AC 2011-1369: USING BOUNDARY NEGOTIATING ARTIFACTS TO INVESTIGATE INTERDISCIPLINARY AND MULTIDISCIPLINARY TEAMS

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Using Boundary Negotiating Artifacts to Investigate Interdisciplinary and Multidisciplinary Teams

Abstract: *Teamwork, and interdisciplinary teamwork in particular, are increasingly recognized as an important part of engineering education. Engineering educators have therefore taken an interest in employing and studying teamwork in their curriculum. Yet much of their scholarship has focused on documenting student and faculty experiences of teamwork and describing programs and courses only. Examinations of the actual practices and artifacts, that students create and use to manage interdisciplinary team collaborations are an underexplored research area. However, such studies hold much potential for illuminating how teamwork is undertaken, thereby pointing to strategies for successful collaborations. Drawing on prior work in Science and Technology Studies (STS), and based upon a one-month ethnographic study of an interdisciplinary graduate research team, we found that the team used boundary negotiating artifacts (BNAs) to navigate their work. In this paper, we discuss the significance of boundary negotiating artifacts—which build on boundary object literature—and propose the concept as a useful framework for investigating and facilitating interdisciplinary graduate and undergraduate teams. This new framework has the potential to shed light on aspects of interdisciplinary collaboration and cooperation that have previously been underexplored within engineering education.*

Introduction

The importance of interdisciplinary teamwork is widely recognized.[1-4] Some engineering education research on interdisciplinary teamwork has begun to focus on student and faculty beliefs about interdisciplinary work, competencies, learning outcomes, and assessment, but the majority of engineering education publications are limited to course and program descriptions.[4-6] Further, there are few, if any, studies of the day-to-day practices of interdisciplinary teams in engineering education settings and the objects they create and use in those practices. In Science and Technology Studies (STS) and Engineering Studies, on the other hand, observations of scientists' and engineers' work practices have long been an established line of research[7-12] and many have focused specifically on the inscriptions, visual representation, or objects involved in those practices.[13-18] However, focusing on inscriptions and objects specifically in the context of interdisciplinary team collaborations is an underexplored research front in engineering education. With this paper we aim to begin filling this gap in research in hopes of better understanding how interdisciplinary teamwork happens in engineering education settings. More specifically, we use the concept of *boundary negotiating artifacts* to discuss the work practices of an interdisciplinary graduate research team.

Studying the objects involved in engineering collaborations reveals facets of engineering work that otherwise remain unseen and are not revealed through either normative descriptions of engineering work or through interviews alone.[13] Studying such objects and following their circulation among collaborators helps identify and categorize key features of engineering design practices that are otherwise unseen, including, significantly, the relationships and interactions between people.[13] Even though at first sight such objects might appear unimportant, marginal, or overly formalized aspects of engineering practices, they are actually an integral and revealing aspect of engineering work, the subject of lively discussions, and take up much of engineers' time.[13] Recent work by Vinck and others helps demonstrate the value of exploring engineers' work practices in more depth.[13, 19-20] A similar case can be made for engineering education as a site for studying the work practices of future engineers.

The purpose of this paper is three-fold. First, we suggest the addition of boundary negotiating artifacts (BNAs) to the toolbox of engineering education teamwork analysis and demonstrate that this construct opens promising lines of inquiry for engineering education scholars. Second, we suggest ways in which knowledge of BNAs can help both faculty team leaders and their students navigate the challenges of interdisciplinary and multidisciplinary teamwork as well as contribute to other desirable outcomes for engineering graduates, such as communication skills. Third, we propose that BNAs could be a site of mutually beneficial exchange between engineering education and STS or Engineering Studies. While we present some preliminary data, the primary aim of this paper is to introduce the concept of boundary negotiating artifacts. The following questions guided our analysis: 1) What BNAs did the team use and how did they use them? 2) How does knowledge about BNAs contribute to understanding and facilitating teamwork?

While the data for this paper come from a team that specifically aimed for interdisciplinarity, the concept of boundary negotiating artifacts originally came from observations of different communities of practice working together on a project in a way that could be described as multidisciplinary. "Interdisciplinarity is a means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches."[21] Multidisciplinarity, on the other hand, is less integrative, and combines contributions from multiple disciplines in a weaker and often temporary manner, with collaborators staying rooted in their own disciplines.[22-25] Because most engineering design work at minimum requires engineers to engage in multidisciplinary interactions,[10, 11, 26, 27] knowledge of and attention to BNAs could benefit faculty and students in many teamwork settings, and not only those that are interdisciplinary.

