The dynamics of micro-conflicts and uncertainty in successful and unsuccessful design teams

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What differentiates successful from unsuccessful design teams? Building on new research on design innovation that emphasizes interactions between social and cognitive processes, we investigated a potential distinguishing feature: Successful design teams may harness interpersonal conflicts (a social design process) to mitigate uncertainty (a cognitive design process). We analyzed temporal relationships between brief, expressed interpersonal disagreements and subsequent spoken individual uncertainty in 30 h of conversations of 10 successful and 11 unsuccessful engineering product design teams. We discovered that micro-conflicts were followed by a relative reduction in uncertainty in successful design teams, whereas uncertainty rose after micro-conflicts in unsuccessful design teams, suggesting that interactions between conflict and uncertainty may be a differentiating factor for design team success.

Keywords: teamwork, innovation, problem solving, collaborative design, conflict

What differentiates successful from unsuccessful design teams? After decades of research on this question, design studies researchers have learned much about the nature of successful design teams. For example, successful design teams make heavy use of mental simulations and analogies (Ball & Christensen, 2009; Christensen & Schunn, 2009); use design tools and media that are appropriate to the phase of the design process (e.g., sketching early on, prototypes later on; Jang & Schunn, 2012); and work through consensus to build a robust shared understanding of the design problem (Agogino, Song, & Hey, 2006; Dong, 2005; Yang, 2010). Yet, much remains to be understood about the complex factors that lead to team design success (Dinar et al., 2015). For instance, while critical inquiry—which may include conflict—is a foundational part of design education and practice (Dym, Agogino, Eris, Frey, & Leifer, 2005; Oh, Ishizaki, Gross, & Yi-Luen Do, 2013; Schön, 1983), theoretical and empirical work on team cognition suggests that conflict still needs to be appropriately harnessed such that

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relationship conflict is minimized, open-minded discussion is maximized, and the benefits of disagreement can occur (Jehn, 1997; Tjosvold, Wong, & Chen, 2014). Yet, we know little about the preconditions, attendant processes, and mechanisms that make these desirable outcomes possible.

An emerging research area in design team innovation emphasizes interactions between social and cognitive processes (Paletz & Schunn, 2010). The key assertion of this perspective is that understanding how social and cognitive processes are intertwined could help improve our understanding of how design innovation truly occurs, and thus improve interventions designed to improve design team performance (e.g., because social dynamics might alter how cognitive interventions are perceived, or vice versa). This perspective also has the potential to yield fresh insights into pathways to design team success. This social-cognitive perspective is motivated by numerous prior findings of complex interactions between social and cognitive processes in teams. For example, simple social phenomena like turn-taking can shape individual memory retrieval dynamics (Nijstad & Stroebe, 2006). In addition, dissent from a minority opinion holder can trigger a broader information search in other team members, whereas dissent from a majority of team members biases information search in favor of the dissenting opinion (Nemeth & Rogers, 1996).

In this paper, we investigate how the interplay between disagreement (a social process) and individual team members' uncertainty (a cognitive process) could help differentiate successful and unsuccessful design teams. Specifically, we discover that, in successful teams, open expression of disagreements helps to reduce individual uncertainty (a desirable effect in the design process), whereas in unsuccessful teams, similar expressions of disagreement *elevate* uncertainty levels. Although both disagreement and uncertainty are natural to design teams, harnessing disagreement to resolve uncertainty may be advantageous, if not necessary.

1 Background

1.1 Intra-team conflict and micro-conflicts in design

Conflict has been studied at intra-personal, intrateam, interteam, and national levels, in design teams and between countries (e.g., De Dreu & Gelfand, 2008; Ozkaramanli, Desmet, & Ozcan, 2016). We focus on intrateam conflict as between individuals within the same design team. For this study, we define conflict to be when one team member explicitly opposes or contradicts statements or plans proposed by another team member. Thus, we focus on conflict as disagreement, which is inherent to problem-solving conversations, regardless of its negative affect, intensity, or directness (Paletz, Schunn, & Kim, 2011; Weingart, Behfar, Bendersky, Todorova, & Jehn, 2015). Such disagreements within a team can arise from differences in values, needs, interests, opinions, goals, or objectives (Barki & Hartwick, 2004). This definition draws from the psychology literature, rather than from rhetoric or argumentation theory, which examines different types of arguments as discourse (e.g., Stumpf & McDonnell, 2002). Most importantly, while team conflict can be a barrier to design success, conflicting needs and objectives can also inspire design and promote creativity (Miron-Spektor, Gino, & Argote, 2011; Ozkaramanli et al., 2016).

This paper draws from the organizational behavior, organizational psychology, and social psychology literature on teams, with the understanding that those research domains have only rarely examined design teams (see below). To better understand the relationship between conflict and team performance, social/organizational conflict researchers (De Dreu & Weingart, 2003; Jehn, 1995, 1997; Paletz et al., 2011) have found it important to distinguish between *task* conflict (disagreements about the task); *process* conflict (disagreements about *how* to go about doing the task, including scheduling or priorities); and *relationship* conflict (disagreements about values and personal issues). Process and relationship conflict are considered problematic, disruptive, and dysfunctional (e.g., Jehn, 1997; De Dreu & Weingart, 2003; De Wit, Greer, & Jehn, 2012). Task conflict, in moderate levels and when unrelated to relationship conflict, may be positively related to team performance (De Wit et al., 2012; De Wit, Jehn, & Scheppers, 2013; Farh, Lee, & Farh, 2010).

Another useful distinction is the length of a conflict and how it is measured. Much prior research on conflict has examined it via retrospective self-report surveys, and that kind of data has generally found that conflicts are negatively related to performance (e.g., De Dreu & Weingart, 2003). By contrast, observational research on brief conflicts in-the-moment (micro-conflicts) suggests immediate, sometimes positive relationships with subsequent cognitive processes (e.g., Chiu, 2008a; Paletz, Schunn, & Kim, 2013). Thus, the often negative portrayal of conflict in the organizational behavior literature may be due to how conflict is conceptualized and measured, such that brief disagreements are generally healthy, unless they snowball into long, salient conflicts (Paletz et al., 2011). In the aggregate, these micro-process relationships between brief disagreements and cognition may have a positive impact on overall design team performance. The give-and-take of specific, brief disagreements in design and other creative, collaborative settings may not only be normal, but desirable. Still, understanding the specific social-cognitive processes that are related to these disagreements could not only give insight into why they might be desirable, but also enable teams to negotiate potential tradeoffs with other aspects of team performance (e.g., team cohesion early in the lifecycle of a team).

1.2 Uncertainty in design

Successful problem solving in real-world, complex domains, such as engineering design, relies on effectively detecting and resolving uncertainty

(Ball & Christensen, 2009; Chan, Paletz, & Schunn, 2012; Christensen & Schunn, 2009; Schunn & Trafton, 2012). Significant effort is spent detecting, diagnosing, and resolving uncertainty (Chan et al., 2012; Downey & Slocum, 1975; Kahneman & Tversky, 1982; Schunn & Trafton, 2012). Psychological uncertainty, specifically, is when an individual perceives information to be incomplete, missing, or vague, regardless of whether or not it is objectively uncertain (Schunn, 2010; Windschitl & Wells, 1996). Designers can be uncertain not only about how to solve the various problems, but also about what the underlying problems truly are and about what they know (Ball, Onarheim, & Christensen, 2010). Analogy and mental simulation can be used as strategies to resolve uncertainty (Ball & Christensen, 2009; Chan et al., 2012), and/or co-occur with greater uncertainty (Christensen & Ball, 2016a), and uncertainty can lead to attentive returns to the topic to resolve the uncertain issues later (Christensen & Ball, 2016b). On the other hand, a recent study found that *certainty* triggered immediate creative reasoning and information elaboration (Christensen & Ball, 2016b).

