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MESSY TALK AND MUTUAL DISCOVERY:
EXPLORING THE NECESSARY CONDITIONS FOR SYNTHESIS IN VIRTUAL TEAMS

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ABSTRACT

The challenges of engineering team collaboration—establishing trust, fostering productive informal communication, cultivating knowledge exchange—are often exacerbated in virtual teams by geographical separation as well as team members' cultural and linguistic differences. Researchers have observed that powerful collaboration in collocated teams is supported by shared visualizations with which the team engages in informal, flexible and active ways. In order to better support virtual teams, we explore the mechanisms of and the necessary conditions for collaboration and synthesis known as messy talk and mutual discovery. In studying virtual team interactions in a virtual world known as the CyberGRID, we see that just as with AEC collocated teams, shared visualizations were instrumental for the teams as they define, understand, and generate knowledge when working on interrelated tasks. Emerging from this analysis is an empirically supported theory that messy talk requires both a flexible, active, and informal shared visualization that support a distributed team's mutual discovery, critical engagement, knowledge exchange, and synthesis. We are able to conclude then that when virtual team members make their knowledge work more explicit and mutable through shared visualizations, (particularly those that are flexible, active, and informal thereby exposing the dynamic knowledge creation process), they can overcome the barriers to geographic distances and share opportunities for knowledge exchange through messy talk and mutual discovery.

KEYWORDS: Global Virtual Teams, Collaboration, Communication, Visualization, Information Technology, Building Information Modeling, Virtual Worlds

INTRODUCTION: SHARED VISUALIZATIONS IN AEC TEAMS

For collocated teams, much work has been done around how shared visualizations, such as Building Information Modeling (BIM), support distributed knowledge exchange through interaction, collaboration and communication in architecture, engineering and construction teams (Orlikowski 2000; Liston et. al. 2007; Taylor 2007; Whyte et. al. 2008). Knolwedge and

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information exchange is vital in AEC teams (Carrillo and Chinowski 2006). For the practitioner who creates them, visualizations and models both serve as a way to communicate knowledge and as a means of knowing (Whyte et al. 2008). Those who receive a drawing or a model reinterpret it through their own domain lens, their role on the project, and their disciplinary expertise (Dossick and Neff 2010). Consequently, models and documents are sites for conversation where meaning is made in part through talk when practitioners exchange perspectives, knowledge and interpretations (Neff et al. 2010). Dossick and Neff defined messy talk as "unplanned, unforeseen and unanticipated" supporting brainstorming and mutual discovery (2011, p. 85). Visualization helps lead to "unexpected discoveries" through designers' rapid-fire process of sketching, analysis, and synthesis (Suwa, et al. 2000, p. 240). In this paper, we argue that when visualizations are co-created through a discursive process, especially in multidisciplinary settings, new ways of identifying, analyzing, and synthesizing problems can occur.

Using virtual teams composed of geographically distributed members who collaborate to accomplish organizational tasks is a growing phenomenon in global engineering projects (Gibson and Gibbs 2006; Nayak and Taylor 2009; Kirkman et al. 2002). The challenges of engineering team collaboration—establishing trust, fostering productive informal communication, cultivating knowledge exchange—are often exacerbated in virtual teams by geographical separation and team members' cultural and linguistic differences.

Therefore, it is increasingly important to understand how to accomplish effective collaboration involving knowledge exchange and synthesis in virtual teams, where all interactions are mediated through technology. To accomplish this, we extend our understanding of messy talk from collocated teams to study how it is achieved in virtual teams. We now ask, if messy talk emerges from social interaction with shared visualizations, how and in what ways do geographically-distributed AEC teams achieve knowledge exchange and synthesis when working together with shared visualizations in virtual worlds?

In this paper, we compare three geographically dispersed student teams collaborating on complex engineering problems in a virtual world with shared BIM visualizations to illustrate how messy talk emerges and determine both the technological and organizational contexts that support messy talk in virtual teams. We compare instances of messy talk with non-messy talk exchanges to isolate necessary conditions that spark mutual discovery and engender messy talk.

