognize the novel features of the resulting outcome. In other words, when the number of experts with the focal tool is not high, the perceived creativity of a team's outcomes is going to be affected by the diffusion of the toolkit as a whole. On the other side, teams with a high number of experts with the focal tool will be more likely to use just that tool to generate creative outcomes; consequently, their outcomes' interpretability is less likely to be fostered by the diffusion of the toolkit as a whole, which could even become virtually irrelevant. The Pixar case provides a clear example: until Lasseter joined the Lucasfilm team, their creative efforts were praised just by computer graphic users, but not by classic animators, who at the time constituted the large majority of the field.

Hypothesis 3A. *The effect of toolkit size on team creativity is stronger when the number of team members who are experts with the focal tool is low than when it is high.*

Hypothesis 3B. *The effect of toolkit field diffusion on team creativity is stronger when the number of team members who are experts with the focal tool is low than when it is high.*

Methods

Setting: The Hollywood Animation Industry

To study the relationship between team toolkit characteristics and cross-disciplinary team creativity, data should allow us to identify teams of creators from different disciplines, as well as to measure the value of creative outcomes and the characteristics of teams' toolkits. The Hollywood animation industry is a unique setting that provides data meeting these empirical requirements. From the 1938 release of the first animated feature, *Snow White and the Seven Dwarfs*, the Hollywood animation industry has evolved to become one of the most creative and innovative industries. Animated features like *The Lion King*, *Toy Story*, *Chicken Run*, and *Shrek* have revolutionized animation techniques and moviemaking in general (Rodowick 2008). Technology and creativity are strictly interrelated in the Hollywood animation industry: in the words of Lasseter, "art challenges technology, and technology inspires art" (Catmull and Wallace 2014, p. 204). In particular, the creative success of the movie is almost entirely dependent on the use of technological tools, with actors' performance playing a very marginal role.

The animation industry is composed of a variety of creators, hired by studios such as Disney, Pixar, and Dreamworks to conceive, develop, and realize feature-length animated movies. The creative process in animation starts with the initial idea, the so-called "high concept," which is usually conceived by individual creators or within small teams (Catmull 2008). This idea needs then to be refined enough to convince decision makers—usually producers and/or senior filmmakers—that the idea has the potential to become a film that is viable and valuable from both the artistic and economic points of view. If the idea receives the green light, the creative process enters the production stage, where the initial idea is turned into a movie by a team involving multiple disciplines and functions like writing, drawing, editing, and animating. The final movie is the combination of the creative outcomes generated by different individuals, each contributing with their own specialized knowledge, technical expertise, and talent.

Technological Tools in Context: Animation Tools

I operationalize technological tools as animation tools. Animation tools (commonly known as animation techniques) are the most important technological tools used in the animation industry and constitute the shared stylistic vocabulary of creators. Animation tools have different meanings within different disciplines: for producers, an animation tool represents something that shapes the characteristics of the production process they will have to manage; for directors, the artifact that will give shape to their visual ideas; for screenwriters, something affecting their expressive possibilities in terms of characters and plot. However, tools possess some features that are common to all disciplines and make them a shared artifact that can be used to for effective cross-disciplinary communication and collaboration (Catmull and Wallace 2014, Laybourne 1998). Altogether, these arguments suggest that animation tools possess the characteristics to act as boundary objects: they have different meanings for different groups, but some common features that allow them to serve as means of translation without the need of "deep sharing" (Carlile 2002, Nicolini et al. 2012). Table 1 illustrates the animation tools used to realize feature animated movies during the observation period considered in my data set.

Animated movies can be grouped according to their focal tool, identified as the tool that was mainly used for their realization. The focal tool is used to realize the more "visible" parts of the movie and defines its visual style and aesthetical appearance (Laybourne 1998). Each movie is characterized by only one focal tool (Laybourne 1998). Everyone is required to have at least a basic understanding of the main characteristics and functions of the focal tool, even if they cover a role (e.g., producers, composers) that does not require the active use of animation tools. For example, producers can be asked to decide which level of image detail the budget will allow, and to answer properly, they need to understand how the image creation process works. While this is particularly true for the focal tool, this applies also to other tools in the team's toolkit. During the creative process, in fact, creators might have to use tools different from the focal one, either for a specific task or in mingling the focal tool with elements