We draw a strong contrast between uncertainty and conflict in our conceptualizations to avoid circularities: We focus on uncertainty as mental states within individual team members, and conflict as interactions *between* team members. All combinations of uncertainty and conflict can occur within the same team; for example, conflict can occur between team members who are currently not uncertain (e.g., strongly felt opposing plans) and uncertainty can occur within team members without conflict (e.g., individuals are uncertain about the same things).

Although uncertainty is challenging for design teams, having uncertainty is not a sign itself of dysfunction (Kirschenbaum, Trafton, Schunn, & Trickett, 2014): Indeed, uncertainty is inherent to the ill-structured nature of design problems (Goel & Pirolli, 1992; Tracey & Hutchinson, 2016). Nevertheless, uncertainty that persists over time, unmitigated or unaddressed, can harm design outcomes. For example, heightened uncertainty can increase a bias against creative ideas (Mueller, Melwani, & Goncalo, 2012). Also, prolonged uncertainty can increase psychological strain (Bordia, Hogman, Jones, Gallois, & Callan, 2004; Bordia, Hunt, Paulsen, Tourish, & DiFonzo, 2004), potentially reducing team members' effectiveness in contributing to the team's problem solving. Thus, devising and deploying appropriate strategies for dealing with uncertainty is central to the design process. Such strategies may include acknowledging it and taking it into account (Lipshitz & Strauss, 1997), or reducing it by collecting additional information, making assumptions and/or analogies, and problem solving (Berlyne, 1962; Chan et al., 2012; Lipshitz & Strauss, 1997).

1.3 Research questions about uncertainty and conflict in design teams

Both team disagreement and individual uncertainty rise and fall naturally over the course of conversations (Ball & Christensen, 2009; Chan et al., 2012; Christensen & Ball, 2016b; Paletz, Chan, & Schunn, 2016; Paletz et al., 2011; McDonnell, 2012). Prior research on interactions between social and cognitive processes has often found important correlations between *temporal dynamics* of social/cognitive processes (e.g., conflicts sparking analogies during conversation; Paletz et al., 2013). In this work, we hypothesize that temporal dynamics, or patterns of interactions over time, of disagreement and uncertainty can distinguish successful from unsuccessful design teams.

The context of design may also influence the effects of conflict and uncertainty on each other and on team performance. The broader intrateam conflict literature examines a large range of laboratory and natural teams, from executive teams to production teams, including creative teams (e.g., De Dreu & Weingart, 2003; De Wit et al., 2012). Design teams, however, have specific features that may help focus our research questions. First, design teams experience greater uncertainty than many other types of teams, as exhibited by their frequent need to engage in problem finding and choose which approach is best to solve their problems (Mehalik & Schunn, 2006). Second, it is therefore normal for design teams to tolerate, but also engage with and resolve uncertainty (Beheshti, 1993). Third, because the goal of design teams is creation, critical thinking and disagreement are valued and taught as part of the socialization of design students (Dym et al., 2005).

Even given these norms, however, not all design teams succeed. Successful design teams are likely better at managing and harnessing task conflict. Constraints can be raised in an open manner, thereby increasing the likelihood that disagreement will be productive (Tjosvold et al., 2014). One mechanism by which disagreement can lead to success is via the free expression and discussion of different/opposing views, which encourages information sharing (De Dreu & West, 2001; Tjosvold et al., 2014). Similarly, dissent arising from minority opinions can lead to greater information search (Nemeth, 1986; Nemeth & Rogers, 1996). Mild disagreement can promote greater information acquisition (Todorova, Bear, & Weingart, 2014). These dynamics of participation and information sharing have been shown to be vital to team success (Mesmer-Magnus & DeChurch, 2009). Importantly, information can decrease problem-solving uncertainty (Lipshitz & Strauss, 1997). Thus, because successful teams are likely to have effective resources and conflict resolution processes that enable shared understanding (Kleinsmann & Valkenburg, 2008), conflict in those teams should not be dysfunctional, and uncertainty should be productively resolved. We therefore expect that more successful design teams should generally experience a *decrease* in uncertainty after a disagreement. In other words, temporally speaking, we expect disagreements in such teams to be followed by decreases in individual uncertainty.

Even as all design teams encounter conflict, not all manage it productively. Less successful design teams may have more difficulty in drawing insights from and resolving task conflict. Task conflict can mix with relationship conflict, damaging performance (De Wit et al., 2012). Minority opinion disagreement in teams has been associated with lower confidence in team decisions, suggesting that lopsided conflict within a team may increase initial uncertainty and the questioning of previously held opinions (Schulz-Hardt, Jochims, & Frey, 2002)—potentially exacerbating and getting in the way of resolving existing levels of uncertainty that are inherent in design teams. Poorly managed disagreement may raise individual uncertainty in the moment that could then remain unresolved and need to be revisited again and again (Christensen & Ball, 2016b); individuals may use tentative speech to soften a response to a disagreement (McDonnell, 2012). Thus, because less successful teams are likely to lack effective knowledge resources or conflict resolution strategies, conflict in such teams should raise uncertainty that is not productively resolved, which may then raise overall levels of uncertainty.

From a design perspective, conflict could lead to additional uncertainty for less negative reasons. Disagreements reveal differences, ambiguities, or errors that are then noticed by others (Dama & Dunbar, 1996). Ill-defined problems necessitate the uncovering of design requirements (Ball et al., 2010; Simon, 1973), such that a team tasked with a poorly-defined problem could disagree about the nature of the problem and its solutions, leading to the revelation of greater uncertainty. Temporally speaking, we expect disagreements in such teams to be followed by increases in individual uncertainty.

Motivated by these extant findings, in this paper, **we investigate whether there is an interaction between team success and conflict, such that micro-conflicts *decrease* uncertainty in successful teams, but *increase* uncertainty in unsuccessful teams**. This study explores this question with a dynamic, time-lagged, behavioral observation approach using a large dataset of natural problem solving in design teams. Given the prior differences found for task versus process conflict, we examine these relationships separately by these different types of disagreement.

2 Methods

2.1 Research context

This study examined engineering student design teams working in a product realization course at a large research university in the Mid-Atlantic United

States. Our overall sample consisted of 57 teams across seven semester-long implementations of the course.

In each semester, multidisciplinary student teams, primarily from various disciplines in engineering (e.g., mechanical, electrical, industrial, chemical, bioengineering), took products from concept to functional prototype. Each team was on a different project from a variety of product domains, such as diaper redesigns, solar-powered water heating systems, and Radio Frequency Identification (RFID) personnel badge systems. Each project received up to $2500 from an external sponsor for design/prototyping efforts and had industry, graduate student, and/or faculty mentors.