MESSY TALK IN AEC TEAMS

Part of the challenge for virtual teams in the architecture, engineering, and construction (AEC) industries is that these teams are most commonly organized in medium-term temporary teams or project networks that rely heavily on the process of documentation (Neff et al. 2010; Taylor and Levitt 2007). Visualizations from sketches to models must simultaneously serve the cognitive purposes for their creators, provide a starting point for conversation and collaboration, and fulfill a purpose for documenting work within the project (Ewenstein and Whyte 2007; Neff et. al. 2010; Suwa et al. 2000; Whyte et al. 2008). From collocated teams working with BIM tools, Dossick and Neff (2011) defined messy talk as an active, informal, and flexible collaboration process that is characterized by the emergent contextual mutual discovery of issues that may impact others or have unintended, unforeseen consequences for the project which occurs in interstitial moments of conversation. It is only through the experience of messy talk that project participants understand that they know something others also need to know.

Dossick and Neff further argue that active, informal and flexible documents and visualizations support messy talk by allowing people to draw, write, sketch, talk, or otherwise modify shared knowledge together. Visual materials, such as Building Information Models, have traditionally been created by participants independently and brought into coordination meetings where they are treated as static entities (Aspin 2007; Whyte, Ewenstein et al. 2008). While BIM supports problem definition and explicit knowledge creation, its static (i.e. passive) and "formal" appearance makes it less powerful for joint problem solving (Dossick and Neff 2011). This may foreshorten conversation because, as currently used, these tools limit opportunities for "messier" mutual discovery and unanticipated problem solving at the expense of more efficient or "cleaner" documentation (Dossick and Neff 2011). Whyte et al. (2008) found that when visual materials were owned and negotiated by the team, as opposed to being created independently as described above, a more effective knowledge development emerged through exploration. From this we hypothesize that BIM (or any other medium) may be used for "messy" problem-solving if it is created by the team interdependently through mutual discovery and negotiation. To achieve this, the medium must necessarily be active, informal, and flexible.

Ingram and Hathorn (2004) define collaboration as having three essential elements: participation, interaction, and synthesis (creation of new knowledge). While participation and interaction are supported using current BIM and collaboration software such as Skype or WebEx, achieving synthesis could be more challenging in virtual spaces where traditional media used for informal and flexible side conversations leveraged by collocated teams, such as paper or whiteboards, are not as readily available. Virtual teams must find new ways using less traditional electronic tools to achieve effective collaboration. Consequently, we need to understand the necessary conditions for synthesis in order to understand how tools in the virtual environment can support collaborative dialogue. How can virtual teams balance the technological affordances of systems like BIM, which support documentation well, with the needs of groups to share knowledge in unplanned, unforeseen, and unanticipated ways?

EXTENSION OF MESSY TALK

The collocated teams that Dossick and Neff (2011) studied were experienced design and construction professionals from multiple disciplines. To identify messy talk in settings other than collocated MEP coordination meetings, we first need to operationalize the definition of messy talk. Using the examples from Dossick and Neff (2011) we defined the following four key elements of messy talk:

1) Mutual Discovery: The process is one of discovery, both the discovery of solutions and of new problems that emerge from proposed solutions.
2) Critical engagement: Individuals actively engage in thinking through the issues and problem solving
3) Knowledge Exchange: Team members exchange information about a situation that was previously distributed among them—no one member has knowledge or information that leads to the identification of the problem and the solution
4) Synthesis: Statement of a joint solution or resolution; there may or may not be recognition that the solution was the result of a joint effort.

To operationalize these elements, we analyzed interactions from Dossick and Neff (2011), defining how they are characterized for each. Table 1 below outlines the analysis framework, which we used to then analyze interactions in the virtual teams we studied. In teamwork there are many types of discussions team members have with each other, and to identify messy talk we use the four key elements listed above. In this operational definition of messy talk, the teams do not achieve messy talk unless all four elements are present.