Table 1. Descriptions of the Animation Techniques

Technique	Description
Cel animation	In this technique, each frame is drawn by hand on one side of thin, clear sheets of plastic called cels, while colors and details of the characters are painted on the reverse side. Then, the cels involved in a frame are laid on top of each other, and the composite image is photographed by a special animation camera, called rostrum camera. The cels are removed, and the process repeats for the next frame until each frame in the sequence has been photographed.
Rotoscoping	In this technique, animators trace over live-action footage, frame by frame, to turn it into drawings that will be subsequently animated. Tracing should be extremely precise to avoid, when animated, the lines shaking unnaturally and the result appearing blurred.
Live action/animation	In this technique, live-action and animated elements are combined and typically interact. Animated and live-action footage can be combined in several ways, from simply overlapping the two negatives into the same release print to using special printers and cameras. It is important to ensure exact positioning and a fluid interaction between live-action and animated characters and props.
Photorealistic computer animation	In this technique, animation is created through a computer and one or more animation softwares. Digital models are constructed out of geometrical vertices, faces, and edges in a 3-D coordinate system and are then sculpted, working from general forms to specific details with various sculpting tools. The models are then animated to simulate emotions and movement, and integrated with computer-generated backgrounds, lightning, and camera movements.
Motion capture	In this technique, animation is created by recording the actions of human actors in an attempt to approximate the look of live-action cinema. The movements of human actors are sampled many times per second and then mapped onto a computer-generated character model. The model is subsequently animated in such a way that it performs the same actions of the actor. Motion capture can also get the physical features of the actor and transfer them to the digital character model.
Clay animation	In this technique, each character and background element is created from clay or other malleable materials and then physically manipulated to make it appear to move on its own. The clay model is usually built around a wire skeleton—the armature. The resulting model is arranged in a certain position on the set and photographed once, before being slightly moved by hand to prepare it for the next shot.
Puppet animation	In this technique, characters are realized through puppets and movable dolls that are subsequently manipulated to make them appear to move on their own. The puppets are moved in small increments between individually photographed frames, as in clay animation, creating the illusion of movement when the series of frames is played as a continuous sequence.

from others (Laybourne 1998, Neale 2014). For example, character designers working in computer graphics movies often realize sculptures of their characters, like those you have in puppet animation, before translating them into digital images (Price 2009); creators working with cel animation can decide to use computer graphics to realize certain backgrounds (Laybourne 1998); and hand-drawn storyboards are often animated to give creators an early sense of what the movie will look like, even if the movie is not realized using hand-drawn animation as the main technique Catmull and Wallace (2014).

Data and Sample

The sample consists of the 218 animated movies produced in the United States and released in movie theaters from 1978 through 2012. The unit of analysis is the core team of creators. While recognizing that a movie is the result of the creative effort of a large number of individuals, I decided to concentrate on the restricted group of people that usually receive the credit for the creative work in a motion picture. This group, named the "core crew" or "core creative team" (Goldman 1983) includes the producer, director, writer, editor, cinematographer, production designer, and composer of original music score. In the animation industry, the roles of cinematographer and art director tend to overlap and are often covered by a single figure. I thus decided to consider also art directors in the sample. The choice of concentrating on the core creative team follows an established tradition in creativity literature (e.g., Cattani and Ferriani 2008, Delmestri et al. 2005, Perretti and Negro 2007).

I began the data collection by identifying all the animated movies produced in the United States and released between 1978 and 2012. I included all those movies for which animation was indicated as the main genre. This selection resulted in a sample of 218 movies. For each of these, I then identified the core crew members to gather information on toolkits, team size, and other team characteristics. The source for these data was the Internet Movie Database (IMDb), an online source used by a growing number of studies in recent years (e.g., Cattani and Ferriani 2008, Sorensen and Waguespack 2006). The reliability of the information obtained through IMDb was cross-checked with another data set, the Big Cartoon Database, as well as with company websites and other sources. The yearly average number of core crew members per movie ranged between 10 and 21. This number differs from

Table 2. Animation Techniques by Number of Movies

Technique	*N* movies	%
Cel animation	91	41.74
Rotoscoping	6	2.75
Live action/animation	18	8.26
Computer animation	83	38.07
Motion capture	6	2.75
Clay animation	5	2.29
Puppet animation	9	4.13
Total	218	100

the number of roles considered because sometimes the same person covered more than one role.

Another important step of the analysis was to identify the focal animation tool used for each movie. I classified the animation tools following the taxonomy provided by Laybourne (1998) and cross-checked it with the descriptions provided by Taylor (1999) and the IMDb "Movie Terminology Glossary." Table 2 shows the distribution of focal tools by number of movies. Not surprisingly, cel animation and computer animation are the most popular techniques, representing respectively 41.74% and 38.07% of the total number of movies realized in the observation period.

Measures

Dependent Variable. Creativity is defined as the generation of ideas, solutions, or products that are judged to be novel and useful by appropriate expert observers (Amabile 1996, Oldham and Cummings 1996). This definition is rooted in the notion that novelty and usefulness are not objective properties, but are shaped by the sociocultural context within which the creator is embedded (Amabile 1996; Csikszentmihályi 1988, 1999; Perry-Smith and Shalley 2003). Consistent with this definition, I recruited two expert judges to assess *team creativity*. The judges were recruited for their expertise in the animation industry (they were both critics with many years of experience) and provided their assessments independently. They were provided with the definition of creativity and were instructed to rate each movie's creativity on a Likert scale, ranging from 1 (not creative) to 5 (very creative). The fact that the ratings were provided 2 years or more after the movies were released allowed us to avoid simultaneity problems and thus reduce issues of reverse causality. However, since the judges also had to rate movies that were released up to 35 years ago, there was the risk that ratings were affected by a memory recall bias. Moreover, the evolution of tastes could also affect the validity of ratings, causing movies that were considered highly creative many years ago to no longer be considered creative today. I took two steps to rule out this possibility. First, judges were asked to rewatch movies they did not remember well. Second, I checked whether there was a significant difference between the mean ratings of movies produced before and after 2001 (the mean value of the production year). The difference was not statistically significant ($\text{mean}_{\text{before}} = 5.78$; $\text{mean}_{\text{after}} = 5.75$; $t = 0.14$, $p > 0.10$, two-tailed). Analyses run using more recent years as thresholds yielded identical results. I can thus safely conclude that creativity ratings were not affected by recall bias.