Literature Review

From Boundary Objects to Boundary Negotiating Artifacts

The concept of boundary objects was introduced by Star and Griesemer in their study of diverse groups (amateurs, professionals, and administrators) from different "social worlds" working together to create a science museum during the early decades of the 20th century.[14] They found that two factors in particular helped enable successful collaboration among diverse individuals and groups, namely standardized methods and boundary objects. They explained that boundary objects can be abstract or concrete objects

> …which are both plastic enough to adapt to local needs and the constraints of several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual site use. … They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation.[28]

Examples of boundary objects in their study included diagrams, maps, and repositories of items catalogued in a standardized manner. Boundary objects have been taken up enthusiastically by scholars in a plethora of fields, and many modifications and additions to the original concept of boundary objects have been proposed.[29] For example, conscription devices,[16] prototypes,[30] intermediary objects,[13, 31, 32] and standardized packages[33] have all been proposed as necessary modifications or alternatives to the original concept. Despite the fact many of these modifications retain the label of boundary objects, Lee contends that the modifications do not in fact meet the requirements of boundary objects.[29] She argues that the concept is not incorrect, but rather, incomplete, and we should resist the temptation to treat boundary objects as a "catch-all for several theoretical constructs."[34] She then clearly identifies what we have to gain from such a move:

> The black boxing of boundary objects has entailed an uncomfortable separation between artifacts and the socially negotiated processes that give them meaning. … By avoiding the temptation to treat the boundary object as a black box, we open ourselves to models of collaborative work that go beyond simple exchange to more comprehensive and richly specified models of negotiation and enactment.[34]

In other words, by developing a better ontology for the objects involved in collaborations, we gain nuance and deeper understanding of the distinctions between different types of objects, as well as insights about how their different uses affect collaboration. Other recent work makes a similar case for refining the ontologies of intermediary objects because doing so reveals how engineering work actually unfolds.[13] For example, intermediary objects such as technical drawings are a fundamental but understudied aspect of many types of collaborative engineering work.[13]

In part, the limitations of the concept of boundary objects stem from the fact that there are many different kinds of projects, problems, and collaborative work[35-36] and the original concept may not be sufficient to describe and understand all kinds.[29] When studying a given collaboration, scholars will need to decide which concepts are most appropriate. One way to identify different kinds of collaborative work is to draw on Strauss's work on complex and non-routine projects.[37] Strauss developed a categorizing schema that locates projects along two axes. The first axis ranges from *routine* to *nonroutine*, where routine projects have "a project path that has been traversed frequently, clear anticipatable steps, experienced workers, an established division of labor, stable resources, and strategies for managing expected contingencies."[38] Nonroutine projects are not as stable and predictable. The second axis ranges from *simple* to *complex*, where complex projects have "many types of work, many workers and many types and levels of workers, a complicated division of labor, variable workers' commitments, possibly more than one explicit project goal, and a complex organizational context for the project."[38] Simple projects are characterized by fewer people and kinds of work, minimal divisions of labor, singular goals, etc.

The original concept of boundary objects was developed during a study that involved "a somewhat routine and fairly simple" project.[39] It is therefore possible, Lee suggests, that boundary objects are most appropriate for studying these kinds of projects. For complex, nonroutine projects, on the other hand, a different concept may be needed to develop a more nuanced, in-depth understanding of the work and objects involved. To this end, she introduces the notion of boundary negotiating artifacts (BNAs), which are more appropriate in the context of nonroutine and complex projects.[29]

An Ontology of Boundary Negotiating Artifacts

The concept of BNAs emerged from observations of the creation of a museum exhibit that required members from diverse communities of practice to work together. She observed that designers used "artifacts and surrounding practices to iteratively coordinate perspectives and to bring disparate communities of practice into alignment, often temporarily, to solve specific design problems that are part of a larger design project."[40] As described by Lee, BNAs:

- are surrounded by sets of practices that all members may or may not agree upon,
- facilitate the crossing of boundaries (the transmission of information),
- facilitate the pushing and establishing of boundaries,
- may seem "effortful" rather than effortless,
- are fluid and changing, meaning that they can transition from one type of BNA to another and that they can be incorporated or transformed into another artifact, and
- are possible predecessors of boundary objects.[41]

Vinck's extensive discussion of intermediary objects[13] is also useful here in helping to understand the ontology of BNAs because of some key similarities between intermediary objects and boundary negotiating artifacts. Namely, differentiating between one type of object and another is often a matter of small details and is determined by looking at how the object is used in context. In other words, the same or similar objects can be viewed as different types depending on how and by whom they are used. Furthermore, the categorization of both intermediary objects and boundary negotiating artifacts has a temporal dimension, such that they often transition from one type to another over time. Lee identified five types of artifacts in her study.[29] The two we focus on in this paper, which are most appropriate to our data and are summarized in Table 1, are *inclusion artifacts* and *compilation artifacts*. The other three types of artifacts identified by Lee, which we will explore further in future work, are: *self-explanation, structuring*, and *borrowed*.

