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Adopting Design Thinking in Novice Multidisciplinary Teams: The Application and Limits of Design Methods and Reflexive Practices*

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Scholarly and practitioner literature have both described the potential benefits of using methods associated with a "design thinking" approach to develop new innovations. Most studies of the main design thinking methods—needfinding, brainstorming, and prototyping—are based either on analyses of experienced designers or examine each method in isolation. If design thinking is to be widely adopted, less-experienced users will employ these methods together, but we know little about their effect when newly adopted. Drawing on perspectives that consider concept development as broadly consisting of a divergent concept generation phase followed by a convergent concept selection phase, we collected data on 14 cases of novice multidisciplinary product development teams using design methods across both phases. Our hybrid qualitative and quantitative analysis indicate both benefits and limits of formal design methods: First, formal design methods were helpful not only during concept generation, but also during concept selection. Second, while brainstorming was valuable when combined with other methods, increased numbers of brainstorming sessions actually corresponded to lower performance, except in the setting where new members may join a team. And third, increased team reflexivity—such as from debating ideas, processes, or changes to concepts—was associated with more successful outcomes during concept generation but less successful outcomes during concept selection. We develop propositions related to the contingent use of brainstorming and team reflexivity depending on team composition and phase of development. Implications from this study include that novice multidisciplinary teams are more likely to be successful in applying design thinking when they can be guided to combine methods, are aware of the limits of brainstorming, and can transition from more- to less-reflexive practices.

Introduction

Both scholarly and practitioner literature have exhibited widespread interest in the application of design methods for promoting innovation, often referred to as the use of "design thinking." Management scholars have been increasingly interested in how design methods are applied to innovation challenges (Beckman and Barry, 2007; Ravasi and Lojacono, 2005; Verganti, 2008; Veryzer, 2005), and design practitioners advocate the application of design thinking across many areas of business (Brown, 2009; Lockwood, 2010; Martin, 2009). An important aspect of a design thinking approach is that "design has become too important to be left to designers" (Brown and Katz, 2011, p. 381), and so design thinking can be viewed as the application of design methods by multidisciplinary teams to a broad range of innovation challenges.

While the precise terminology describing the formal methods used in design thinking can differ among authors, three main methods are typically described: needfinding, brainstorming, and prototyping (cf. Brown, 2009; Hargadon and Sutton, 1997; Shane and Ulrich, 2004). Some studies have looked at a single method in great detail, such as in the long history of experimental studies of brainstorming effectiveness (Diehl and Stroebe, 1987; Nijstad, Stroebe, and Lodewijkx, 1999; Taylor, Berry, and Block, 1958). Other studies have looked at methods when used together, using field work of experienced designers (Hargadon and Sutton, 1997; Perks, Cooper, and Jones, 2005). What has been underexplored is how the range of design thinking methods are actually used in multidisciplinary teams that newly adopt a design thinking approach.

Understanding how novice multidisciplinary teams make use of design methods is an area of increasing importance, considering that organizations are being encouraged to adopt design thinking in areas where people may not have prior experience with such methods.

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If implemented poorly, challenges to adoption may lead to abandonment of a design thinking approach without realizing potential benefits. In a study of brainstorming among experienced designers at product design firm IDEO, one designer noted that "The skills for successful brainstorming develop in an individual over time" (Sutton and Hargadon, 1996, p. 693). The adoption of design thinking by novice multidisciplinary teams may require practices not apparent when studying experienced designers.

To explore this research gap, we designed a study to address the following question: How do novice multidisciplinary teams use design methods to successfully develop novel concepts? The study employed a case-based research approach using both qualitative and quantitative data, examining the use of formal design methods and informal practices among teams of varying performance. The research design included gathering data across the two main phases of concept development described by the scholarly and practitioner literature. The first phase is focused on a divergent process of creating a range of product concepts and is often termed "concept generation" (Beckman and Barry, 2007; Crawford and Di Benedetto, 2011; Ulrich and Eppinger, 2012). The second phase is primarily convergent, evaluating and selecting a final concept prior to proceeding through to detailed development and product launch (Crawford and Di Benedetto, 2011; Ulrich and Eppinger, 2012). Common terms for this second phase include "concept evaluation" (Crawford and Di Benedetto, 2011) or, as we will use, "concept selection" (Beckman and Barry, 2007; Ulrich and Eppinger, 2012).

The results indicate both benefits and limits of formal methods and informal practices. First, formal methods were helpful not only during concept generation, but also during concept selection. Second, there were limits to effectiveness, as holding more brainstorming sessions was related to lower performance, and we develop propositions about how formal methods such as brainstorming can best be tailored to the context. Finally, increased group task reflexivity (West, 1996)—specifically seen in more debate over ideas, processes, and concept changes—was associated with more successful outcomes during concept generation, but during concept selection the opposite was true. The implications are that the successful adoption of design thinking relies on coupling formal methods and reflexive team practices according to team composition and phase of development.

BIOGRAPHICAL SKETCHES

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Design Thinking as an Approach to Innovation

A central proposition of design thinking is that it can be helpful for a range of business challenges that exceed the traditional focus of industrial design (Beckman and Barry, 2007) and should be pursued by nondesigners as well as designers (Brown and Katz, 2011). As an approach to innovation, design thinking draws on a long history of studies of the new product development process. However, the design thinking approach can be cast in contrast to more rationally analytic approaches that have developed out of the management, engineering, and marketing literature (Beckman and Barry, 2007). The literature on design thinking lays out three main formal methods, as outlined in the next section.

Formal Methods of Design Thinking

While there are some differences in precise terminology of the formal methods that underlie a design thinking approach, common themes emerge. Beckman and Barry (2007) survey the design literature and describe the design-led innovation process as including observation, the use of frameworks for insights, the development of ideas, and the selection of solutions. Across this process, three methods are commonly cited within a design thinking approach (cf. Brown, 2009; Lockwood, 2010; Martin, 2009): (1) needfinding, encompassing the definition of a problem or opportunity through observation; (2) brainstorming, a formal framework for ideation; and (3) prototyping, building models to facilitate the development and selection of concepts. The main characteristics of these formal methods will be discussed in turn.