I assessed interrater reliability using Cohen's (1960) weighted kappa, which is more appropriate in the presence of ordinal variables (Bakeman and Gottman 1997). The average k for the overall reliability of creativity ratings was 0.86 ($Z < 0.000$), which is well above the accepted threshold of 0.61 that is acknowledged as a good level of overall agreement (Kvalseth 1989). The average of the two ratings was thus used as the measure of creativity.

Independent Variables. I computed the characteristics of a team's toolkit in three steps. First, I assessed the toolkit of each individual crew member as the set of tools that she or he had acquired up to a given year. For example, if a creator worked in movies using cel animation and computer graphics, her or his toolkit was composed by these two tools. As a second step, I assessed the composition of a team toolkit as the combination of the team members' toolkits. Finally, I computed the size and field diffusion of the team toolkit. I measured team *toolkit size* as the number of non-overlapping animation tools present in the team toolkit in the focal year. For example, if a team had a member whose individual toolkit included cel animation and computer graphics and another member whose toolkit included cel animation and rotoscoping, that team had a team toolkit size equal to three. I calculated a team's *toolkit field diffusion* as the ratio between the total number of teams using a specific toolkit up to the focal year and the total number of teams that were active up to that year. Finally, I calculated the *number of experts with the focal tool*. Since the level of expertise was also likely to play a role, I decided to create a weighted measure of the number of experts. I took two steps to create this measure. First, I computed the number of team members that had already used the focal tool for at least two movie projects before the observation year. Then, I multiplied this number for the team members' average expertise with the focal tool.

Control Variables. I included several control variables to account for movie and team characteristics that can influence the team's ability to generate creative outcomes and the characteristics of their toolkit. First, I included a binary variable measuring whether a movie was a sequel or not (*sequel*) to account for possible variations of judges' evaluation in case of movies that do not reflect a search for artistic novelty in terms of situation and characters. Second, I controlled for the movie's *budget*, calculated as the natural logarithm of the production budget of the movie. Creativity research has argued that financial resources can have positive (Amabile et al. 1996, Madjar et al. 2011) and negative (Baer and Oldham 2006, Ohly and Fritz 2010) effects on creativity. While I remain agnostic on the direction of its effect, I decided to include production budget in the analysis. Information on this variable was retrieved from IMDb and cross-checked using www.boxofficemojo.com, an online website devoted to providing financial information about motion pictures. I also controlled for *team size*, calculated as the number of team members. This measure was included because larger teams have been found to generate more creative outcomes because they provide access to a wider array of perspectives (e.g., Taylor and Greve 2006). I controlled for teams' *disciplinary diversity*. As for financial resources, disciplinary diversity has been found to affect team creativity, but the direction of this effect is still in question, with research reporting both positive (e.g., Bantel and Jackson 1989) and negative (e.g., Ancona and Caldwell 1992) effects. Moreover, controlling for this variable is particularly relevant for the present study, given the theorized effects of tools as boundary objects affecting cross-disciplinary collaboration. To compute this variable, each creative role was considered as a different discipline. Disciplinary diversity was calculated by using Blau's (1977) index. I also controlled for *repeated collaboration* patterns among team members, calculated as the number of dyads within the team with previous collaboration history. Finally, I controlled for *team quality*, expressed as the sum of the number of awards and nominations bestowed by relevant Hollywood societies that team members received prior to the focal year.

I also included control variables to account for tool and toolkit characteristics that could also affect team creativity and/or the team's capability to effectively use the toolkit as a whole. First, I controlled for the diffusion of the focal tool (*focal tool diffusion*), calculated as the ratio between the number of movies realized with that tool up to the focal year and the total number of movies realized up to that year. While the collaborative nature of filmmaking and the nature of tools make team toolkit characteristics more relevant for team creativity, the diffusion of the focal tool could independently affect the team's ability to communicate with others. Teams using a niche toolkit might enjoy some advantage in terms of perceived uniqueness and novelty, or suffer disadvantages because of low interpretability. Second, I controlled for the degree to which a toolkit was similar to others in the field. I measured *similarity to other toolkits* using the Jaccard similarity index (Hanneman and Riddle 2005). I computed the index with a two-step procedure. First, I created a rectangular two-mode matrix of toolkits (rows) by tools (columns), indicating a value of 1 when the tool was included in the toolkit and 0 otherwise. I then computed the index based on this matrix, using the procedure included in UCINET (Borgatti et al. 2002). This index reflected the degree to which toolkits where similar to each other.