Team members were paid $250 to complete background surveys, submit presentations and final documents to the researchers for analysis, and do the bulk of their (team)work in a specially prepared room with a table and chairs, a computer with engineering-related software (e.g., CAD software), and other useful technology. The students were audio−video recorded whenever they used these rooms. Informed consent was obtained from the participants.

2.2 Sample

Because of the extremely time-consuming nature of observational coding, we sampled 21 teams to be coded for uncertainty and conflict, choosing teams that were clearly high vs. low success, focused on hardware projects (i.e., excluding unique project types, like software design), and regularly used the room set up for video data collection. The 21 teams ranged from three to five members ($M = 4$, $Median = 4$, $SD = 0.63$) for a total of 84 undergraduate students.

Team meeting clips were chosen for transcription based on having no more than 5 min of off-task talk within them and meeting a minimum level of audio and video (transcribable) quality. A total of over 30 h of talk was transcribed into utterances (clauses or thought statements, Chi, 1997) and coded for the variables of interest for a total of 38 445 total utterances, 35 148 of which were coded as on-task (ICC = 0.79 for triple coded sets, average kappa = 0.72 for double coded sets). On-task talk included anything relevant to their product or class, including process discussions (e.g., shopping trips for materials). When a team meeting had a stretch of off-task conversation of over 5 min (e.g., about football), the video clip was broken up, resulting in 59 video clips ranging from 5 min to 1 h 40 min long ($M = 31$ min, $SD = 23$ min).

Attendees ranged from 2 to 7 individuals with the rare higher numbers because of occasional mentor visits ($M = 3.7$, $Median = 4.0$, $SD = 1.0$). At the team level, 24% were all male, 29% of the teams had 50% females, and the rest had females but in a minority proportion (proportion female of the team $M = 28\%$).

2.3 Measures

To reveal the patterns of quick, brief social and cognitive process interactions in design teams, this paper draws on recent research that studies interpersonal conflict communication behavior within team interactions (e.g., Paletz et al., 2011; Poole & Dobosh, 2010). It is within conversations that design team members do the work of joint problem solving and develop group cognition. When studying brief processes, observational methods can tease apart their interplay as they unfold over time (e.g., Chiu, 2008a; Gottman & Notarius, 2000; Kauffeld & Lehmann-Willenbrock, 2012; Weingart, 1997).

The three primary measures for this study were design team success/outcome, micro-conflicts and their types, and spoken individual uncertainty. Both uncertainty and micro-conflicts were 100% double-coded by two different sets of paired independent coders who were blind to the research questions of this study, the results of the other variable's coding, and the team's success score. Thus, uncertainty and conflict could co-occur or not, in any combination, and were not exclusive of each other. All coding disagreements were resolved via consensus.

2.3.1 Design success

Building on professional design practice (Otto & Wood, 2000; Ullman, 2002; Ulrich & Eppinger, 2008), we took a requirements-based approach to measuring team design success. Customer needs, given by design brief documents and initial meetings with sponsors, were translated into specific design requirements (e.g., safety, cost, ease of use, efficiency) and weighted by importance to the overall product (using a 1 to 5 importance scale, 5 = most important).

Each team's design requirements were evaluated by a course instructor most familiar with the project and knowledge domain. The instructor rated the degree to which the project requirements were met (e.g., 0 = Did not come close to meeting requirement; 1 = Fell just short of meeting requirement; 2 = Met requirement, but did not exceed significantly; 3 = Significantly exceeded the requirement). While satisficing a requirement threshold is important, there is usually a preference for exceeding requirements. For example, while a car manufacturer may obtain an adequate profit if production cost stays below $12 000, an engineering team that produces a car that costs $8000 would be even more desirable. All course instructors had extensive experience in product realization, including numerous patents, startup company experience, and industry consulting, as well as relevant content knowledge (e.g., materials science, electrical engineering), and were blind to the questions of this study.

The final success measure for a given team was calculated by the ratio of the earned success score (sum of requirement ratings multiplied by their importance weights) and the maximum possible success score (sum of requirements' maximum possible ratings multiplied by their importance weights), normalized (multiplied by 100) to yield a score on a 0 to 100 scale (Goncher, Chan, Schunn, & Lovell, 2012). Because of our sampling strategy, our teams fell into a bimodal rather than a normal distribution. We thus used the team's scores to create a dichotomous variable, 0 = low success (success score < 69, 11 teams), and 1 = high success (success score > 79, 10 teams).

As a validation of our success measure, there was a significant overall relationship between success score and whether or not the teams' products were submitted for patent or implemented in some fashion by the sponsor, $r_{pb} = 0.50$, $p < .001$. In our sample, 7 of the 10 high success teams' products were submitted for patent or implemented, in contrast to only 3 of the 11 low success teams. Information on patenting/implementation was not available for 2 of the teams in our sample (1 high and 1 low success). We use the ratings as the success measure rather than whether the product was used at the company or patent submissions, because complex factors outside the local project (e.g., differences in company intellectual property management approaches, time/budget constraints) played a large role in determining immediate use at the company or decision to file a patent.

2.3.2 Micro-conflicts

We coded for micro-conflicts at the utterance level by adapting a pre-existing coding scheme (i.e., if this utterance includes conflict, the utterance was marked as 1, and if not, it was marked as 0; Paletz et al., 2011, 2013). Micro-conflicts were identified when a speaker explicitly, whether via tone and/or words, disagreed with something said earlier in the video clip. Simply stating a potentially controversial viewpoint was not sufficient. Constraints, which limit the search for solutions (Ball et al., 2010), can be (but need not always be) raised via disagreements (Paletz, Sumer, & Miron-Spektor, 2016). Coders both read the transcript and listened to/watched the audio–video recording simultaneously to improve reliability (average conflict event kappa of 0.70 across coder pairs).

The micro-conflicts were coded by utterance for type of conflict, using categories typically used in the conflict literature (e.g., Jehn, 1997): *task* micro-conflict utterances were directly related to the engineering product realization task, including choosing materials, design, and testing; *process* micro-conflict utterances were about scheduling, communicating their findings (e.g., creating presentations, how to dress for presentations), how to go about doing work, assigning tasks, prioritization, and who said what to whom; finally, *relationship* micro-conflicts were about values, being critical of others' personality and style, and personal likes/dislikes. Because of the potential co-occurrence of these three conflict types in real-world settings, their presence/absence were coded separately (task kappa = 0.87; process kappa = 0.61, and relationship kappa = 0.65).

Micro-conflict *events* were clusters of utterances defined as relating to a very specific topic. For instance, the exchange ‘It won’t fit,’ ‘Well, just make it bigger,’ ‘Well, I’m dumb, I can’t,’ ‘You can’t make it bigger?’ ‘No,’ ‘What the hell, [name], you suck’ is actually two micro-conflicts: one that is predominantly process (the students were discussing whether and how to change the font size on a Powerpoint slide, rather than the content), and then a micro-conflict event immediately following that is predominantly relationship conflict, where the first speaker’s competence is called into question (for another example, see Table 1).

To test the alternate supposition that successful teams were simply better at resolving conflicts, micro-conflict events were also coded as to whether they were resolved immediately, within 25 utterances of the last micro-conflict utterance coded (kappa = 0.79). Coders judged the micro-conflict event as resolved if the disagreeing parties came to an agreement, whether by one person acquiescing to the other’s (or others’) opinion or the parties coming to a compromise. Twenty-five utterances were chosen because it was often not possible to tell if the micro-conflict was resolved after that point, as micro-conflicts blended into each other over time, and some may have been resolved by the participants at untranscribed later times (e.g., via email or during other meetings).