Needfinding encompasses a set of activities for determining the requirements for a novel concept, drawing on a user-focused framework (Patnaik and Becker, 1999). Needfinding is first undertaken as part of concept generation, drawing on existing technologies and design capabilities (Verganti, 2008), and it emphasizes the development of deep user insights gained through observation, empathy, and immersion in the user's context (Brown, 2009; Leonard and Rayport, 1997). As an example of the ethnographic approach used in needfinding, Brown (2009, p. 50) presented the case of a designer who, in order to develop a deep understanding of the experience of a patient needing treatment, checked himself into a hospital and went through the emergency room experience from admission to examination. The designer captured his experience with a video camera tucked underneath his hospital gown so he could later share his insights with his team. In addition to enabling finding better and more innovative solutions, achieving clarity on needs among a team is helpful, as a clear project goal has been associated with success in the context of highly innovative concepts (Lynn and Akgün, 2001). In a multidisciplinary team engaged in design thinking, needfinding has been considered an integral part of the initial process.

Brainstorming is a group process applying techniques that promote the search for new solutions that might not be possible through individual ideation. Both practitioners and academics have written about the potential advantages and possible drawbacks of brainstorming (Kelley, 2001; Nijstad et al., 1999; Sutton and Hargadon, 1996). The potential advantage of brainstorming is typically attributed to the possibility to use a structured environment to build on other team members' ideas. The research record indicates mixed results with brainstorming when compared with individual outcomes aggregated into equivalent-sized "nominal groups." There is a long history of finding negative results (Diehl and Stroebe, 1987; Taylor et al., 1958), although some studies have found more positive results, such as recent work suggesting brainstorming as more effective than nominal groups for problems of moderate levels of complexity requiring input from multiple disciplines (Kavadias and Sommer, 2009). Most studies of brainstorming have used experimental approaches (Diehl and Stroebe, 1987). In contrast, an influential field-based work of experienced design teams illustrated how brainstorming may contribute to a firm's objectives beyond ideation, such as in providing skill variety and wisdom within a design community (Sutton and Hargadon, 1996). In summary, the brainstorming literature has either focused on inexperienced users working under experimental conditions or experienced designers within creative teams, and the empirical results are somewhat mixed on effectiveness.

Prototyping is the process by which novel ideas are developed into a preliminary model, enabling evaluation of a given approach as well as the potential for further ideation. Researchers and advocates of design thinking approaches point out that prototyping, particularly at the earliest phases of product development, is not so much about validating an idea as it is a method to stimulate the imagination (Hargadon and Sutton, 1997) or "building to think" (Brown, 2009). For that reason, it can be less the fidelity of the prototype that matters, but rather the speed with which it can be built and used, sometimes dubbed "agile prototyping" (Meyer and Marion, 2010). Prototyping as a formal design method extends beyond products as it also has been applied in the design of experiential services (Zomerdijk and Voss, 2011). Prototyping has been found to be beneficial and integral to the design process in experienced teams, although relatively unexplored in novice teams.

In summary, three areas of design methods, each with their own set of more specific activities, provide the basis for how a "design thinking" approach gets underway in organizations. However, these methods are usually examined either individually under experimental conditions or as a group but only using experienced teams. Little research has looked at novice multidisciplinary teams working with all of these methods, and the implications of such teams are considered next.

Novice Multidisciplinary Teams

There are many potential benefits of staffing innovation projects with members that come from a range of disciplines because of the breadth of perspectives offered (Edmondson and Nembhard, 2009; Pelled, Eisenhardt, and Xin, 1999). Functional diversity, however, comes at a cost as teams need to find forms of communications for efficient task work (Ancona and Caldwell, 1992; Pelled et al., 1999). Such ways of communicating may not be explicitly covered in the use of formal design methods, and the intersection of diverse functional background with novice members presents a potential for challenge and conflict within such teams.

The academic literature on teams distinguishes between task conflict and relationship conflict. Studies suggest that relationship conflict always affects team performance negatively, whereas task conflict can affect team performance positively (Pelled et al., 1999), although only when below moderate levels and constructively managed (De Dreu and Weingart, 2003). Research has more recently begun to treat process conflict as distinct from task and relationship conflict (Jehn, Greer, Levine, and Szulanski, 2008). Within the context of creative teams in which iterating through brainstorming and prototyping plays a major role, the process aspect deserves more detailed attention. It has been observed that in these settings, teams shift their concepts by replacing certain elements in response to newly arrived information about markets or technologies (Seidel, 2007). In summary, not only do teams face various kinds of conflict in first establishing a concept and the process to follow, there can also be debate about later changes. Informal practices that either enable or constrain conflict are likely to be even more important when considering novice teams. Furthermore, while past studies have looked in detail at how team work practices may affect outcomes, there is little known about how these informal practices may work in concert with design methods when used by novice teams.

A further difficulty with many past studies is that they collect data of team dynamics at a project level and then relate these to performance measures (Pelled et al., 1999; e.g., Jehn et al., 2008), but they do not look at how team behaviors may change over the duration of a project. It has been long understood that teams may proceed through phases in which group dynamics change in a predictable manner (Tuckman, 1965). Projects that are concerned with creating novel products can be considered to include a concept generation phase focused on creating a range of options, followed by a concept selection phase focused on evaluating and choosing a primary concept (Crawford and Di Benedetto, 2011; Ulrich and Eppinger, 2012). This difference in focus can also make particular practices more useful in some phases but can create unintended consequences in other phases (Fixson and Marion, 2012). Such prior research suggests that following projects longitudinally is important to understand potential differences across phases.