Finally, I included a dummy for each observation year and for each focal tool to control for the existence of unobserved time-varying factors and tool-specific characteristics. To control for the possibility that team creativity is affected by unobserved company characteristics, I also included a dummy for production companies. Including a dummy for production companies with only one movie produced in the observation period would have resulted in collinearity problems. Moreover, adding an excessive number of control variables could result in an overspecification of the model with little or no increase in predictive power (Greene 2011). I thus included a dummy for each company that produced more than five movies (the median number of movies produced) in the observation period. These companies accounted for 55% of the total sample.[1]

Results

Table 3 displays the correlations and descriptive statistics. While I mean centered toolkit size to compute the squared term to avoid collinearity, here I provide the statistics for the uncentered variable. I ran hierarchical regression analyses to test the hypotheses. I entered the variables into the analysis at four hierarchical steps: (1) control variables, (2) predictor variables, (3) linear interactions, and (4) a quadratic interaction. Table 4 summarizes the results. Among the control variables, we find budget ($\beta = 0.24$, $p < 0.05$) and disciplinary diversity ($\beta = 0.14$, $p < 0.10$) to be positively and significantly related to team creativity, while focal tool diffusion and being a sequel have a negative effect ($\beta = -0.75$, $p < 0.01$ and $\beta = -0.13$, $p < 0.05$, respectively). The coefficient for the linear term of toolkit size is positive and significant ($\beta = 0.50$, $p < 0.01$), and the squared term is negative and significant ($\beta = -0.35$, $p < 0.01$). This result seems to support Hypothesis 1. To further support presence of an inverted-U-shaped relationship, I ran the test recommended by Haans et al. (2016) using the command *utest* in STATA 14. The test was significant ($t = 3.62$, $p < 0.001$), indicating the existence of an inverted-U-shaped relationship between toolkit size and team creativity. Hypothesis 1 is thus supported. Consistent with expectations, teams with a moderately large toolkit are more likely to produce creative outcomes. Figure 1 plots the curvilinear effect. In line with Hypothesis 2, the field diffusion of the toolkit is positively related to creativity ($\beta = 0.21$, $p < 0.05$), suggesting that teams using a more diffused toolkit are judged to be more creative. Hypotheses 3A and 3B

Table 3. Correlation Matrix and Descriptive Statistics

Variable	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12
1. *Creativity*	5.764	1.605												
2. *Toolkit size*	2.532	1.057	0.235											
3. *Toolkit size squared*	7.523	6.308	0.161	0.966										
4. *Toolkit field diffusion*	0.130	0.126	−0.110	−0.547	−0.498									
5. *Number of experts with the focal tool*	2.571	4.373	0.117	0.203	0.167	−0.081								
6. *Sequel*	0.133	0.340	−0.065	0.135	0.103	−0.093	0.308							
7. *Budget*	7.579	0.524	0.332	0.465	0.391	−0.314	0.306	0.156						
8. *Team size*	15.225	5.131	0.144	0.278	0.253	−0.212	0.078	−0.045	0.338					
9. *Disciplinary diversity*	0.728	0.085	0.129	0.176	0.157	−0.096	0.032	0.106	0.136	−0.458				
10. *Repeated collaboration*	10.188	15.288	0.076	0.236	0.219	−0.134	0.565	0.372	0.219	0.291	−0.175			
11. *Team quality*	7.688	9.496	0.363	0.479	0.431	−0.262	0.490	0.225	0.540	0.253	0.092	0.441		
12. *Focal tool diffusion*	0.407	0.275	−0.133	−0.447	−0.395	0.542	0.123	−0.000	−0.319	−0.079	−0.154	−0.004	−0.174	
13. *Similarity to other toolkits*	0.765	0.104	0.052	−0.548	−0.354	0.455	0.187	0.228	0.418	0.149	0.222	0.089	0.366	−0.215

Notes. $N = 218$. All correlations above $|0.13|$ are significant at $p < 0.05$.

predicted that the effects of toolkit size and field diffusion were going to be less strong when the number of experts with the focal tool was high. The coefficient of the linear interaction is negative and significant for both toolkit size and diffusion ($\beta = -0.28$, $p < 0.01$ and $\beta = -0.18$, $p < 0.05$, respectively). Hypothesis 3B is thus supported. Model 4 shows that the coefficient for the quadratic interaction is only marginally significant ($\beta = 0.21$, $p < 0.10$), thus providing only partial support for Hypothesis 3A. However, the analysis of the average marginal effects reveals that the squared term of toolkit size is significant at low levels of expertise with the focal tool ($p < 0.01$), and not significant at higher levels. The same pattern can be observed for toolkit field diffusion, with diffusion having positive and significant effects on team creativity when expertise is low ($p < 0.01$) and nonsignificant effects when expertise is high. Slope analysis (Aiken and West 1991) confirms these findings, with toolkit size squared and toolkit diffusion having positive and significant effects for low levels of expertise ($p < 0.01$ and $p < 0.05$, respectively) and nonsignificant effects for high levels of expertise. Figures 2 and 3 plot the marginal average effects for toolkit size squared and toolkit diffusion.[2] Overall, the marginal effect analysis and slope analysis provide support for Hypothesis 3A and further support for Hypothesis 3B. This corroborates the idea that toolkit characteristics matter only when the number of experts with the focal tool is low or moderate; otherwise, their effect becomes nonsignificant.