Table 1. Extension of Messy Talk

Messy Talk Elements	Operational Characterization	Example Phrases[6]
1) Mutual Discovery	Discussion leads to statement of problem or issue being brought to others' attention	"Have we thought of…" "Oh, I just realized…" "That reminds me…"
2) Critical Engagement	Iterative discussion and questioning, critiquing, clarifying of problem or issue; "thinking out loud" jointly.	"What do you mean by…" "Why do we need…" "What if we tried…"
3) Knowledge Exchange	Sharing of experience, understanding or knowledge; bringing in examples or previous work.	"In my experience…" "In the past we …" "I've understood this to be…"
4) Synthesis	Statement of a joint solution or resolution; there may or may not be recognition that the solution was the result of a joint effort.	"Ok, we've decided to…" "We can all agree then…" "That will work for everyone?"

This extended definition of messy talk is based solely on the collocated teams studied in Dossick and Neff (2011), and this definition will now be used to define and analyze messy talk interactions in geographically distributed virtual teams.

SETTING & METHODS: STUDENTS IN CYBERGRID

In this paper, we analyze qualitative ethnographic data to examine collaboration effectiveness of distributed virtual engineering project teams, based on an examination of the collaborative interactions from an online project. In the winter/spring of 2011, thirty-one graduate and undergraduate students from the University of Washington (UW) and Columbia University (CU) met in eight teams of students from both universities. Each team met once a week for ten weeks in an online environment called the CyberGRID (Cyber-enabled Global Research Infrastructure for Design), a virtual collaborative space developed at Columbia University. In the CyberGRID, participants are represented by a 3D human avatar and they share a 3D virtual world with a meeting space and a 3D model of their building project. They communicate with each other via VoIP (Voice over Internet Protocol), text chat, and file exchange. In the meeting room, a "team wall" allows members to share their computer desktop in real-time. Team members could provide non-verbal cues within the system akin to hand-raising or nodding in the form of head bubble gestures or avatar position reinforcing the sense of copresence, i.e. the sense of being there together (Anderson et al. 2011). Figure 1 shows a typical

[6] These are example phrases that typify the types of statements we can use to identify the elements in team interactions. These do not come from a specific team interaction, but are theoretical examples to establish the sampling framework.

meeting space when avatars are in the space. Thought bubbles used for backchannel communication such as the green bubble for “I agree,” are located at the top center of image and the team wall shared desktop tool (showing SimVision in this image). The green waves over the avatar’s head indicate when someone is talking. The team members were assigned to complete all of their working during the lab sessions. Therefore, they were virtually co-present during their synchronous meetings.

Figure 1 CyberGRID: virtual collaboration space

We created an experiment wherein each team was asked to complete a complex design and planning task for a fictitious building project, with each university being responsible for one component of the task.7 Their individual assignments were closely interrelated such that they needed to share information and work jointly on the problem. The teams worked with simple 3D models developed in Maya for importing into the CyberGRID. Students at Columbia University were responsible for creating the baseline schedule and organizational analysis in Simvision and students at the University of Washington were responsible for the 4D model based on the Simvision schedule. Each team was then asked to optimize their models. It was in the optimization process in particular that we expected to see messy talk emerge as these were the types of tasks for which we observed in collocated teams leverage messy talk (Dossick and Neff 2011).

All interactions that took place in the virtual collaboration space were audio- and video-recorded. Researchers also took detailed ethnographic notes and completed ethnographic observation sheets for each meeting using categories for use of tools, teamwork, and communication. Key potential messy talk interactions when teams were reviewing the Simvision and Navisworks models together were identified using these ethnographic observation sheets. For example, while one team was reviewing their models, the ethnographer wrote “They collaborate using the team wall, they are commenting, analyzing each activity, their crew size, experience level.” We also analyzed interactions around troubleshooting of an interoperability issue transferring data from Simvision (used at CU) to Navisworks (used at UW). We then used the extended definition of messy talk to characterize the elements at work in each of these interactions.