In summary, formal methods coupled with informal practices related to conflict and debate can play an important and changing role over the design process. The increasingly widespread use of design thinking leads to expanded involvement of novice multidisciplinary teams adopting these methods, and such teams may have many challenges in working together effectively. The need to understand how these teams work over the duration of an innovation project provides the motivation for this empirical study.

Research Method

Our research question was to address how novice multidisciplinary teams use design methods to successfully develop novel concepts. A case-based research approach using both qualitative and quantitative data was the most appropriate means to address our question, as will be described next.

In their review of field research methods, Edmondson and McManus (2007) outline how the maturity of prior theory spans a continuum. At one end of the spectrum is mature theory, where focused questions with defined constructs and quantitative data can provide hypothesis testing, such as in detailed studies of brainstorming (e.g., Diehl and Stroebe, 1987). In contrast, in developing nascent theory, research is characterized by open-ended inquiry and qualitative data, such as in the inductive study of the innovation process among experienced designers at IDEO (e.g., Hargadon and Sutton, 1997). In the context of interest to this study, there is some existing theory that provides guidance, but there is no mature theory on the use of design methods by novice teams. Given the intermediate stage of prior theory, we designed a study using hybrid field methods as being most appropriate for "methodological fit" (Edmondson and McManus, 2007). This hybrid approach combined qualitative data collection from interviews, written accounts, and observation, and this was complemented by a focused set of quantitative data collected by questionnaire, allowing the use of multiple data sources to inform the findings.

Research Design Using Case Studies

In case-based research, the selection of the research setting and corresponding cases is important in allowing the variables of interest to be examined directly (Eisenhardt, 1989). In other words, this study required a setting in which we could examine the work of teams that (1) were multidisciplinary in composition, (2) had members engaged in design thinking activities for the first time, (3) had performance that was directly comparable with other teams, and (4) could be studied longitudinally to ensure capturing intraproject dynamics in real time.

The use of multidisciplinary student teams working on innovation projects fit these requirements especially well, while providing some advantages over studying novice teams based in firms. Over the past two decades, several universities have developed courses in which multidisciplinary teams work on semester-long projects focused on the creation of new product concepts (Fixson, 2009). We selected courses in two private educational institutions, which we will refer to as East Coast and West Coast. Projects to develop novel concepts, run by multidisciplinary student teams, served as the unit of analysis. Below we describe four reasons why the characteristics of this setting represent a very good fit with our research design requirements.

First, the teams were truly multidisciplinary. Members of the teams were required to be from different disciplinary backgrounds, and each team had members from at least three different departments or schools. Second, all team members had only minimal experience in design thinking methods. This setting is similar to the situation in a firm deploying design thinking methods to members of an organization who are unfamiliar with this approach. Third, the setting enabled direct comparison of team-level performance across projects. Each team was given comparable resources, the time allotted for the task was fixed and dictated by the academic calendar, and funding for materials and prototyping was similar across teams. Fourth, the teams could be followed over time, allowing for understanding contrasts across phases and for reducing potential memory bias problems when gathering data.

There were additional specific advantages to using student teams to address the research question. Because the concept development time frame and costs were held constant, team performance differences became directly measurable and attributable to how they applied design methods. If teams within firms had been used, control of competing explanations of observed performance differences would have been more difficult; managers may need to increase or decrease time or resource allocation over the course of a project, and such changes can be difficult to capture. In addition, the level of detailed data for which there was direct access may not have been as complete if obtained within firms.

One objective of case study selection is to be able to provide both theoretical sampling by selecting cases with a variety of outcomes of interest and a degree of replicability by selecting cases in different contexts to show broader application of findings (Eisenhardt, 1989). The final case selection, based on concept development performance, satisfied the first criterion, and the use of both East Coast and West Coast settings addressed the second criterion. Data were first collected on all potential cases, which began with six East Coast teams and 13 West Coast teams.

There were two main phases of concept development in both settings: concept generation and concept selection. Separating out such phases is common in product development teaching (Fixson, 2009) and practice (Crawford and Di Benedetto, 2011; Ulrich and Eppinger, 2012). During concept generation, teams used design methods to produce from three to five initial concepts. The initial concepts were evaluated by a panel consisting of industry experts and faculty who arrived at an overall assessment of the innovativeness of the concepts and potential for eventual commercialization. This assessment of concept generation was similar to how initial concept screening may be handled by an executive committee within a firm. During concept selection, teams took the initial concepts and applied design thinking methods to further evaluate concepts and select a single concept for final assessment. This final assessment was designed to be similar to a screen within a firm prior to commissioning detailed design, manufacturing planning, and product launch. For the East Coast setting the teams were the same through both phases, and for the West Coast setting teams could change membership after concept generation, and so there could be new members during concept selection. The East Coast course allowed a broad range of product concepts to be considered, and the West Coast course focused on medical device concepts. An illustration comparing the settings and providing an overview of data is given in Figure 1; the specific data collected are described in the following section.