2.3.3 Uncertainty

Although psychological uncertainty is an internal state, cognitive scientists have frequently operationalized uncertainty via coding individual utterances within design and science team conversations, picking up ‘hedge words’ (words that typically accompany and communicate uncertainty) such as ‘maybe’ and ‘possibly’ (e.g., Ball & Christensen, 2009; Ball et al., 2010; Chan et al., 2012; Trickett, Trafton, Saner, & Schunn, 2007). These kinds of words demonstrate behaviorally, via verbal expression, when an individual is perceiving uncertainty. This coding scheme had been previously validated using convergent and discriminant methods, such as comparing speech to gesture based uncertainty measures, and distinguishing uncertainty from approximations (Schunn, 2010).

Leveraging the relatively simple and stable predictive nature of hedge words as cues (in contrast to the much more variable and complex nature of expressed disagreements), we employed a two-step semi-automated approach. First, we trained a Support Vector Machine classifier (a supervised machine learning algorithm) on an initial set of human-coded utterances, and used the classifier to identify utterances that might contain uncertainty (for technical details, see Luo, Litman, & Chan, 2013). Second, two trained humans coders assessed for uncertainty those utterances identified by the algorithm as likely to include

Table 1 Segmented transcript with uncertainty (italics) and micro-conflict (bold) codes

Speaker	*Utterance*	*Conflict type*
4	I thought yeah	
4	It would be cool to put some little hydroelectric power generators	
3	Yeah	
4	You know those little mini ones	
4	Right	
3	That would be uh	
3	And those, these like micro-generators	
3	***They'd be enough to power maybe a light***	Task, onset
3	**But not a battery**	Task
3	**You know like the overall cost of electricity would not be decreased**	Task
3	***I don't think***	Task
3	**But then again these are like**	Task
3	***They seem to be high cost solutions***	Task
3	**These generators you know**	Task, end
4	Mmhmm	
1	Yeah	
3	Putting in generators	
2	Yeah with that liquid water thing	
2	*Just that some people have their tanks underground too?*	
4	Mmhmm right	
2	So you wouldn't be able to do that	
3	*But perhaps*	
3	*Perhaps that instead of marketing it as an individual solution*	
3	*Maybe it could be a solution for an entire group of people, community, building*	
2	*I think that was one of the things*	
2	*That was just probably the only good thing on this paper*	
3	*Yeah?*	
2	Yeah it was	
2	It said something about	

Note. From Team 20070106. Speakers are numbered based on who spoke first in a transcript. Blocks indicated by section divides. Conflict types are the dominant type at that utterance.

uncertainty. This process saves time and coder effort given the massive dataset, and it also helps to avoid coder drift and decreased validity and reliability due to fatigue. Inter-rater reliability was high (Cohen's kappa = 0.80). Table 1 presents an example of both conflict and uncertainty from a team that was tasked with creating a product that could be attached to a light bulb socket and indicate the power usage, with the end goal of informing consumers of their energy consumption.

2.4 Analyses

2.4.1 Blocks, video clips, and teams as three-level nested data

As the goal was to examine the effects of disagreement on *subsequent* uncertainty, we needed a data structure that supported time-lagged analyses. We created segmented blocks centered on the incidents of the independent variable, conflict. This event-centering strategy ensures that the predictor block (i.e., conflict events) would be relatively homogenous in its content, and the dependent blocks would be standardized in length (Paletz et al., 2013). Blocks were created by (1) identifying the conflict event (or contiguous conflict events), (2) segmenting the 10 utterances before and after each conflict event as two additional blocks, and (3) breaking up the rest of the clips into successive blocks of 10 utterances, each ending at the 10th utterance, the end or beginning of the clip, or with the next conflict. Ten-utterance long blocks were chosen because initial descriptive visualizations suggested that was the best grain size for observing fluctuations in uncertainty. Previous analyses of temporal patterns of uncertainty in other datasets suggested that uncertainty in design teams tends to show significant rises and declines in windows of 15−30 utterances (e.g., Chan et al., 2012; Christensen & Schunn, 2009). As uncertainty involves some problem solving prior to uncertainty resolution, we conducted analyses at two lags: both 0−10 utterances before the dependent variable (first block, Lag1) and 11−20 utterances before the dependent variable (second block, Lag2). The number of utterances rather than time was the unit of analysis because the focus of the study was on expressed behavior. That noted, 20 utterances also represented roughly 1 min after the end of a micro-conflict, so the first lagged block was at about 0−30 s after the conflict, and the second at about 30−60 s.

2.4.2 Statistical analyses

Most regression analyses assume that (1) data points are independent, and (2) that the dependent variable is continuous and normally distributed. Both of these assumptions were violated with these data. First, these data are nested—blocks within video clips within teams—such that data points were not independent. Second, the main dependent variable was count data, which is skewed (mostly zeroes, then ones, etc.). Thus, we employed statistical analyses that appropriately accounted for both these features: three-level hierarchical linear modeling, time-lagged, variable exposure overdispersed Poisson models using HLM7 (7.01) software (Raudenbush, Bryk, & Congdon, 2013).[1] We used three-level hierarchical linear modeling to account for the inherent dependence of having blocks (Level 1) within video clips (Level 2) within teams (Level 3) and to handle unequal cell sizes (Raudenbush & Bryk, 2002).[2] The segmentation method resulted in 3969 blocks at Level 1, 59 video clips at Level 2, and 21 teams at Level 3. Overdispersed Poisson models were necessary because the main dependent variable was count data (number of uncertainty utterances in a block), and its variance (2.0) was greater than its mean (1.5; σ^2 was 1.1 instead of 1). *Variable exposure* Poisson accounts for the number of utterances being different for different blocks because the block creation process drew from naturalistic data (e.g., endings of clips, beginnings of new conflict events).[3]

We employed time-lagged analyses, such that uncertainty in one 10-utterance block was predicted by the presence/absence of conflict, or a particular conflict, at either Lag1 (1−10 utterances *before*) or Lag2 (11−20 utterances *before*). In creating the models to test our research questions, the time-lagged conflict to uncertainty tests were at Level 1 (blocks). The binary low/high success variable was a main effect at the team level (Level 3) and a moderator at the team level on the block level conflict variables (interaction between Level 3 and Level 1 variables; Figure 1).