FINDINGS: MESSY TALK, MUTUAL DISCOVERY AND TROUBLESHOOTING

To examine messy talk, we closely analyze three different examples of work-related interactions around shared visualizations in the CyberGRID below (See Table 2). The first two of the three types of interactions, Troubleshooting and Mutual Discovery, represent interactions that contain some of the conditions for messy talk. In these types of talk, the students sought to define and resolve problems, but they did not leverage all four necessary elements for messy talk. In the third example, the team achieves knowledge exchange and synthesis through messy talk and typifies the types of messy talk interactions we observed in these teams. In the next section of the paper we present each of these three interaction types and discuss how troubleshooting and mutual discovery alone do not meet the messy talk criteria. Virtual teams can, and do, achieve messy talk and generative solutions when they engage troubleshooting and mutual discover in combination with knowledge exchange and synthesis.

Table 2. Interaction Types: Messy Talk, Mutual Discovery and Troubleshooting

	Interaction 1: Troubleshooting	**Interaction 2: Mutual Discovery**	**Interaction 3: Messy Talk**
Team Setting	CU projects MS project on team wall. The team reviews together. UW1 makes suggestions and CU students follow her instructions through a drawn out trial and error troubleshooting process	CU students realize they are missing the stairs in their model as they watch the UW students work on the 4D model. No subsequent discussion about the problem	CU3 shares Simvsion model with team and asks others "are these the same crew?" UW3 defines what a carpenter does. They agree that all of the activities could be carpenter crew
Transcript Excerpts	UW1: What happens when you do that? CU1: It just highlights the whole column… UW1: Yeah, I get something different. I get more than a day… UW1: Can you try exporting again?… CU1: so you think … is … correct?... I think our duration should first… … CU1: Can you start working … now? UW1; Sure, yeah. I can	CU2a: Ohhhh [groans] CU2b: What's up? CU2a: You know where the stairs go? …in Simvision … so I'm going to have to redo it. CU2b: Sorry. Not mentioned again, UW students continue to work on the Navisworks model.	UW3: All of these? … CU3: Um, no not the …MEP. I just mean the cladding and the exterior doors. UW3: Sure, yeah you could, … could do all the same stuff. … be a carpenter. CU3: Cool. Carpenter. That's the word I was looking for… UW3: They'll also do all the windows. The roofing. CU3: I'm just going to … concrete, roofing, cladding, windows, finishing. UW3: Ok, that sounds good.

Troubleshooting

Some of the interactions in the CyberGRID did not meet the criteria for messy talk, but did contain elements of mutual discovery and critical engagement. Even when students were engaged and talking with each other, they often lacked needed information or knowledge for the tasks at hand. In these cases, teamwork was characterized by trial and error troubleshooting, exploring together different options, working together in joint learning and exploration. For example, all of the teams had to work through interoperability issues in transferring data between Simvision and Navisworks, or what they called the "Simnav Conflict." In Table 2, the excerpt from Interaction 1 exemplifies what happened during these troubleshooting interactions. In the example, the team tried to figure out why the schedule they exported from Simvision did not have the correct data needed for Navisworks. CU1 projected the MS Project schedule on the team wall and the team reviewed it together. UW1 led the discussion, using the pens to circle the shared document. What followed was the team jointly experimenting within the models in real time, with each group suggesting various ideas for trial. Even though this was a team effort, what was missing was mutual discovery and sharing distributed knowledge that results in a synthesis or generative results. Although they worked through the problem as a team and collectively brainstormed ideas as to what to try next, they did not experience unanticipated discoveries or synthesize knowledge that is characteristic of powerful generative messy talk.