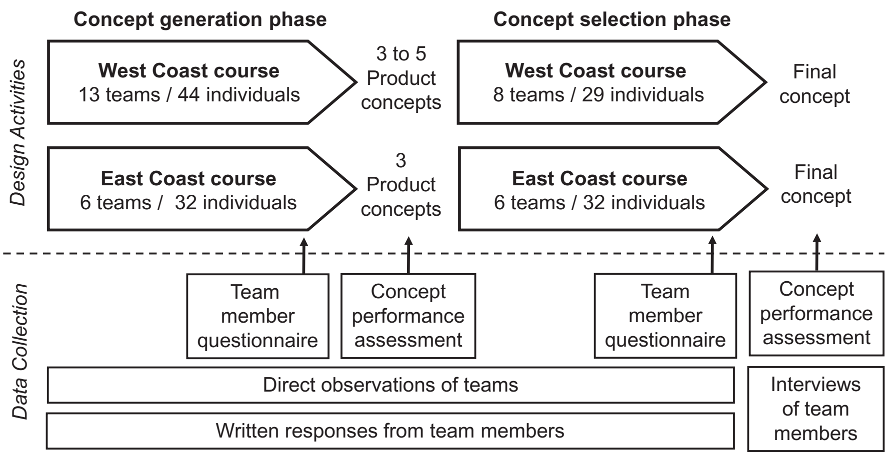

Figure 1. Overview of Data Collected Over Two Phases of Concept Development

Data Collection

The nature of the research setting allowed collection of observational, interview, written response, and quantitative measures. An author was present at each of the research settings and observed the concept development process within each team on at least a weekly basis and collected a range of materials relating to the projects, including team reports and images of prototypes developed. For the East Coast setting, this observational period lasted 14 weeks and for the West Coast setting it was 20 weeks. Observations included the teams in break-out sessions, applying methods such as brainstorming, and presenting their findings to an expert panel. In addition, we collected self-assessments of the process. In the East Coast setting, this was done through weekly written reflections from each of the six teams. In the West Coast setting, we interviewed twelve members at the end of the process but before final evaluations were known. These interviews lasted from 30 to 60 minutes each and were transcribed.

To understand how teams within our cases applied different design methods, qualitative data was complemented with a questionnaire that collected primarily quantitative measures. The questionnaire was designed not to statistically test hypotheses, but to provide relative values of the use of formal methods and informal practices among teams. As Eisenhardt (1989) describes, ". . .the combination of data types can be highly synergistic. Quantitative evidence can indicate relationships which may not be salient to the researcher" (p. 538). We gathered questionnaire data from over 90% of team members on a number of questions that related to their use of both formal design thinking methods and less formal practices. To understand how formal methods were used, the questionnaire included questions related to the value attributed to needfinding, brainstorming, and prototyping. For informal methods, items focused on debate over ideas, processes, and changes to the concept. The questionnaire was administered twice, once at the end of concept generation and once at the end of concept selection. Team members completed the questionnaire before they knew how their concepts were rated. Individual assessments of the use of methods and practices were averaged to gain measurements at the project team level.

Team performance was evaluated by a combination of faculty and industry experts. Industry experts consisted of people who held senior positions in companies that might commercialize similar products and those who funded new ventures. These experts provided ratings of the quality of the concepts produced at each phase. Rating the concepts allowed us to divide teams into those in the top third, middle third, and lower third. We treated the top third in each setting as our high-performing teams and the bottom third as our low-performing teams. The average responses on the use of design methods of all high-performing teams at each phase were then compared with the average responses of all low-performing teams. A summary of the cases that were included in our study are indicated in Table 1.

Results: Adopting Design Thinking by Novice Teams

The objective of the study was to understand how both formal design methods and informal team practices were

Table 1. Overview of Cases

Team Name	Novel Concept	Weeks Studied	Team Members	Some New Members?	Concept Generation Performance	Concept Selection Performance
Water	Product for novel water supply	14	6	N	High	High
Dorm	Product for furniture in small spaces	14	6	N	High	High
Stent	Medical device for stent procedures	20	4	Y	High	High
Spine	Medical device to help spine surgeons	20	4	Y	High	Medium
Prevention	Medical device to prevent clots	20	4	Y	High	Medium
Audio	Medical device to improve hearing	20	4	Y	High	Low
Blood	Medical device to address blood clots	20	5	Y	Medium	High
Compliance	Medical device for helping drug delivery	20	3	Y	Medium	Low
Surgical	Medical device for surgical application	20	4	Y	Low	High
Needle	Medical device to improve injection	20	4	Y	Low	Medium
Diagnosis	Medical device for disease diagnosis	20	4	Y	Low	Medium
Monitor	Medical device to monitor disease onset	20	4	Y	Low	Low
Manhattan	Product for helping food delivery	14	7	N	Low	Low
Cheese	Product for improving food preservation	14	6	N	Low	Low

Performance was divided into thirds; high- and low-performance cases at each phase used for analysis.

used by novice multidisciplinary teams. The following sections present our results across both the concept generation and concept selection phases. Following the recommended approach for case-based research (Eisenhardt, 1989), we make some initial links and contrasts to existing literature in our results section, before elaborating further in the discussion section. The results demonstrate that formal methods were sources of insight not only in concept generation, but also in concept selection, that brainstorming may be overused by some teams, and that the benefits of informal practices related to debate depends on phase.

Overall, members of high-performing teams found design methods more helpful than members of low-performing teams in both the concept generation and concept selection phases. In the questionnaire, team members of high-performing teams consistently rated the use of these methods higher in terms of their use as a source of ideas, and our qualitative data also support more focused use of these methods. Both quantitative and qualitative data are summarized in Table 2 for concept generation and Table 3 for concept selection. The use of each design method is discussed in turn, with a focus on brainstorming as a particular method where there may be limits to application.

Needfinding

High-performing novice teams managed to better agree on the clarity of user needs across both phases of the project. For example, at West Coast the high-performing Spine team felt that they had identified a clear need for spine surgeons through applying observational approaches highlighted in needfinding, even though some practicing surgeons were skeptical. Related one team member: "The practitioners certainly don't want to admit that they're having difficulty . . . they would think it would only take a couple of minutes, but if we actually timed them it might take them longer. Even though they said it wasn't much of a need, we felt it was a need, so we continued with it."

In contrast, the low-performing Compliance team was still working among different sets of needs during the selection phase. Despite similar training in needfinding methods, one team member mentioned how they still had not decided on whether the concept was targeted for providing something ". . . that could be sold to the general market. Or can we upgrade that to . . . an institutional setting such as a hospital?" The precise need for a new drug compliance concept for home or an institutional setting remained unclear to these team members.