Robustness Checks

I took three steps to assess the robustness of the results. First, to further explore my moderation hypotheses, I performed a split sample analysis (Shaver 2007). I estimated Model 2 at above-mean and below-mean levels of number of experts with the focal tool. The results of this analysis were consistent with those presented above: at below-mean levels, the effect of toolkit size is curvilinear ($\beta_{linear} = 0.70$, $p < 0.01$; $\beta_{squared} = -0.40$, $p < 0.01$), while diffusion has a positive effect ($\beta = 0.36$, $p < 0.01$); at above-mean levels, toolkit size and diffusion do not have a significant effect on creativity.

Second, I tested the robustness of the results to different specifications of the moderator. In particular, I tested the moderating effect of the two variables that together constituted my weighted measure of number of experts: (1) average expertise with the focal tool and (2) the number of experts with the focal tool in the team. Results were consistent with those presented above for both measures: toolkit size squared had a negative and significant effect at low levels of expertise and number of experts ($p < 0.01$ for both variables), and a nonsignificant effect at higher levels. In the same fashion, the effect of toolkit diffusion was positive and significant effect when average expertise and number of experts were low ($p < 0.01$ for both variables), and was not significant at higher levels.

Third, I ran the analysis using another operationalization of team creativity: average critics' ratings (mean = 5.96; S.D. = 1.40). Critics are independent field experts that provide systematic assessments of cinematic creativity (Hsu 2006, Simonton 2004). Their job is to assess the creativity of a movie, without taking into consideration other elements like its box office success. While in theory they can still be affected by other elements not directly related to creativity, such as movie quality and enjoyment, they have already been validated as a measure of creative success (e.g., Uzzi and Spiro 2005) and represent a natural version of Amabile's (1996) consensual assessment technique. Data were obtained from a well-established online public source, www.rottentomatoes.com, which assigns each movie a score of critical reception. The score is based on a wide number of movie reviews from accredited media outlets and critics' societies. For each review, the

Table 4. Hierarchical Regression Analyses Predicting Team Creativity

Variables	Model 1	Model 2	Model 3	Model 4
Step 1: Controls				
Team size	0.025	0.024	0.012	0.005
	(0.026)	(0.025)	(0.025)	(0.025)
Sequel	−0.633*	−0.749*	−0.670*	−0.564†
	(0.318)	(0.300)	(0.296)	(0.300)
Budget	0.736*	0.611*	0.559*	0.602*
	(0.300)	(0.284)	(0.278)	(0.277)
Disciplinary diversity	2.618†	2.841†	2.927*	2.650*
	(1.546)	(1.469)	(1.437)	(1.435)
Repeated collaboration	0.003	0.008	0.007	0.002
	(0.008)	(0.009)	(0.009)	(0.009)
Team quality	0.012	0.006	0.009	0.014
	(0.016)	(0.015)	(0.015)	(0.015)
Focal tool diffusion	−4.383**	−3.940*	−4.010**	−4.100**
	(1.629)	(1.557)	(1.523)	(1.513)
Similarity to other toolkits	3.538	−2.169	−3.176	−3.832
	(2.263)	(2.479)	(2.469)	(2.478)
Step 2: Main effects				
Toolkit size		0.762**	0.696**	0.604**
		(0.172)	(0.171)	(0.177)
Toolkit size squared		−0.311**	−0.292**	−0.237**
		(0.067)	(0.067)	(0.073)
Toolkit field diffusion		2.716*	2.532*	2.341†
		(1.284)	(1.257)	(1.252)
Experts with focal tool		−0.052†	−0.022	−0.026
		(0.030)	(0.033)	(0.033)
Step 3: Linear interactions				
Toolkit size × Experts			−0.102**	−0.177**
			(0.033)	(0.053)
Toolkit field diffusion × Experts			−0.663*	−0.880*
			(0.319)	(0.339)
Step 4: Quadratic interaction				
Toolkit size squared × Experts				0.043†
				(0.024)
Year dummies	Yes	Yes	Yes	Yes
Company dummies	Yes	Yes	Yes	Yes
Tool dummies	Yes	Yes	Yes	Yes
R^2	0.319	0.405	0.431	0.439
ΔR^2		0.086**	0.026*	0.008†
N	218	218	218	218

Note. Unstandardized coefficients are shown with standard errors in parentheses.
†$p < 0.10$; *$p < 0.05$; **$p < 0.01$.

quantitative score provided by the critic is converted to an 11-point scale (i.e., 0 to 10). The individual scores are then averaged to produce an overall critics' rating. The resulting measure was highly correlated with the creativity measure used in the main analysis ($r = 0.86$). Results are consistent with those presented above, with toolkit size having a significant curvilinear effect on team creativity ($\beta_{linear} = 0.34$, $p < 0.01$; $\beta_{squared} = -0.19$, $p < 0.05$) and diffusion having a positive and significant effect ($\beta = 0.25$, $p < 0.05$). Expertise negatively moderates the effect of diffusion ($\beta = -0.22$, $p < 0.05$), while it does not moderate the effect of toolkit size squared.