In this example, the team simply does not have the technical knowledge needed for this task. Consequently, they collectively struggle with the problem in a linear trial and error exercise, with a resolution when the data exchange finally works. With neither experience with Simvision conversions nor understanding how Simvision works, teams experimented rather than relied on the expertise of their members. When tackling this same problem, some teams sought out a teaching assistant or professor for the answer. Of course, without the answer residing within knowledge already distributed across the team, messy talk could not get them to this solution.

Mutual Discovery

Mutual discovery is the unanticipated results of the process of working together and a necessary, although not sufficient characteristic for messy talk. We found in the transcripts several instances when a team jointly discovered issues, only to have those absorbed back into individual problem solving. This resulted in a quick moment of knowledge exchange and interaction without team discussion, knowledge exchange, critical engagement or synthesis. Teams that created a divide-and-conquer approach to their division of labor, as opposed to more richly collaborating, typically arrived at a mutual discovery that was not resolved through messy talk. In the example shown in Table 2, the team in the Interaction 2 example used the CyberGRID as a virtual office; they were all present in the GRID at the same time, but worked independently on their tasks. In this case, UW students projected the Navisworks model on the team wall. While the two UW students were working together on the model discussing possible improvements, the one of the CU students suddenly realize that they are missing the stairs in the Simvision model. A CU student, CU2a, states "You know where the stairs go?... in Simvision… so I'm going to have to redo it." The discuss ends there, and the UW students did not respond and continue to work on the Navisworks model that remains shown on the team wall during the exchange. The student makes the correction himself in the Simvision model on his own computer, which is not shared with his teammates.

In reviewing the operational definition of messy talk then, we see that first all four students are participating, however they are focused on coordinating their models. Consequently, they do not seem to be critically engaging in the model creation and refinement. Only the UW students are talking at the time of discovery, and the shared visual triggers discovery. While this is a classic mutual discovery, it does not result in messy talk. The discovery is contextual and happens in the context of the UW student work. Because CU students are observing the UW work, they realize something about their own work. However, the shared experience is only limited to the discovery, as the CU students do not discuss the missing stairs with their UW counterparts, but rather open Simvision on their side and fix it without sharing it on the team wall. Furthermore, in this example, knowledge exchange is confined to the subteams of two. The two UW students know about their Navisworks model, while the two CU students know about their Simvision model. However, beyond assuring some level of coordination between the two models, this team does not engage in knowledge sharing that results in shared generative results. This exchange was a 'messy moment" of mutual discovery. The work of two teammates sparked a discovery in a third about his own scope of work—CU2a realized that his Simvision model did not have stairs—but they made the correction without further discussion with the team. While mutual discoveries will occur when team members with different but interrelated disciplinary scopes actively engage with each other's work, they do not always lead to messy talk exchanges that synthesize the team's knowledge into a shared solution.

Synthesis through Messy Talk

Messy Talk then is characterized by the combination of mutual discoveries, critical engagement, knowledge exchange, and synthesis. In interaction 3 the team used the CyberGRID as a virtual office; they worked independently on their tasks, but called the team together when they had something they wanted to talk through. Interactions of this team often started with students calling out to their teammates through CyberGRID, asking if they were available for chatting.

Messy talk in the CyberGRID was characterized by critical engagement, the sharing of distributed knowledge and synthesis. The team described in Interaction 3 often came together to compare notes, confirm their understanding of the problem at hand, and came to a group decision that was a synthesis of the team's distributed knowledge. In the example listed in Table 2, a CU student, CU3, is unsure about which crews should be allocated to schedule activities. He knew that a UW teammate, UW3 had some construction experience and asks about crews for different schedule activities projected on the team wall, "all of these?" UW3 responds "Sure, yeah you could, I mean … carpenters could do all the same stuff…." CU3 says, "Cool. Carpenter. That's the word I was looking for." The team agrees that all of the activities CU3 is projecting should be assigned the carpenter crew. This exchange meets the operational definition of Messy talk. The students are critically engaged. They ask questions of each other's models, ask each other for help and make suggestions for solutions, which the team then discusses. In the illustrative example in Table 2 the team sought a resolution to CU3's known problem—what are the correct crews for the schedule? Knowledge is distributed across the team, such that students seek out each other for their perspective and opinion. CU3 has knowledge of Simvision and understands that the crew loading can impact the schedule performance, while UW3 has industry experience to share with his team. Both students are working towards improving the Simvision model and the norm of working together and supporting the creation and optimization of the models is already established. This is in direct contrast with teams from the first two examples in Table 2 who worked on their models independently and didn't have a shared sense of purpose around the models but only shared data (Interaction 1) or coordinated their assignments (Interaction 2). Even in this short example, the team in Interaction 3 acknowledged the shared resolution. CU3 stated the solution they had been discussing and UW3 acknowledged this solution. "Ok, that sounds good." While the team didn't discover the problem together, instead CU3 brought it to the team for discussion, they resolved the issue collectively and the solution was a synthesis of the team's conversation.