Table 2. Use of Formal Design Methods During Concept Generation Phase

	High-performing teams	Low-performing teams
Needfinding: Clarity of needs	*Higher* Average score = 4.6 *Interview example of clarity of needs*: "Even though [surgeons] said it wasn't much of a need, we felt it was a need, so we continued with it."	*Lower* Average score = 4.3 *Written response example of only broad set of needs:* Two teams reported long lists of user needs (12 and 17) but failed to focus on a smaller subset.
Prototyping: Use as a source of ideas	*Higher* Average score = 5.1 *Observation example of benefits of prototyping:* One team used many configurations prototyped using foam board and plastic bottles.	*Lower* Average score = 3.5 *Observation example of limited prototyping:* Team developed three-dimensional models, but these models were only aesthetic models and did not address identified user needs.
Brainstorming: Use a source of ideas	*Higher* Average score = 5.8 *Interview example of benefits of brainstorming:* "So we were kind of the poster process of brainstorming. We came up with some really cool stuff and ideas."	*Lower* Average score = 5.2 *Written response example of not benefitting:* "We got caught up with [whether] the technology or given budget is going to make this doable or sellable, which sort of limited our creativity a little."
Brainstorming: Number of sessions	*Lower* Average number of sessions = 3.6	*Higher* Average number of sessions = 4.0

Average scores based on aggregate team member responses on a range of 1 (strongly disagree) to 7 (strongly agree).

Table 3. Use of Formal Design Methods During Concept Selection Phase

	High-performing teams	Low-performing teams
Needfinding: Clarity of needs	*Higher* Average score = 6.1 *Observation example of continued focus on needs:* ". . . we went and watched surgeries and we talked to surgeons about what was transpiring and what they might need: the shape of the device, what might be beneficial"	*Lower* Average score = 5.8 *Interview example of struggle to articulate needs:* ". . . in hindsight, we didn't do a very good job of really nailing the need down – it was pretty fluid over time."
Prototyping: Use as a source of ideas	*Higher* Average score = 5.6 *Interview example of continued prototyping:* "[We] had to talk to the butcher, get some big hearts and whatnot [to prototype our product]"	*Lower* Average score = 5.2 *Interview example of failure to prototype:* "[We lacked the] ability to make a prototype and actually sticking it into somebody's ear"
Brainstorming: Use a source of ideas	*Mixed results* Changed teams average = 5.6 Ongoing teams average = 5.4 *Summary:* High-performing on-going teams reported more benefit from brainstorming (5.4 vs. 4.6 average score)	*Mixed results* Changed teams average = 6.2 Ongoing teams average = 4.6 *Summary*: Low-performing on-going teams reported least benefit than changed teams (4.6) perhaps due to lack of new member ideas
Brainstorming: Number of sessions	*Mixed results* Changed teams average sessions = 4.8 Ongoing teams average sessions = 3.0 *Summary*: Increasing number of sessions corresponds to higher performing for changed teams but not ongoing teams	*Mixed results* Changed teams average sessions = 2.8 Ongoing teams average sessions = 3.9 *Summary*: New member reported on brainstorming that "There wasn't anything formal like that" but that it would have helped.

Average scores based on aggregate team member responses on a range of 1 (strongly disagree) to 7 (strongly agree).

Much of the design literature on needfinding stresses using it early in the process (Kelley, 2001; Patnaik and Becker, 1999). However, high-performing teams did not discard this method later but continued needfinding in concept selection, as reflected in the qualitative and quantitative data in Table 3. For example, a team working on a surgical device noted that they used observations to better understand the implications of a specific shape of the device during concept selection, stating that "we talked to surgeons about what was transpiring and what they might need." The results broadly confirm the benefit of a needfinding approach but highlight its continued significance to teams across phases, as opposed to abandoning it during concept selection.

Prototyping

High-performing novice teams used prototyping regularly at both phases and rated it more highly than low-performing teams as a source of ideas. A high-performing team at East Coast that focused on developing new concepts for public water fountains quickly built rough initial models of parts of the system. Different shapes and configurations of form board and cut-up plastic bottles facilitated initial user testing and improved feedback. In the concept selection phase, a member from the high-performing Stent team at West Coast discussed how they "had to talk to the butcher; get some big [animal] hearts and whatnot" to test their concept for a new stent design, enabling them to actually insert their prototype into animal tissue. In contrast, a member of the low-performing Audio team reflected that in refining their concept, they were "a little disappointed in our [in]ability to make a prototype [of the hearing aid] and actually sticking it into somebody's ear, see if it feels comfortable. I think that would have been a big help." While all teams had been equally introduced to prototyping, high-performing teams tended to cite the use of the method more and to value the ideas that came from its use, drawing on it across both generation and selection.

Brainstorming

The findings on brainstorming are more nuanced than the assumption that increasing use may generate additional value. There were two separate questions on brainstorming in the questionnaire. First, team members were asked whether brainstorming was an important source of ideas. Second, they were asked the number of formal brainstorming sessions that they conducted. During concept generation, high-performing teams on average consider brainstorming a more important source of ideas than do low-performing teams. However, it is the quality, not the quantity of brainstorming sessions that matters. While a past experimental study has looked at the implications of the length of an individual brainstorming session (Nijstad et al., 1999), this study examined how many sessions teams actually held. High-performing teams actually held fewer brainstorming sessions than low-performing teams in the concept generation phase.

Some of the interviews suggest that fewer brainstorming sessions closely linked to prototyping can be more effective than more sessions isolated from other methods. A member of the high-performing Spine team noted that they felt each session should involve not only conceptual brainstorming, but a means to quickly test ideas with materials at hand, drawing from the terminology used in a well-known consultancy that the teams had studied: "It wasn't just brainstorming, but we also did what we call 'deep dive' prototyping. We just had a bunch of random materials and we are like: 'Okay, what can we do?' And they just happened to have a material that had those properties. . . ." In contrast, a low-performing team had engaged in brainstorming but focused on a more conceptual assessment of evaluating ideas, relating that they would "come up with some kind of composite score and then rank them," without specific links to prototyping. Such conceptual brainstorming in the absence of prototyping appears to hamper effective use of the method to both generate and evaluate ideas.