Before examining our independent variables, we tested for the significance of several covariates that were plausibly connected to uncertainty or conflict and therefore could be potential third-variable confounds. At Level 1, we tested the percentage of on-task talk that was about the product itself (rather than, say, presentations or planning); the average number of words per utterance in that block, in order to control for underlying number of words available to be coded; and the number of speakers in the block, in order to control for uncertainty due to more people participating in the conversation. At Level 2, we tested the number of uncertainty on-task utterances in the overall video clip, the number of people at the meeting, the presence of a non-team member (e.g., a client or faculty advisor), and two gender composition vectors (to

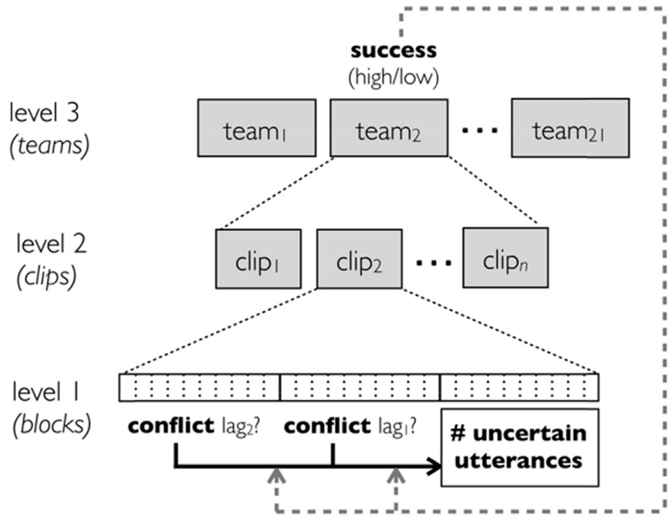

Figure 1 Three-level data structure of lagged blocks, clips, teams, and team success

account for the three types of clip gender compositions). At Level 3, we tested the binary success variable, two team-level gender composition vectors, and the size of the team. Gender composition for both the conversational clip and the team was examined because of the known positive relationship between the percent of women in a team and collective intelligence (Woolley, Chabris, Pentland, Hashmi, & Malone, 2010), which could then be associated with team success or other team processes. We first tested the potential covariates at Level 1, then those significant at Level 1 with Level 2, then those significant at Levels 1 and 2 with Level 3. Potential covariates had to be statistically significant to be kept in the final covariate model. Two Level 1 variables passed these tests: the average number of words per utterance and the number of speakers in the block, both of which were positively associated with the presence of uncertainty. In keeping with standard practices, Lag2 effects always controlled for Lag1 parallel variables, and interaction effects always controlled for their respective main effects, regardless of statistical significance.

When a significant interaction effect with team success occurred, we also tested for the main effects of micro-conflicts on subsequent uncertainty for the dataset broken up into low and high success teams (i.e., we conducted simple effects analyses to better understand significant interactions).

3 Results

We first describe the frequency of design team uncertainty in the data set. We then present the relationship between different kinds of design team conflict on subsequent uncertainty levels, as well as the moderation tests with team success.

3.1 Frequency of uncertainty and micro-conflicts

At the block level, uncertainty occurred relatively frequently, with 70% of the 3970 blocks having uncertainty, but with a wide variety in amount of uncertainty in a block: range 0–14. In contrast, conflict was less common: only 6% of the 3970 blocks had conflict. Of the 244 blocks coded as having conflict in them, 65% had at least one utterance of task conflict, 57% had at least one utterance of process conflict, and 12% had at least one utterance of relationship conflict. The relationship micro-conflict frequency (1% of all blocks) was insufficient for use in these analyses.

Importantly, as noted in subsequent sections, there were no differences by team success on the simple *prevalence* of uncertainty or overall conflict, task conflict, or process conflict. Further, more successful teams were not simply better at resolving conflicts: At the team level, the proportion of quickly resolved conflict events out of all on-task conflicts were the same between the more successful ($M = 0.54$, $SD = 0.27$, $n = 10$) and less successful

($M = 0.71$, $SD = 0.22$, $n = 11$) teams, $t(19) = 1.57$, $p = 0.13$.[4] With uncertainty as the dependent variable using the analysis technique noted previously, and the covariates of number of words per utterance and number of speakers, there was a non-significant relationship trending in the negative direction between concurrent uncertainty and conflict, with a large confidence interval. This analysis suggests what the coding procedure implied—that there was no reliable relationship between uncertainty and conflict in the same block.[5]

3.2 Relationship between conflict, team success type, and uncertainty

3.2.1 Overall conflict

First, we tested whether conflict one block or two blocks earlier (Lag1 and Lag2) had significant main effects on subsequent uncertainty and then whether they had significant interactions with the team success variable. Team success alone was not related to uncertainty (i.e., both low and high success teams had similar rates of uncertainty). The interaction of conflict at Lag1 with team success was not significant. However, at Lag2, there was a significant interaction: high success teams had less uncertainty following micro-conflicts, compared with low success teams, which had relatively more uncertainty following micro-conflicts (see Table 2, Figure 2).

3.2.2 Micro-conflict by subtype

We then repeated these analyses for task and process conflict. These micro-conflict types were not mutually exclusive, but were negatively correlated with each other: Blocks with task conflicts were less likely to have process conflicts, $X^2(1, 239) = 49.82$, $p < 0.001$, phi $= -0.46$ (at Lag2).[7] Thus, testing them

Table 2 Full model of micro-conflict and team design success on uncertainty

Variable	*Event rate ratio (95% confidence ratio)*
Intercept, γ_{000}[a]	0.17 (0.13, 0.22)***
Average words per utterance	1.07 (1.05, 1.09)***
Speakers in block	1.26 (1.20, 1.32)***
Conflict Lag1	0.95 (0.87, 1.05)
Conflict Lag2	1.09 (0.99, 1.20)+
Team Success (L-3)[a]	1.06 (0.83, 1.34)
Conflict Lag2 × team success	0.78 (0.65, 0.95)*
Low success teams	
Conflict Lag 2[b]	1.09 (0.94, 1.26)
High success teams	
Conflict Lag 2[c]	0.85 (0.72, 1.01)+

Note. +0.10 > p > 0.05; * p < 0.05; *** p < 0.001. Degrees of freedom (df) = 3736 unless otherwise noted.
[a] $df = 23$.
[b] $df = 1951$.
[c] $df = 1782$.

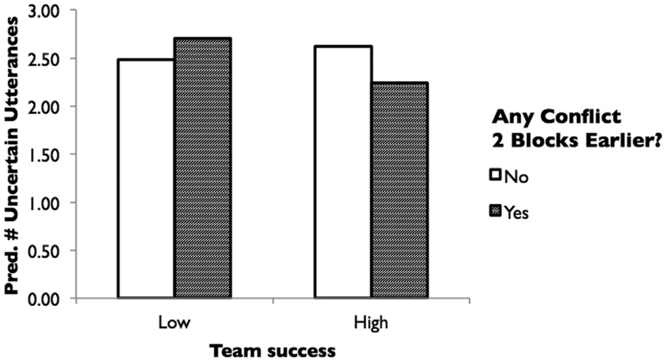

Figure 2 Predicted number of uncertain utterances by team success and time-lagged micro-conflict, controlling for covariates[6]

separately gives a more complete view and helps us determine whether the effect is the same for different kinds of conflict.

For task conflict, we found that, consistent with the analyses of overall conflict, there were no significant main effects of team success ($p > 0.60$), task conflict Lag1 ($p > 0.80$), and task conflict Lag2 ($p > 0.40$) on subsequent uncertainty, controlling for the significant covariates. However, task conflict Lag2 had a significant interaction with the team success variable ($p < 0.05$), again showing decreasing uncertainty after task conflict in high success teams but increasing uncertainty after task conflict in low success teams (Figure 3A).[8]

Process conflict Lag2 has the same interaction effect with team success (Table 3) with growing uncertainty in low success teams and decreasing uncertainty in high success teams following process conflict two blocks earlier (Table 3, bottom rows, Figure 3B).