Summary

In this paper, we present detailed analysis of three typical interactions found in the CyberGRID and these are summarized in Table 3. In the first interaction type, Troubleshooting, students were engaged in a problem solving activity, but lacked the knowledge within the team to achieve a synthesis or resolution. Consequently, they spent a good deal of time proposing solutions and then testing to see if those solutions worked. In the second interaction type, Mutual Discovery, a shared visualization sparks the realization that one of the models is missing an activity for stairs, but the team stops short and does not discuss or synthesis based on this discovery. The third interaction then fulfills all four requirements of messy talk and results in a resolution that is a synthesis of the team's distributed knowledge.

Table 3. Interaction Analysis: Four Key Messy Talk Elements

	Interaction 1: Troubleshooting	Interaction 2: Mutual Discovery	Interaction 3: Messy Talk
1) Mutual Discovery	**None** Collectively trying things but not through mutual discovery	**Mutual Discovery** Visualization triggers recognition that something is missing in the CU Simvision model. No further collaboration used.	**Mutual Discovery with Resolution** Collectively selecting the problem scope to discuss.
2) Critical engagement	**Engaged but not critically** A student led discussion suggesting different things to try, others followed these without much response or discussion about the result	**Engaged but not critically** Actively watching work, but not questioning each other's models, only their own work. No critique of or input on others' work.	**Critically Engaged** Thinking through the problem together, asking for input, and making suggestions.
3) Knowledge Exchange	**None** No one knew the technical solution; could not share it or use to generate new knowledge	**Direct Translation** CU student knows Simvision model, UW knows Navisworks, but little shared learning	**Distributed Knowledge** One team understands the scope of their activities, while the other understands how to implement
4) Synthesis	**No resolution** They find a work around and proceed with the exercise	**No joint resolution** No joint discussion. An individual works off line to make the correction.	**Recognition of Synthesis** They agree on the path forward implying a joint solution. All in agreement with the resolution.

DISCUSSION: MODELING IN REAL-TIME: TECHNOLOGY AND TALK

As we analyzed the CyberGRID teams and implemented the messy talk operational definition we came to the conclusion that to cultivate and engender messy talk interactions, all four elements of messy talk –mutual discovery, critical engagement, knowledge exchange, and synthesis – must be present in the interaction in addition to the flexible technical solutions proposed in Dossick and Neff (2011). This project shows that we can study and understand how teams of student learners share disciplinary-specific knowledge in integrated team settings. Not only does this have implications for better understanding virtual organizations for industry practice, it also may have enormous implications for understanding the exchange of knowledge in face to face settings as well. Emerging from this analysis is an empirically supported theory that messy talk requires both the flexible, active, and informal setting described in the 2011 study as well as mutual discovery, critical engagement, knowledge exchange, and synthesis.