Table 1. Overview of Inclusion and Compilation Artifacts[29]

Type	Purpose	Examples
Inclusion	Used to propose a new idea, concept, or form to other team members	• Sketches or drawings • Text summarizing a new idea
Compilation	Used to create alignment and coordination between the team members to bring them together long enough to produce a shared understanding of a problem and/or to communicate important information	• Tables • Technical sketches

Inclusion artifacts, often in the form of sketches or text, are used by a member of one community of practice to propose a new idea, concept, or form to members of a different community of practice. The inclusion artifact, which is a reference or symbol for the new idea, is presented to the team and undergoes an informal group screening process that can be viewed as a form of “communal gatekeeping.”[42] In Lee’s case, she observed an inclusion artifact in the form of an “object theater” that one curator employed to convince educators to include exhibit content that they initially opposed.

Compilation artifacts are involved in constantly evolving processes of alignment between the various communities of practice that bring them together long enough to produce a shared understanding of a problem and/or to communicate important information. They serve to coordinate team members. According to Lee, “Compilation artifacts are involved in a web of compiling practices: remembering, gathering, organizing, discussing, anticipating needs, presenting, and explaining.”[43] In Lee’s case, the observed compilation artifacts included tables with information about artifacts for the exhibit and technical sketches. This literature reveals that identifying nuanced typologies of the objects involved in collaborative work is necessary, firstly, for understanding how engineering teams work, and secondly, for understanding how those objects/artifacts can be best leveraged to facilitate successful team work. Additionally, the section that follows helps demonstrate that work on boundary negotiating artifacts becomes particularly significant when considering the importance of team mental models, including considerations such as effective communication and shared knowledge, understandings and vision among team members.[44-50]

Boundary Negotiating Artifacts, Communication, and Team Mental Models

A thorough review of teamwork literature is beyond the scope of this paper. We will instead focus on two topics that are particularly relevant to boundary negotiating artifacts: team mental models (TMM) and communication skills. A recent review of engineering education literature on interdisciplinary teamwork revealed that very few publications have attempted to identify and measure concrete interdisciplinary learning outcomes.[4] However, two of the outcomes that were found were the ability to identify what collaborators in other disciplines need and the ability to “learn from both the methods and content of other disciplines to contribute to the project and inform future work.”[51] Both communication skills and a team mental model contribute to those outcomes, and boundary negotiating artifacts can help facilitate communication and the development of a TMM, thereby also contributing to desired interdisciplinary learning outcomes.

Communication skills are recognized as an important facet of teamwork.[52-53] As noted below, good communication is also a requirement for establishing a team mental model. BNAs have the potential to advance scholarship on communication by highlighting the need to look at actual practices and objects rather than merely normatively identifying communication as important, or only examining select types of artifacts (e.g. formal documentation). By focusing on the daily, micro-level practices of engineers, a fuller, more accurate description of communication processes emerges. For example, by studying intermediary objects, Vinck revealed that the chains of communication that engineers are supposed to follow, and are assumed to follow, were in fact not followed.[13] Moreover, by thinking about BNAs, specific items involved in communication processes can be identified, in turn revealing where problems in communication occur and how successful communication can be replicated and taught.

Team mental models (TMM) are shared knowledge structures that enable a team to form accurate explanations and expectations of the task, to coordinate their actions, and to adapt their behavior to demands of the task as well as other team members. [44-48,50] Components of TMMs include awareness and understanding of team-member composition and resources (e.g. representations of individual members' knowledge, beliefs, and skills) as well as the team task, including its goals, performance requirements, and problems.[46] Researchers have documented evidence of a positive relationship between TMMs and team performance.[44-48] Boundary negotiating artifacts play a role in developing the shared knowledge necessary to produce a TMM. Therefore, faculty interested in developing TMMs could benefit from attention to BNAs. For example, if faculty want students to have a shared understanding of a team's goals and problems, the faculty may find it useful to pay attention to what and how compilation artifacts are used, because one feature of compilation artifacts is that they produce a shared understanding of a problem.

Methods

Settings and Participants

This study was conducted at a large public research university in the Southwestern United States. IRB approval was obtained at both the researchers' and participants' institutions. The team observed was part of an innovative interdisciplinary graduate program that spans several traditional departments, as well as a new interdisciplinary degree program funded in part by the U.S. National Science Foundation's Integrative Graduate Education and Research Traineeship (IGERT) Program. The observed team was part of a larger research unit that focused on a research and development project for physical rehabilitation of stroke patients using mixed media technologies that incorporated audio and visual feedback into physical therapy. Because the team aimed for interdisciplinarity, it was trying to develop its own community of practice but had not yet achieved this because the students' backgrounds and training (e.g. core coursework) were more aligned to traditional disciplines than the project at hand.