Tables 4 and 5 are illustrative examples of two micro-conflict events and the uncertainty that followed them. One team, which did not fare well on its final success score, was tasked with investigating how to put a radio-frequency identification chip and antenna (RFID technology) in drill bits used in manufacturing. As they disagreed about the optimal size they needed, that discussion raised other elements of their task that were uncertain (Table 4).

In the second example, a successful team was working on a presentation and had a minor task disagreement about what the summary should include, with one team member noting it should be a summary of the whole paper. They quickly moved on to discussing in colorful terms how they would do that, with very little uncertainty (Table 5). While Speaker 1 raised the initial micro-conflict, the little uncertainty being communicated seems to be hedges against seeming too dominant, rather than uncertainty about any underlying issues.

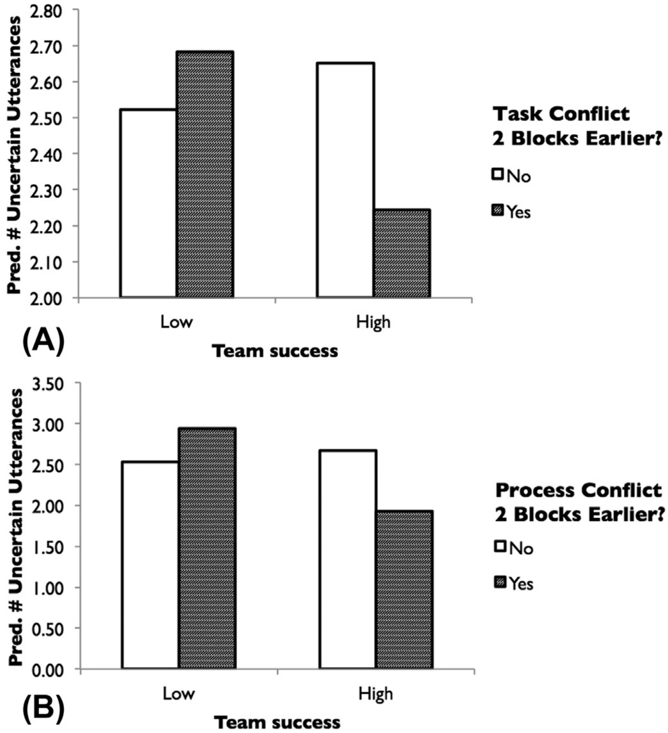

Figure 3 Predicted number of uncertain utterances by team success and time-lagged (A) task and (B) Process micro-conflict, controlling for covariates

Table 3 Process micro-conflict and team success on uncertainty

Variable	*Event rate ratio (95% confidence ratio)*
Intercept, γ_{000}[a]	0.17 (0.13, 0.22)***
Average words per utterance	1.07 (1.04, 1.09)***
Speakers in block	1.26 (1.20, 1.32)***
Process conflict Lag1	0.91 (0.77, 1.08)
Process conflict Lag2	1.16 (1.03, 1.30)*
Team success (L-3)[a]	1.06 (0.83, 1.34)
Process conflict Lag2 × team success	0.62 (0.50, 0.78)***
Low success teams	
Process conflict Lag 2[b]	1.17 (0.99, 1.38)+
High success teams	
Process conflict Lag 2[c]	0.72 (0.54, 0.95)*

Note. +0.10 > p > 0.05; * p < 0.05; *** p < 0.001. Degrees of freedom (df) = 3736 unless otherwise noted.
[a] df = 23.
[b] df = 1951.
[c] df = 1782.

Table 4 Example of unsuccessful team (ID 20070304) micro-conflict and uncertainty

Speaker	*Utterance*	*Conflict type*
2	Let's find the biggest small drill bit we have,	
2	*if they're all the same,*	
2	I saw some 3–3.4s	
2	*3.4 might do it, three seven*	
3	These are	
3	This is 3.4 here	
2	This is too big	
1	Well	
1	**big is better for us**	Task, onset
1	***I think***	Task
1	**Because that will give us more apoxy**	Task
2	Well	
2	This <missing word>	
3	Yeah	
1	*I think we may need <missing word>*	
2	***But I don't think this is the appropriate size***	Task
3	**Right,**	Task
3	**That looks a little big**	Task
4	**Little bit too big**	Task, end
3	*Would we be allowed to use these drill bits?*	
3	*Because they are somehow not right*	
3	<missing word> leave this to join together	
2	*I could have sworn we had some 3.4s*	
3	We do,	
3	They're right here	
2	Okay	
3	And there is another set	
3	Right here	
2	We only got 6,	
2	Better not to mess them up	
3	*I don't know*	
3	What <missing word>	
2	Oh	
2	These are too small,	
2	*These are what, 4.2…*	
2	Yeah	

(*continued on next page*)

Table 4 (*continued*)

Speaker	*Utterance*	*Conflict type*
1	Yeah	
1	*I think that one we have would actually be*	
2	*The 7?*	
1	Yeah	

Note. Bold = **conflict**; italic = *uncertainty*. Speakers are numbered based on who spoke first in a transcript. Blocks indicated by section divides. Conflict types are the dominant type at that utterance.

Table 5 Example of successful team (ID 20070301) micro-conflict and uncertainty

Speaker	*Utterance*	*Conflict type*
2	So the conclusion should just be a summary of this kind of stuff[a]	
1	***I think it's supposed to be a summary of the whole paper***	Task, onset
1	**Err the whole project**	Task, end
3	You could do it like that	
1	So it's just a bit more general	
1	You don't have to	
1	You should go into detail	
2	I know I can bullshit	
2	But I want	
2	I kinda want	
2	Or meant to be	
2	Uh, you know	
2	Bullshit that everyone else has piled on	
1	Well you can kinda,	
1	all you have to do for the conclusion is restate the summary	
2	Great	
1	Just reword the <missing word>	
2	Cool	
3	So	
1	That's pretty much	
1	*I guess what you should do tomorrow*	
1	I don't know	
1	I wasn't really paying attention too much	

Note. Bold = **conflict**; italic = *uncertainty*. Speakers are numbered based on who spoke first in a transcript. Blocks indicated by section divides. Conflict types are the dominant type at that utterance.

[a] Speaker is referring to cost calculation formulas

These examples are merely illustrative and should not replace either an in-depth qualitative analyses or our statistical analysis. Indeed, for some kinds of psychological phenomena, explicit cognitive processes play a strong role, whereas for other psychological phenomena, implicit emotional/memory processes play a role (e.g., priming effects or blocking effects in memory). In the case of implicit processes, statistical evidence, as we used, may be more revealing than qualitative analyses of specific speech. These examples show there is no simple explicit mechanism underlying the connection between uncertainty and conflict.

3.2.3 Uncertainty and subsequent micro-conflicts

Because our data are observational, the temporal relationship between conflict and uncertainty could be explained by 'third variable confounds:' For example, it is possible that increases in task difficulty raise both conflicts and uncertainty (instead of conflict per se leading to decreases/increases in uncertainty). To rule out this alternative explanation, we also tested the effects of uncertainty (Lag1 and Lag2) on subsequent task and process conflicts, as well as the interaction of lagged uncertainty with type of team on conflict. If there are third variable confounds, the reverse temporal relationships should be found for the same conflict type-to-uncertainty connections obtained above.