In comparing the 2011 messy talk study, Dossick and Neff (2011) with this analysis of the CyberGRID teams (Table 4), we see that both mutual discovery and messy talk leading to problem resolution emerge from both. The key difference between the MEP teams in Dossick and Neff (2011) and the CyberGRID teams is the ways in which they completed their work once the problems were discovered. In the 2011 study, the 3D models supported problem discovery, while problem resolution often occurred outside of the model on more flexible, active and informal medium such as pen and paper or whiteboard. In the clash detection meetings, the MEP detailers reviewed clashes together in the consolidated model. They found issues, negotiated solutions, and made lists for themselves of the corrections to be made off-line after the meeting was concluded. After the formal MEP coordinate meeting ended, team members would huddle in informal groups to resolve some of the stickier issues using paper, pens, whiteboards and drawings at hand. Conversely, in the CyberGRID experiments, the students were directed to work on the models together as a team in real time. Therefore they made changes as they talked. They were specifically asked to not work outside of the CyberGRID team meetings and had to submit work product at the end of each meeting that represented to work completed. In our analysis, this distinction appears to be significant. While the Dossick and Neff (2011) MEP teams shared a visual representation of their models, this representation was static. Their solutions were not visually represented in the BIM models, and the team relied on the meeting minutes and personal notes to record the solutions. Conversely, the CyberGRID teams not only talked through the issues, but then proceeded to resolve them in the models during the meeting with all eyes watching. The real time changes were completed using shared visual representations on the team walls. In this way, the team members participated in the co-creation of the models, co-optimization, and the co-resolution of issues. When not changing a model themselves, they often watched their teammates making a change.

We theorize then that working in real time with the models activated these models and in doing so messy talk was supported. As the students in the CyberGRID opened Simvision or Navisworks and with shared visualization worked through the development and refinement of the model, it converted to models from formal, passive and inflexible (as the consolidated MEP models were in the Dossick and Neff (2011) study) to more active, informal and flexible tools. The students went beyond simply sharing their completed models with each other, and actively created schedule tasks, 4D model colors and made changes, pushing and pulling activities around and making choices together. We propose that this broke the formal finished quality that computer models can imbue and allowed the technology to be a more mutable tool that was changed while they worked together in real time.

Table 4. Comparison between 2011 MEP paper and this CyberGRID study

	Dossick and Neff (2011)	**This paper**
Task	MEP Coordination	CyberGRID Student Teams
Technology	Projector with 3D model coordination (clash detection)	Team wall/3D model with Simvision Model and 4D Navisworks Model
Discovery	A problem finding and resolving task. Model was very effective at finding problems, but often not part of the resolving task.	Team members' could see each other's work unfold. Can generate messy moments of discovery when the team is copresent around the work. Digital tools became active, informal and flexible.
Resolution	Pen & Paper or Whiteboard. Dynamic messy interactions aligned with the flexible, active nature of the immediate mutability of the technological media.	Generative problem solving discussion emerged when team members had technical and professional knowledge to share with their team mates. Shared visualizations where the sites of these messy interactions, allowing for a shared experience and defining the shared goal – optimizing the model.

We found that when knowledge tools (such as drawings, spreadsheets, construction schedules, 3D and 4D models) were created or changed in real-time with the other team members, messy talk flourished. Shared visualizations alone lead to moments of Mutual Discovery as well as supported the team's troubleshooting work. In the generative messy talk exchange however, the shared mutable visualizations provided contextual cues for the distributed teams to understand each other's work and dynamically joint-problem solve while the task—the creation and optimization of a construction schedule and 4D model—was being conducted. Although in this analysis, we focused on interactions around shared visualizations. From the ethnography, we are also able to understand that when work was not visually shared, team members sat idle, waiting for the work to be completed by others. This did not engender messy talk or discovery as there was no shared experience. Nor did subsequent team reviews of completed work (completed models seeming passive, inflexible and formal). With shared completed work, without a specific question to address, team members seemed to just accept the work without the same level of critical engagement as those teams who visually shared the co-creation.