Results from these analyses are not reported, because of space constraints, and are available from the author upon request.

Discussion and Conclusions

My overarching goal was to gain a deeper understanding of the relationship between technological toolkits and team creativity. In particular, I wanted to understand how the characteristics of the technological toolkit used by a team affect its creativity. I hypothesized toolkit size and field diffusion affect teams' ability to generate outcomes that are judged to be creative by the field. I found empirical support for these

Figure 1. Main Effect of Toolkit Size

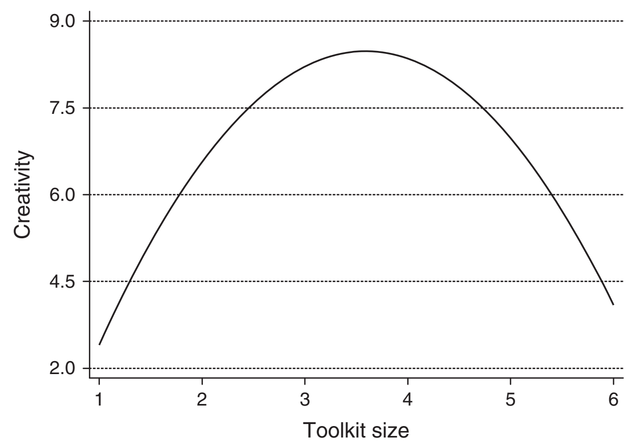
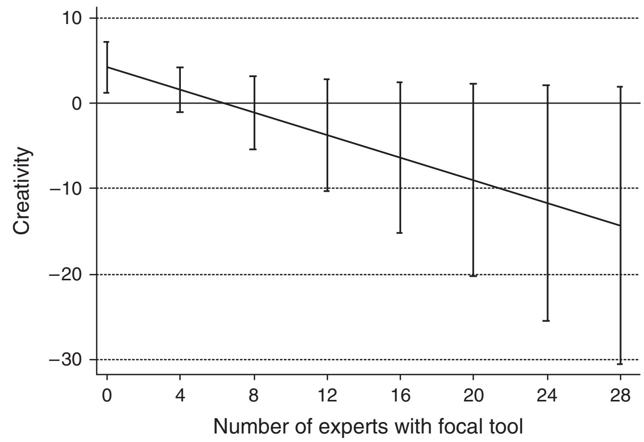


Figure 3. Average Marginal Effects of Toolkit Diffusion on Team Creativity

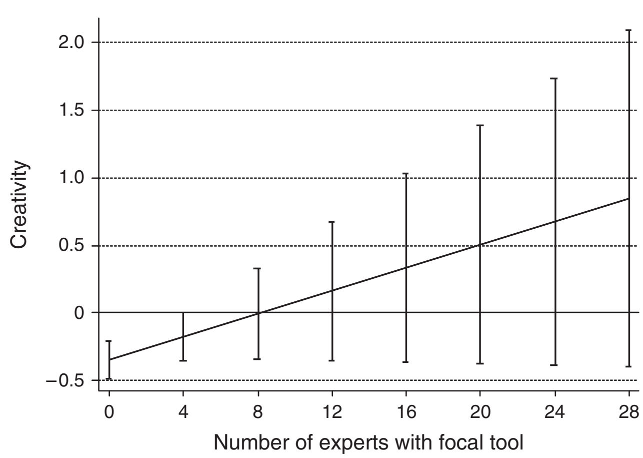


hypotheses. First, results showed that teams with moderately large toolkits are more creative. Second, results suggest that working with a toolkit that is highly diffused in the field positively affects team creativity. Finally, I also found support for two moderation hypotheses on the role of the number of experts with the focal tool. Results show that when the number of experts is high, the effects of toolkit size and toolkit field diffusion become less relevant.

Theoretical Contributions

Overall, this study makes a number of contributions. First, it introduces a focus on technology into research on team creativity. Creativity scholars have not closely examined the role that structural elements like technology play in the creative process, concentrating on personal, social, and contextual characteristics (for reviews, see George 2008, Shalley et al. 2004). However, literature has been suggesting for a long time that technological tools might play a relevant role in shaping team processes that are relevant for creativity, particularly in cross-disciplinary teams (Carlile 2002, 2004; Carlile and Rebentisch 2003). This study extends this line of research by focusing on the characteristics of the technological toolkit (rather than tools in isolation) that the team can use to execute its creative tasks. My results suggest that toolkit characteristics have a very relevant effect on cross-disciplinary teams' creativity. In the words of James Cameron, the director of many groundbreaking movies such as *Terminator 2* and *Avatar*, "it is the technology that enables the creativity" (Rottenberg 2014).