We used HLM 7.01 to conduct three-level hierarchical logistic regression analyses, with dichotomous conflict variables as the dependent variables (presence of conflict or not) and percent of uncertainty utterances in the block (Lag1 and Lag2) as the independent variable. For all models, we controlled for three significant Level-1 covariates: number of speakers in the block, total number of words, and percent of on-task talk that was specifically about the hardware product itself. The gender variables (at either the meeting or team level) and eventual team success were not significantly related to any subtype of conflict. As with the earlier analyses, we controlled for potential main effects and Lag1 effects.

Controlling for those three covariates, we found no significant effects on overall conflict for either uncertainty Lag1 ($p > 0.19$), uncertainty Lag2 ($p > 0.10$), team success ($p > 0.80$), or, most importantly, the interactions between team success and either uncertainty lag variable (Lag1, $p > 0.32$, Lag2, $p > 0.15$). There was a significant positive main effect of uncertainty Lag2 on task conflict, odds ratio = 1.69 (1.01, 2.82), $df = 3717$, $p = 0.044$. However, uncertainty Lag1 ($p > 0.12$), team success ($p > 0.34$), and, most importantly, the two interactions were not significant (success × uncertainty Lag1, $p > 0.64$, X Lag2, $p > 0.55$).[9]

Of particular relevance, there was a marginally significant interaction between uncertainty Lag2 and the team success variable on process conflict, odds ratio = 0.076 (0.006, 1.035), $df = 3717$, $p = 0.053$, when controlling for the three covariates, uncertainty Lag1 ($p > 0.25$), uncertainty Lag2 ($p > 0.17$), team success ($p > 0.64$), and the interaction between success and uncertainty Lag1 ($p > 0.22$). While this interaction echoed the interaction between process conflict Lag2 and success on subsequent uncertainty, this interaction was much weaker in size and marginal in significance. Conducting analyses separately for low and high success teams, there were no significant relationships for uncertainty (Lag2) on process conflict (ps > 0.18).

3.2.4 Summary of findings

The general pattern of our findings was that, for high success teams, some micro-conflicts (particularly process conflicts) were negatively related to the prevalence of subsequent uncertainty, whereas for low success teams, some micro-conflicts were positively related to uncertainty in subsequent blocks. This interaction effect was significant for both task and process micro-conflict subtypes, even though these two types of conflict were negatively related to each other. Importantly, low and high success teams did not differ overall on their levels of uncertainty or any type of conflict; all teams had regular uncertainty and conflict. Instead, the differences by team success were specifically in the interrelationship between prior (Lag2) conflict and subsequent uncertainty. Further, there was no strong parallel interaction effect between uncertainty and success on subsequent conflict. Task conflict was significantly preceded by high uncertainty (Lag2) as a main effect, but this effect occurred for both types of teams. Thus, the observed temporal relationships between conflict and uncertainty cannot be explained by general co-occurrence patterns between conflict and uncertainty (e.g., triggered by a third variable confound).

4 Discussion

Using novel methods, this study provides evidence that successful and unsuccessful design team problem solving can be differentiated in terms of the nature of the temporal relationship between micro-conflicts between team members and subsequent psychological uncertainty. We observed that, in successful design teams, micro-conflicts decreased uncertainty, while in unsuccessful teams, micro-conflicts comparatively increased uncertainty. These correlational findings suggest a new hypothesized distinguishing factor between successful or unsuccessful problem solving: Successful teams may be achieving better problem solving by harnessing their disagreements to reduce individual uncertainty in the moment.

One might wonder whether our findings are simply another story about how successful teams are better at resolving conflicts. If this were true, the lower success teams should have displayed higher levels of conflict (or lower levels of uncertainty) *overall*, compared to the higher success teams. However, this was not the case: The lower success teams did *not* have significantly more conflict (of any type) or more uncertainty *overall* than the highly successful teams, including the proportion of quickly resolved conflicts. Thus, our findings cannot be explained by general differences in propensity to conflict or uncertainty in low vs. high success teams.

4.1 Implications

This study makes a contribution to the design studies literature by enriching our understanding of successful design teams. This study deliberately examines brief, minor conflicts, and finds that for successful teams, micro-conflicts can be potentially beneficial by decreasing uncertainty. Uncertainty, particularly brief uncertainty, is not always negative, but it needs to be managed for problem solving to be successful (Schunn & Trafton, 2012). For example, problem solving in ill-defined domains (a common situation in real-world engineering design problem solving) is inherently imbued with uncertainty related to problem detection, finding, and structuring (Goel & Pirolli, 1992; Runco, 1994), activities that occur early in the problem solving process (Mumford, Reiter-Palmon, & Redmond, 1994; Runco, 1994). In the course of solving a problem, this uncertainty is assessed, managed, and reduced. This study suggests that teams—specifically, design teams, which encounter a lot of uncertainty relative to other types of teams in organizations—may successfully manage uncertainty by iteratively raising and dealing with alternative conceptions in a way that helpfully reduces uncertainty in the moment, leaving time to address more issues that arise in problem solving.

This study also builds on other team cognition research. Within conversations, team members engage in problem solving, but also develop, challenge, and maintain underlying shared mental models. In particular, design teams are trained to engage in critical inquiry in order to effectively find and solve problems (Dym et al., 2005; Schön, 1983). Shared mental models occur when individual mental models are similar with regards to tasks and teamwork (e.g., Burke, Stagl, Salas, Peirce, & Kendall, 2006; Johnson-Laird, 1980; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). Both the accuracy and congruence of shared mental models have been identified as important aspects of group cognition and positively predictive of team performance (e.g., Burke et al., 2006; DeChurch & Mesmer-Magnus, 2010). Disagreements may arise due to differences in shared mental models (Bearman, Paletz, Orasanu, & Thomas, 2010; Cronin & Weingart, 2007; Paletz & Schunn, 2010). Our findings suggest that for more successful teams, disagreements may be used in uncovering and settling these differences. As Dong (2005, p. 458) noted, "*Team communication reflects the formation of mutual expectations and shared understandings*" (italics in the original). However, even with greater tolerance for disagreement, some design teams may get bogged down in irreconcilable issues. Differences in shared mental models—for instance, regarding an ill-defined problem—may be too fundamental for some teams to overcome, and/or disagreement may uncover more underlying differences than the team is capable of handling, leaving a state of increased uncertainty. In particular, the examples noted previously illustrate that unsuccessful teams may be grappling with more challenging issues when they are disagreeing.

While our data uncovered temporal relationships between conflict and subsequent uncertainty, they raise further questions about *how* disagreements might help design teams successfully manage individual uncertainty during complex problem solving. Our analyses of the reverse relationship generally did not support the simplest explanation: that disagreement and uncertainty simply co-occur. Thus, our data spur more theoretically interesting questions about the causal proximal and distal relationships between conflict and uncertainty. For example, are successful teams directly better at harnessing conflict for resolving uncertainty, such that they resolve uncertainty by increasing the information exchange during conflicts (i.e., information exchange is a mediator of the disagreement-uncertainty relationship)? Does conflict-driven uncertainty resolution better enable teams to achieve a shared understanding by the end of their project (e.g., Agogino et al., 2006)? Were the less successful teams reacting to disagreement with more tentativeness in order to manage and accommodate conflict (McDonnell, 2012)? In addition, the effect for Lag2 rather than Lag1 suggests an incubation period is necessary: It may simply take time, after a disagreement, for individuals to hear and encode the disagreement and for that to affect uncertainty within individuals, before the change in uncertainty is spoken aloud.