During concept selection, the findings differ between the two settings. In the East Coast setting, the high-performing teams continue to place a higher level of emphasis on brainstorming than the low-performing teams, and they continue to use fewer sessions. Observation of these high-performing East Coast teams indicated that they had settled on an overall concept configuration for their products in the earlier generation phase, had de-composed their concept into subproblems, and then held targeted brainstorming sessions for these narrower problems. For example, the team developing a new water fountain held targeted brainstorming sessions to investigate bubbler arrangements of different geometry and pressure configurations.

In contrast to the East Coast setting, the high-performing teams at West Coast showed decreased emphasis on brainstorming during concept selection relative to the low-performing teams. At the same time, the high-performing teams held more brainstorming sessions during concept selection than the low-performing teams. A difference in team assignment between the two school settings can explain this counterintuitive result. Whereas in the East Coast setting the teams remained the same while they went through both concept generation and concept selection phases, in the West Coast setting only some team members continued from the concept generation to the concept selection phase, and those were joined by newly added team members. A member of the high-performing Blood team related the challenge of working on a changing team, recalling that "at least two members of our group came into this project not having dealt with [the course] before . . . so we had to get ramped up to speed. . . ." His teammate noted the use of initial brainstorming sessions to collectively gain common ground on the need area of how to absorb blood, given that they had not worked together on the initial generation process:

> *It's kind of weird because I know this quarter we were supposed to just hone in on this one concept, but since it was so brand new [to us] it felt like it underwent total transformation; it felt like it we were repeating part of last quarter onto this project. So we did a brainstorming session once or twice [to start off together], and kind of came up with, "Well, what kind of sponge pumps are there?"*

In contrast, a member of the low-performing Audio team noted that when brainstorming during concept selection, even with many new team members: "We didn't do as much. I think we did some [focused only on external] design." It appears as if the higher number of brainstorming sessions of the high-performing teams in the concept selection phase had as much to do with the role of socializing the new team composition and gaining common ground as it did with new idea development. This idea is developed further in the discussion section.

Informal Practices of Team Debate

The results of the investigation of informal practices vary by phase of the concept development process: During the concept generation phase, the high-performing teams experience a higher level of debate, as is summarized in Table 4. In the latter concept selection phase, summarized in Table 5, high-performing teams experience lower levels of debate. The results are discussed in turn.

During concept generation, high-performing teams ranked higher across all three areas of debate: over ideas, over the process to follow, and over changes to the

Table 4. Use of Informal Practices During Concept Generation Phase

	High-performing teams	Low-performing teams
Debating ideas	*Higher* Average score = 2.8 *Interview example of debate on ideas:* "[Our process was] do some more research, back yourself up with data and . . . then represent your argument because you have some data backing it. So, that is the way it actually worked."	*Lower* Average score = 2.4 *Written response example of little debate in ideas:* "The group focused on a motor and pump system for our product since it fulfilled our user needs the most. Then, we thought of design ideas and ways we could arrange the parts inside of the housing."
Debating process	*Higher* Average score = 2.9 *Interview example of debating or changing process:* "So, we built all of the prototypes we had. That was the same day as that brainstorm. I think we did two-days in a row of just trying to get our top ten list of concepts."	*Lower* Average score = 2.2 *Written response example of a focus on efficiency instead of debate:* ". . . the entire process was very efficient, as building the prototype and building the project on solid works helped us solve various issues instantaneously."
Debating changes to concept	*Higher* Average score = 2.7 *Interview example of debating a change:* "Then we had crisis again . . . I had lacing [as a main concept] and I was actually pretty optimistic. The other two [team members] were a little more pessimistic."	*Lower* Average score = 2.3 *Observation example of little debate over changes:* Little discussion about changes to concepts in written responses or in observation of low-performing teams.

Average scores based on aggregate team member responses on a range of 1 (strongly disagree) to 7 (strongly agree).

Table 5. Use of Informal Practices During Concept Selection Phase

	High-performing teams	Low-performing teams
Debating ideas	*Lower* Average score = 2.7 *Written response example of reduced idea debate:* "We occasionally encountered conflicts due to missing team members and communication issues, but in the end we managed to come together as a team to push forward our final idea."	*Higher* Average score = 3.9 *Interview example of debate over ideas:* "So it seemed like they would keep coming back with all these different ideas every single time and a lot of times it went back over the same ground that we'd covered the meeting before."
Debating process	*Lower* Average score = 2.3 *Written response example of reduced process debate:* ". . . as we have approached the more functional areas of the semester's project there has been a higher degree of delegation and specialization among our roles."	*Higher* Average score = 3.1 *Interview example of conflict in executing process:* "So everybody would come to the meeting and say, this is great, we're on track, the next meeting there would be no progress."
Debating changes to concept	*Lower* Average score = 2.0 *Interview example of keeping focus:* "Once we knew that we were going to go ahead with glue we did not re-visit. It was not like okay at every meeting you were going to think about the need criteria . . ."	*Higher* Average score = 2.8 *Interview example of debate over changes:* "Our team didn't do a great job staying focused and having a unified concept . . . it was hard to know what concept that was from one meeting to the next, because it moved so frequently."

Average scores based on aggregate team member responses on a range of 1 (strongly disagree) to 7 (strongly agree).

concept. The finding regarding debating ideas was confirmatory, as it has been established that teams that debate ideas tend to come up with more novel innovations (Pelled et al., 1999), indicating a more thorough exploration of the solution space. One example of being open to a range of options comes from a member of the high-performing Spine team, who noted their early approach "was pretty open-minded. We kind of thought that everything had a reasonable chance. . . ."