Figure 2. Average Marginal Effects of Toolkit Size Squared on Team Creativity



I also extend Carlile's (2002, 2004) work by theoretically considering together two functions played by tools (knowledge repositories and boundary objects), instead of theorizing about them in isolation. In doing so, I answer the call for consideration of the pluralist nature of objects and tools to fully understand their impact within the context of cross-disciplinary collaboration (Nicolini et al. 2012). For example, the effects of toolkit size cannot be fully understood by considering tools only as knowledge repositories representing different knowledge domains, as is usually done in extant creativity literature (Argote and Miron-Spektor 2011). The "variance hypothesis" would in fact predict that the number of domains (i.e., knowledge breadth) has a positive effect on creativity (Dahlander et al. 2016, Taylor and Greve 2006). Considering tools also as boundary objects allows us (a) to identify different mechanisms through which the number of tools in a toolkit can foster creativity and (b) to understand how an excessive number of tools can undermine creativity by hampering coordination and integration. Altogether, my findings raise a strong case for additional research on the role that technology plays in shaping the generation and the external evaluation of creative outcomes. Future research could focus on other toolkit characteristics and on how the interrelationship between tools and task affects team creativity.

Second, I contribute to creativity literature by showing that the relationship between uniqueness and creativity is more complex than what is usually theorized. Uniqueness is generally considered a central feature of creativity (e.g., Audia and Goncalo 2007, De Dreu et al. 2008). However, my findings suggest a more nuanced story, where uniqueness needs to be balanced with interpretability to achieve creativity. On one side, I show that team toolkit uniqueness is detrimental for creativity because it impairs external knowledge exchange and the field's ability to understand, appreciate, and reward the team's creativity. In doing so, I corroborate research that suggests the existence of a penalty for very novel ideas, proposals, and outcomes (Boudreau et al. 2012, Carlile and Lakhani 2012, Criscuolo et al. 2017). On the other side, I show that focal tool uniqueness positively affects creativity. A potential explanation comes from recent research that shows that to be judged as creative by the field, teams should try to generate outcomes that combine a large number of more diffused elements with a small number of unique ones (Uzzi et al. 2013). The present study suggests that using a unique focal tool can have a positive effect on team creativity if the tool is embedded in a toolkit that includes other more diffused tools. This combination will ensure a balance between interpretability and experimentation that allows field members to understand the outcome, enabling them to recognize its novelty. The case of Pixar provides a perfect illustration: the combination of a new tool (computer graphics) with a diffused one (cel animation) allowed the company to create a product that was at the same time novel and understandable by field members. The creation of this more diffused toolkit allowed Pixar to overcome skepticism about the cold and unnatural look of computer graphics and to create characters full of emotions and personality like Buzz Lightyear and Woody, the protagonists of *Toy Story*.

I also contribute to research on toolkits and repertoires. I show how different characteristics of the toolkit can influence its effectiveness in shaping team outcomes. In general, the toolkit literature has looked only at how toolkits are assembled and used, and at how their presence or absence can affect collective outcomes (e.g., Kellogg 2011, DiBenigno and Kellogg 2014). However, recently, Seidel and O'Mahony (2014, p. 695) suggested that considering toolkit size is important to pinpoint "how people draw from a plurality of meanings to accomplish common understanding." In particular, they showed that the effects of possessing a large toolkit on design innovation are contingent on the achievement of concept coherence. My findings on the effect of toolkit size corroborate Seidel and O'Mahony's (2014) idea that toolkit size fosters team creativity, and extend it by showing that its effect is actually curvilinear: size is not always beneficial, as excessive toolkit size can become problematic and constrain, rather than promote, creativity. Moreover, I provide a more fine-grained theoretical explanation for the effect of toolkit size by suggesting that this curvilinear effect is due to the trade-off between recombination and integration and to the tension between coordination benefits and disruption. In addition, I explore the effect of toolkit diffusion, introducing a focus on how toolkits have effects that spur also outside the considered unit of analysis (team or dyad). Finally, building on research on knowledge integration, I also identify the number of experts with the focal tool as a boundary condition limiting the team's ability to use the toolkit in its entirety. In doing so, I corroborate and extend research that suggests that expertise affects the way individuals frame and perceive technology (Leonardi 2011). This suggests that toolkits might not always be effective in promoting cross-disciplinary collaboration. Future research could explore more closely how toolkit characteristics affect team processes and performance, as well as the boundary conditions for their effectiveness. For example, familiarity among team members might affect the relationship between toolkit characteristics and creativity by influencing how team members use and combine their tools. Teams whose members are affectively close and trust each other might be more effective in integrating tools and in applying the toolkits to creative purposes, because of increased willingness and motivation to collaborate.