One possibility is that conflict was associated with problem-solving techniques that then impacted uncertainty. This study aligns with emerging research findings from the design field and elsewhere suggesting that, despite general negative effects of self-reported conflict on team performance (e.g., De Dreu & Weingart, 2003), brief or mild disagreements can, in the right circumstances, have positive outcomes on creativity and cognition (Chiu, 2008a, 2008b; Goncalo, Polman, & Maslach, 2010; Miron-Spektor, Efrat-Treister, Rafaeli, & Schwartz-Cohen, 2011; Paletz et al., 2013; Todorova et al., 2014). For example, in a study on the Mars scientist conversations, process micro-conflicts were found to increase the likelihood of analogies soon after (Paletz et al., 2013). Analogies are useful for team success and creativity (Dunbar, 1995, 1997). Indeed, in successful multidisciplinary expert teams, problem-related analogies reduced uncertainty (Chan et al., 2012), and analogies and mental simulations can be used to reduce uncertainty (Ball & Christensen, 2009). These studies suggest that analogy and/or mental simulation, or other creative cognitive processes, may be possible mediators of the relationship between conflict and uncertainty. In addition, in our data, high uncertainty significantly preceded task conflict with no difference across types of teams, suggesting that uncertainty may serve as a prompt for, or in some indirect way lead to, task-related conflict and not for the other subtypes.

Finally, these findings have potential practical implications for design teams. Design teams, including student design teams like our sample and unlike some teams in other organizational settings, may be encouraged to disagree as part of their divergent search processes (Dym et al., 2005), such that brief conflicts may not be a source of anxiety. Indeed, their existence did not differ between successful and unsuccessful teams. However, harnessing conflict and gaining the best insights can still be a challenge: Team leaders should be aware of and channel what the teams do with that conflict in terms of improving cognition and uncovering or resolving uncertainty. In addition, in non-student teams, managers should also be aware of organizational- and project-level forces that can interfere with or enable shared understanding, as well (Kleinsmann & Valkenburg, 2008). Taking a broader view, this study echoes that teams with greater difficulties in achieving shared mental models, such as a mental model of the problems themselves, may simply struggle more than other teams, and those other teams have an easier pathway to success.

4.2 Limitations and future work

Successful and unsuccessful design teams may differ on many features, including their initial resources (material, intellectual, etc.); the difficulty of their tasks; their team processes (e.g., Kauffeld & Lehmann-Willenbrock, 2012; Post, 2012); their use of collaboration tools (e.g., Jang & Schunn, 2012); and their ability to leverage external support. This study includes many controls to rule out reverse causality or these possible third variable explanations of the obtained relationships. For example, there were no significant effects for team or meeting gender composition or team size on the prevalence of uncertainty. Importantly, unsuccessful teams had essentially equal levels of uncertainty and disagreement as successful teams, removing the possible alternative explanation that the successful teams simply had less uncertainty or were less likely to disagree—though not what topics they were uncertain or disagreed about. Nevertheless, the issue of causality is not fully resolved. For example, even though successful teams are likely to reduce uncertainty following micro-conflicts, this relationship may not have influenced their design success. Future research can also unpack the consequences of these patterns between disagreement and uncertainty on other related processes, such as information search, creativity, mental simulation, and analogy (e.g., Ball & Christensen, 2009; Chiu, 2008a; Christensen & Ball, 2016a, 2016b; Paletz et al., 2013). Given our examples, it is unlikely that any one of these is the only mediator, but that some combination of implicit and explicit processes exist.

This study also examined only one design context in one particular culture, given the highly time-consuming data collection and coding methodology. Other domains with different types of disciplinary and demographic diversity and levels of expertise (novice/experts) should be tested, such as professional design teams across different countries. Comparisons across contexts and cultures will be important for identifying the boundary conditions for observed relationships. One interesting comparison is the relationship between the present findings and a previous investigation of the relationship between conflict and uncertainty in conversations of an expert science team working on the

Mars Exploration Rover mission (Paletz et al., 2016). Even though that team overall was highly successful, disagreements about the planning and interpretation (of the results) of the rover's scientific expeditions led to an *increase* in expressed uncertainty. Of course, there are large differences in tasks and participants across the two studies: the previous study examined members of a *professional*, *long-duration* team engaged in *scientific discovery*; here, we examine more *recently-formed*, *student engineering* teams. One possibility is that the present findings do not apply to the success of teams in general, only to teams engaged in design (vs. scientific discovery, for example). Alternatively, even successful teams may uncover more uncertainty through conflict in extremely novel tasks. Future studies that examine more teams across more contexts may be able to identify contextual factors that may moderate the relationship between team success and conflict-uncertainty dynamics.

4.3 Conclusion

In conclusion, we report our discovery of a temporal relationship between brief disagreements (a social design process) and subsequent psychological uncertainty (a cognitive design process) that differs for design teams with different problem-solving success and failure. This finding was particularly strong for process conflicts. This discovery sheds light on the nature of successful design in teams and spurs additional theoretical questions about the complex factors that underlie team design success.

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Notes

1. Unless otherwise mentioned, we present the test of the unit-specific model with robust standard errors. HLM 7.01 uses penalized quasi-likelihood (PQL) estimation.

2. This choice was statistically justified. An HLM null model tests the dependent variable without any predictor variables using chi square estimation to determine whether there are significant higher-level components. The null model of the uncertainty dependent variable showed that there was significant variance at both Level 2 (video clip level), Tau beta = 0.06, X^2 (38) = 210.41, $p < 0.001$, and Level 3 (team level), Tau pi = 0.04, X^2 (20) = 58.65, $p < 0.001$ (ICC = 4.8% for Level 2, ICC = 3.1% for Level 3). In other words, there was a need to use a multilevel model.
3. As an offset variable, we used (1 + ln[number of utterances]) because the offset variable cannot equal zero.
4. Very similar findings were found when controlling for the number of utterances transcribed for each group and using a univariate generalized linear model.
5. Event rate ratio = 0.83, (0.69, 1.01), $B = -0.18$, $SE = 0.10$, $df = 3870$, $p = 0.061$.
6. Graphs created using unstandardized, uncentered variables because the independent variables are dummy coded. Covariate effects evaluated at their mean values (2.51 for number of speakers in block, and 5.54 for average words per utterance).
7. Testing only Lag2 conflict blocks so as not to artificially inflate relationships between types of conflict.
8. Event ratio = 0.80 (0.63, 0.999), $df = 3736$, $p = 0.049$. There was a marginal negative effect for task conflict Lag2 on subsequent uncertainty for high success teams, event ratio = 0.84 (0.70, 1.02), $df = 1782$, $p = 0.073$, but no significant relationship between the variables in low success teams ($p > 0.56$).
9. This positive effect of uncertainty Lag2 on task conflict was not simply an artifact of controlling for non-significant interactions with success: The effect of uncertainty Lag2 on subsequent task conflict remained when the model was only the three significant Level-1 covariates and uncertainty Lag1 ($p > 0.37$) and Lag2, odds ratio = 1.50 (1.03, 2.19), $df = 3719$, $p = 0.034$.

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