Teams with higher performance also had higher scores on debating the process to follow. In contrast, one low-performing team related that ". . . the entire process was very efficient" as they focused on one method at a time. In our observations, we noted that the more successful teams combined methods and worked between them; while productive, this could also be a cause of increased conflict and debate. Finally, any changes to the concept were also debated more in high-performing teams, and we recorded members speaking of "crises" and other challenging dynamics that tended to lead them to better solutions. Table 4 includes illustrations of qualitative data as well as overall team scores.

The results during the concept generation phase suggests a model of design thinking in which it is not the adoption of individual methods themselves, but the early use of the methods in a reflexive manner that lead to successful innovation. Through considering these results, the construct of group task reflexivity (West, 1996) seemed to best describe how higher-performing teams used design thinking methods during concept generation. Group or team reflexivity refers to the degree to which individuals collectively reflect upon their actions and processes. In the concept generation phase, high-performing teams exhibited reflexivity as they debated ideas, supported with data collected using various methods. They debated the process to follow more regularly, and they tended to combine methods. They also encouraged debate about changes to the concept. A good example of learning a reflexive approach through trial and error was provided by the member of one high-performing team:

> *Stepping back was really important for us though. We latched onto a specific need without remembering to acknowledge our user need weighting system. Our weighting system and concept selection processes were more fluid and based on group consensus, which worked for making decisions, but didn't provide us with hard tangible guidelines to look back at later. It would have been important to step back earlier before going down a path for a long time without really checking ourselves.*

During concept selection, higher-performing teams changed behaviors, now decreasing debate and focusing attention. Across debating ideas, process, and changes, our respondents from high-performing teams had lower average scores, and our qualitative data also described how such teams changed to a markedly different style of work. For example, one member of a high-performing team described how in the concept selection phase: "Once we knew that we were going to go ahead with glue [as a concept feature] we did not re-visit. It was not like: 'okay, at every meeting you were going to think about the need criteria [again]!' " In contrast, one member of a low-performing team related that "our team didn't do a great job staying focused and having a unified concept . . . everybody came in and kept throwing out different ideas every time." Not every team made the transition, such as those like Spine team who were successful in concept generation but not in selection. Rather than viewing team reflexivity as something always valuable (West, 1996), these findings suggest a temporal nature of the advantage or disadvantage of a reflexive approach. This may address some of the puzzle surrounding mixed results in reflexivity research (Moreland and McMinn, 2010), as addressed further in the discussion section.

Discussion

Taken together, these results allow the formation of propositions regarding the application and limits of design thinking when applied by novice teams. The propositions cover brainstorming and team reflexivity, which will be described in turn. In developing these propositions, we highlight how design thinking is not necessarily a set of methods that can be applied in isolation and always to positive effect.

Contingent Effectiveness of Brainstorming

Contributing to the long history of research on brainstorming effectiveness (e.g., Diehl and Stroebe, 1987), it has been argued that to understand the uses of brainstorming requires recognition of the context in which it is conducted (Sutton and Hargadon, 1996). Following this argument, we add two propositions regarding context, both associated with the social dynamics of teams engaged in brainstorming.

First, the results lead to the proposition that successful novice teams combine methods, such that it is not the quantity of brainstorming sessions, but their linkage to other methods that matters. While researchers have described how members of experienced design firms combine methods such as brainstorming and prototyping (Beckman and Barry, 2007; Hargadon and Sutton, 1997), we propose that this contingent nature of brainstorming effectiveness is driven by the fact that most teams struggle with idea selection (Rietzschel, Nijstad, and Stroebe, 2006), and moving among brainstorming, needfinding, and prototyping serves to better link generation and selection. In contrast, less successful teams exhibited more brainstorming sessions on average, suggesting that they were spending brainstorming time in unproductive ways. While prior research has suggested how brainstorming may be less effective than nominal groups (Diehl and Stroebe, 1987) or that there are diminishing returns within a session (Nijstad et al., 1999), our results indicate the number of sessions may not only be decreasingly effective, but can actually correspond to poorer performance. Because brainstorming is often enjoyable to members (Sutton and Hargadon, 1996), poorer performing novice teams could be prone to overuse of this method, rather than moving on to the use of other methods. We cannot determine whether the increased number of sessions was a cause or an effect of performance difficulties, but in either event increasing numbers of sessions can serve as a warning sign regarding team effectiveness.

The second proposition is that brainstorming can serve the purpose of socializing new members, especially within teams in which new members are added midway though concept development. In this way, this study elaborates on Sutton and Hargadon's (1996) research on how brainstorming in experienced teams helps to contribute to many objectives of the firm. We agree that it is not so much a question whether brainstorming works, but what kind of brainstorming session works and works for which outcome. Research on newcomer socialization has proposed that it is not just linear hours of contact that determine how newcomers become socialized (Rollag, 2004). The intense level of activity and the clear demonstration of different skills during repeated brainstorming sessions (Sutton and Hargadon, 1996) may be a particularly effective way in which teams with some new members not only explore new ideas, but also learn how they can best work together toward their end goal.

From a managerial perspective, it is worthwhile noting that most of field-based literature that advocates brainstorming builds on data collected in industries, such as within-product design consultancies, in which many employees may be highly skilled in brainstorming techniques and probably represent, through self-selection, a personality type that has a higher affinity to activities of these kinds. The findings within this study suggest that the quality of brainstorming session matters equally when novices are trying to engage in them, with the added difficulty that their experience level is lower. Managers promoting design thinking in their organizations should ensure that teams using design methods such as brainstorming receive additional guidance and should note an increased number of sessions can signal trouble.