Limitations and Directions for Future Research

This study comes with some limitations. First, my sample of creative teams in the Hollywood animation industry may not be representative of most organizations, given the high degree of technology use and the industry focus on creative activities. Therefore, these findings are likely to be most useful for cross-disciplinary teams working in industries with similar characteristics, such as high technology, product design, automotive, and computer coding. It is also worth noting that research conducted in the field of scientific discovery has shown that technology shapes the ability to make new contributions (e.g., Fujimura 1992, Latour 1987, Pickering 1993). On the other side, my findings might not generalize well to other types of industries where technology use is lower and/or where efficiency and profitability, and not creativity, are the main goals. However, two issues are worth noting: first, the use of technology is becoming pervasive in all types of knowledge-intensive work (Barley 1986); second, the dilemmas experienced by managers in cultural industries are also found in a growing number of other industries (Lampel et al. 2000). For example, cross-disciplinary teamwork is becoming more and more common, with team coordination being a central issue for every kind of group work (Hackman 1987, Okhuysen and Bechky 2009). Despite these features, however, the possibility that the phenomenon of interest plays out differently in other settings cannot be completely ruled out. For instance, in contexts where social judgment is less important or is in the hands of a restricted number of people (e.g., the supervisor), possessing a diffused toolkit might be less beneficial. Future research could explore the relationship between the characteristics of technological toolkits and team creativity in other settings where technology is less pervasive, creativity is not the main goal, and/or social judgment is less relevant.

A second limitation of this study derives from the archival nature of my data. Adopting an archival and quantitative research design provided me with longitudinal data that allowed me to punctually identify toolkit characteristics, as well as to define a pattern of causality. However, the archival nature of the sample did not allow me to directly observe team processes at work, thus limiting my ability to describe precisely what happens within the teams. For example, I cannot say whether the effect of toolkit size on team creativity is driven more by knowledge recombination/integration or by coordination. Moreover, I could not observe the degree to which teams can modify their toolkits over time, and whether they are fully aware of their characteristics. While it is worth noting that a toolkit is defined by the tools the team has at its disposal, regardless of their actual use, the lack of direct observation of technology use, toolkit evolution, and team processes represents a limitation of the current work. Future research could explore this issue through methodologies that allow a more precise assessment of team processes and practices, such as in-depth ethnography, participatory observation, and other qualitative approaches.

Finally, given the archival nature of this study, I could focus only on characteristics of the tools that were observable from outside the team. However, toolkits with the same size and diffusion can vary deeply in terms of which tools are used/not used and of the relative salience of each tool. As an example, consider two Pixar movies, *Monsters, Inc.* and *The Incredibles*. Teams who realized these movies had the same toolkit (including hand-drawn animation, computer animation, and live action/animation), with the same characteristics in terms of focal tool (computer graphics), toolkit size, and toolkit diffusion. However, they differed in the relative salience of each tool. *Monsters, Inc*. posed significant challenges in terms of character animation, and thus saw animators focusing more on the development and use of computer graphics, giving less importance to the other two tools (Price 2009). *The Incredibles*, instead, was characterized by an intensive use of hand-drawn storyboards, which were used to show how the story was evolving and to communicate changes to animators (Catmull and Wallace 2014, Price 2009). While computer graphics was still the focal tool, the use of hand-drawn animation (both to realize the movie and as a boundary object) was much more salient in *The Incredibles* than in *Monsters, Inc.* Exploring how tools are used within a toolkit and their relative salience constitutes a promising avenue for future research.

Managerial Implications

The results of this study have interesting implications for managers and practitioners, particularly in industries where technology use is central to task execution. First, they provide insights into how to increase the likelihood that a cross-disciplinary team will generate creative outcomes. Managers should encourage team members to experiment with different tools and/or assemble teams considering individual toolkits to ensure diversity and complementarity in tool use. This should enable team members to overcome disciplinary barriers and foster cross-disciplinary creative collaboration. In the words of Kit Laybourne (1998, pp. 48–49), “it’s in the breaking out from and cross-fertilization of established techniques that the best new forms of expression are found.” However, at the same time, managers should prevent teams from adding too many tools to their toolkits, to avoid the emergence of subgroups of experts and thus the worsening, rather than the improvement, of internal coordination. Second, this research provides suggestions on whether managers should pay more attention to the characteristics of the focal tool or those of the toolkit. Teams composed by a majority of experts with the focal tool will be unable to use the toolkit in its entirety: for these teams, what will matter are the characteristics of the focal tool. On the other side, teams that do not include many experts with the focal tool will be more affected by toolkit characteristics. Third, managers should carefully balance toolkit size with its field diffusion to ensure the interpretability of team outcomes. While managers do not have full control over how diffused a given toolkit is in the field, they can act to change the toolkit of a team, for example, by changing its members. Managers should thus closely monitor the field and intervene if they notice that the toolkit used by the team is excessively unique.

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Endnotes

[1] I also tried less restrictive specifications of this variable, including a dummy for each company that produced at least two movies within the observation period (87% of the sample). Results were consistent with those presented in the main analysis, but the *R*-squared did not significantly improve despite the inclusion of extra variables. I thus decided to use the model with fewer variables in the main analysis.

[2] I chose to report only the graph for the quadratic term because of space constraints. This is consistent with Aiken and West (1991), who suggest that the significance of the quadratic term is enough to indicate the presence of a curvilinear effect.

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