Just as with AEC collocated teams (Orlikowski 2000; Liston et al. 2007; Whyte et al. 2008; Dossick and Neff 2011), shared visualizations were instrumental for the teams to define, understand, and generate when working on interrelated tasks. We conclude then that when virtual team members make their knowledge work more explicit through shared real-time visualizations of model development, thereby exposing the dynamic knowledge creation process, they can overcome the barriers to geographic distances and share opportunities for the co-production of knowledge through messy talk and mutual discovery. This makes the collaboration more dynamic and lends itself to opportunities for knowledge synthesis in the case of messy talk and more straightforward interaction in the case of mutual discovery and troubleshooting.

CONCLUSION

In this paper we further explored the alignment of task, technology and talk. In the previous work (Dossick and Neff 2011), we defined the tension between the clean characteristics—formal, passive, inflexible—of current shared displays and models and the need for more messy mediums—informal, active, flexible— such as pen and paper that supports messy talk. In contrast to the previous study, in this project the team members' real-time interactions were confined to a virtual workspace where the technological ecosystem provides for both flexible and inflexible characteristics. All interactions then were mediated through the virtual workspace, which requires the users to adapt to this environment and establish new norms of interaction. Some teams adopted more formal or clean interactions with separate work and file exchanges, while others used pens, voice and bubbles to create more active and dynamic interactions some of which were generative and some of which were not. As engineering teams seek efficient and effective teamwork, we argue that teams should engender messy talk interactions, where critical engagement across distributed knowledge networks generates innovative solutions; and these teams should also avoid team troubleshooting, where the absence of critical knowledge requires the team to spin their wheels looking for a solution that is outside of their knowledge domain.

In this experiment, we found the student teams were at times limited in their interactions. We propose that there may be several limitations due to the student's level of expertise. Some of the students has no industry experience and were limited as to the professional knowledge they brought to the problem. Also, many of the students seemed to focus on "getting the project done". Even when there were opportunities for discussion, questions were ignored or set aside because the student doing the model just wanted to finish. Messy talk has implication for interdisciplinary learning as well. When student teams exchange knowledge in messy talk interactions, they are learning from each other in the process of synthesizing their knowledge.

The next steps for research into messy talk in virtual worlds should include an experimental setting that includes participants with some professional knowledge and a genuine interest in critical engagement in the task at hand. In practice as well as future experimental design, it should be noted that messy talk is not appropriate for all team interactions. Messy talk is only useful when the task needs mutual discovery (when people do not know what they do not know), and when individuals who possess distributed knowledge need to generate and synthesize new knowledge around an issue.

Other research questions stem from the interactions of the researchers and authors themselves. We are also a distributed virtual team across several disciplines and universities. We have found that in working through the questions posed here, we cultivated messy talk exchanges in both verbal and written form such as emails and comments within Word documents. There seems to be an interesting future research direction in asking about how and in what ways digital technologies supports asynchronous messy talk for virtual teams and how this talk both mimics or is different from synchronous team discussions. In asynchronous text based interactions, the discussion is mediated through a slower process that allows for more time for thought. The exchange is slower in written asynchronous discussions, but perhaps there is something more generative in the results. As we wrote this paper, the research team themselves experienced messy talk—both via email as well as in a conference room session writing on a whiteboard—thinking through both written and verbal talk the questions and data together as a team. We bounced ideas off each other, questioned out loud and in writing and pushed each other to think, explain, and reason. Future research questions around messy talk then are: can messy talk be asynchronous? Can messy talk occur via email chains, chat rooms, conference and journal papers all generating new knowledge as a synthesis of a collection of individuals? Furthermore, in addressing the tension between solo work and collaboration, how and in what ways can we measure the effectiveness of messy talk? Perhaps, the speed at which the teams achieve the "resolution?" Or the depth of synthesis? How can researchers measure the quality of knowledge synthesis? Finally, as we develop a more refined sense of messy talk as critical team engagement, how do teams avoid group think and the tendency to take the easy path and just accept what someone else suggests, as opposed to critically engage with the work, question the work, and add valuable individual perspectives that change the outcome of the teamwork?

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