The Benefits and Limits of Team Reflexivity

Team reflexivity is a construct well tailored to considering design methods. Interest in the reflective action of practioners draws on Schön's (1983) work, where he proposed that work was most effective when it was pursued with time to consider the complex relationships between cause and effect. West (1996) built upon this work in considering the dynamics of groups working on complex tasks, employing the sociological term reflexivity to capture ". . . the extent to which team group members overtly reflect upon the group's objectives, strategies, and processes. . ." (p. 599). We suggest that the design process lends itself to thinking about team reflexivity across these three fundamental domains he outlined: Reflection on objectives may be captured by the degree to which needs are clear within a team. Reflection on strategies relates to the degree to which ideas are debated. Reflection on processes relates to the degree to which processes are debated and tailored within teams.

The first proposition regarding reflexivity is that novice teams benefit from adopting a reflexive approach during concept generation by working across all three areas: objectives, strategies, and process. This may be particularly difficult for novice teams to do, as teams that are first adopting design methods may not know that they can debate how the methods are applied. In contrast, such skills of reflection may already be part of a professional designer's approach (Schön, 1983); prior studies have demonstrated the ability of experienced designers to cultivate an attitude of wisdom as they work through projects (Sutton and Hargadon, 1996). By adopting a reflexive perspective that covers all three areas, this study can contribute to models of innovation that typically focus only on reflection and debate over ideas, extending this perspective into the realm of debates over processes.

The second proposition is that team reflexivity can become detrimental during concept selection. This runs counter to a presumption in much of the research on reflexivity in innovation that such practices are typically helpful (De Dreu, 2002; Schippers, Den Hartog, Koopman, and Wienk, 2003) or at worst neutral (Hoegl and Parboteeah, 2006). Continued questioning of ideas or process can, on balance, be inefficient. Broadly, more successful teams transition from reflexive to less reflexive behavior.

The nature of the design process may make it especially difficult to abandon certain informal practices. Teams may develop certain behaviors when working with design methods that lead them to continue operating in a highly reflexive manner. Some teams in this study that did well in the concept generation portion of the course failed to maintain performance in the concept selection portion. These teams likely did not attend to making a transition point in behavior, in line with Gersick's (1989) findings that such midpoint transitions are fundamental and important in successful outcomes. Gersick examined how teams attend to deadlines after a midpoint transition and how such transitions are seen in both field and experimental conditions. Formal design practices may still be useful in a later phase, but the results of this study indicate a subtle transition in the nature of reflexive action.

By looking at the contextual nature of team reflexivity, this study provides not only a more developed view of the design process, but also contributes to understanding of reflexive action. Prior results on whether reflexive action contributes to team performance have been surprisingly inconclusive. Moreland and McMinn (2010) surveyed the team reflexivity literature from 1996 through 2009 and found "(a) bold claims about the performance benefits of group reflexivity, and (b) unconvincing scientific evidence for those benefits. . ." (p. 85). They note the challenge of working with the construct and note that "a possible conclusion . . . is that group task reflexivity *can* have performance benefits, but only under very special conditions. . . ." It may be that mixed results in past studies can be explained in part by temporal dependence and that team reflexivity may be unique to a specific timeframe, such as found within early screening decisions (Hammedi, van Riel, and Sasovova, 2011). Our work specifically looked across concept generation and concept selection, and this may have helped us to identify the contingent nature of reflexive action.

Research Limitations and Further Directions

This research provided insight into the application and limits of design thinking methods among novice teams, and it served to form the basis for propositions of how teams can best make use of a design thinking approach. The design of this study was to gain initial insight, setting the groundwork for further research to develop specific hypotheses for testing broad samples of student or firm-based teams. As with any research, there have been inherent limitations to our design. While we were able to collect a range of data related to high-performing and low-performing teams, cause-and-effect relationships can still require further investigation. This study focused on variation in performance among novice teams to understand what methods and practices contributed to their success, but it was not designed to empirically compare results between novices and experienced designers. Based on prior studies, one might expect that experienced designers have already gathered much of the practice-based knowledge of how to use these methods most appropriately, but it could be seen if variation among experienced design teams is related to the same factors as in the present study.

Other areas of additional work could focus on team composition among novice teams and how the use of one or more experts alters the application of methods and practices. The role of individuals in taking on leadership positions within novice teams is also an interesting area of study and may affect how transitions of reflexive behavior between generation and selection are managed within teams. Even without a specific leader, it could be that levels of expertise are more varied in novice teams within firms when compared with student teams, which could have bearing on how design thinking methods are adopted in firms.

As a final area of investigation, one can consider the adoption of design thinking methods as an example of the adoption of a management technique in general. Past research has established that new management methods, such as those surrounding the quality movement, go through periods of adoption and abandonment, described as a management fashion cycle (Abrahamson and Fairchild, 1999). Often abandonment is associated with disillusionment with a set of management methods that are oversold by management consultants but then are improperly implemented. The present study may help to understand design thinking in the context of such management fashions and highlight the danger of overselling the methods without an appreciation of the limitations and importance of context.

Conclusion

There is great potential for novice multidisciplinary teams to benefit from adopting a design thinking approach, but until now there has been little investigation of how they put this approach to use. This unique research setting allowed consideration of the implications of the adoption of design methods by such teams. Design methods can be valuable not only in concept generation, but also in concept selection, but we also found important limits on brainstorming and team reflexivity. Without considering the important contextual factors that lead to these limits, the potential of design thinking could fail to be realized.

It would be unfortunate if a design thinking approach was discarded prematurely by individual teams or entire organizations due to frustration with its implementation. Design thinking—and related activities of brainstorming and team reflexivity—all hold great potential, but they are also in danger of merely becoming a collection of management fads if the details of their application are failed to be understood. We hope that by providing a focus of the contexts in which brainstorming and team reflexivity may be beneficial or detrimental, this study serves to elaborate how design thinking methods may be best adopted. Being aware of such nuance should help both to inform the design of further studies and to guide the innovative capacity of novice multidisciplinary teams.

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