Participants included six doctoral students, two post-doctoral research assistants who recently graduated from the same PhD program, and two faculty members who also held administrative positions in the interdisciplinary unit. The six doctoral students (three men and three women) had backgrounds and were located in departments of engineering, computer science, media arts and sciences, and music. They were in their first, second, third, and fourth years of graduate school at the University. As is typical with graduate research teams some members of the team had been working together for several years while others were new to the team that semester.

The team represents an important and innovative attempt to incorporate interdisciplinary team research into doctoral work. They were each working on a piece of the shared rehabilitation system for their individual dissertation research projects. The rehabilitation system involved incorporating audio and visual feedback and sensing mechanisms for the movements involved in physical therapy. Their project work can be characterized as complex and nonroutine.[37]

Data Collection and Analysis

Ethnographic methods were used to collect data during four consecutive weeks of participant observation and interviewing in September and October of 2009.[54-55] The lead author temporarily relocated to the other university and participated in research group activities for several hours each day. This included attending formal and informal meetings, visiting research sites and observing data collection, and being at the students' offices with them as they went about their daily activities. Each participant was formally interviewed at least once, and most were also interviewed informally on several other occasions, in the course of daily interactions. Extensive notes were taken during the observations and interviews. Originally, when collecting data we began with a broad, general focus on how the team operated, specifically how their interdisciplinary values impacted their behaviors and team processes, and we report on this data elsewhere.[56] While we did not begin the study with the goal of examining BNAs, or any other type of object in particular, the importance of such objects became clear during the observations and interviews, which led us to consult the available literature and develop this preliminary analysis. We were originally coding for other themes but began to notice themes related to how the team was using artifacts to communicate, and subsequently went back and analyzed the data for this new theme.

Findings and Discussion

We found that BNAs are a valuable theoretical construct for describing how the team worked together, and especially for understanding various challenges and tensions they experienced. Perhaps it is not surprising BNAs were important for the team being studied since they were working on a nonroutine and complex interdisciplinary project. We found that many of the artifacts used by the team could be accounted for under Lee's typology. In presenting our preliminary findings here, we focus only on two types of BNAs.

As discussed above, *inclusion artifacts* are used to propose new ideas to people from outside one's community of practice. We observed inclusion artifacts in the form of scholarly articles, literature reviews, web sites, presentation slides, and drawings on white boards. A wiki was used to store many of these artifacts. Because the team consisted of members with different disciplinary backgrounds who had to work together researching and developing a rehabilitation system that could meet all of their individual dissertation research needs, it was vital that they understood how each team member and their research was positioned in relation to the larger project. Each team member's work depended on that of others, and they therefore often needed to learn from other disciplines. Or, conversely, they found that they needed to inform other team members about something from their discipline in order for the team to understand why they wanted to build the system in a certain way. It was not the kind of project that students could "divide and conquer." They needed to take other team members' dissertation research into account when planning their own dissertation research, even if it was on a different part of the system. For example, students whose focus was on the media aspects of the system needed to explain to students from engineering why one kind of sensing mechanism would be preferable, more interesting or innovative than another kind, vis-à-vis the media fields in which their research was situated. Inclusion artifacts were therefore used to suggest a certain design plan or feature because the kind of sensing mechanism chosen would affect the work of everyone on the team. In other words, students from the media fields could not make a choice of sensing mechanism without convincing the other team members to do so, and in order to convince them, the media students employed inclusion artifacts to introduce ideas from media sciences to the engineers.

Looking at the use of inclusion artifacts in the team highlights several challenges they faced and reveals potential drawbacks of some of the artifacts they used. First, the literature reviews and articles posted on the wiki, as well as e-mails detailing various design proposals, such as an idea for a sensing feedback mechanism from a student whose focus was on the audiovisual aspect of the design, were not read by everyone. One student commented that although this was a problem, it was to be expected because everyone was busy: "I thought we were still working at a more theoretical level rather than concrete ideas, but I guess I should have been more explicit in what I was thinking about. But people should have read what I sent around too, and they obviously didn't. I understand though, we are all busy." Second, often during meetings someone would draw on the board a possible set up for the system demonstrating how a given technology could be used. However, because there were multiple sub-groups working on different aspects of the system, each with their own meetings, a student might never see this artifact if they did not attend a given meeting. These challenges indicate that students and faculty should pay attention to the specific benefits and drawbacks of particular inclusion artifacts, including whether they can and should be captured, stored, and shared, such as via a digital photo.

Therefore, both faculty and students have a stake in paying attention to what and how inclusion artifacts are being employed because if there are not enough of them, or if they are not used successfully, students may not be able to communicate their needs to teammates. Additionally, researchers and faculty may find it useful to pay attention to inclusion artifacts as sites of communication, negotiation, contest, and decision-making among team members. How do team members communicate new ideas, including from other disciplines? Are some inclusion artifacts more successful at communicating an idea than others? How does the team undertake the collective gate keeping surrounding inclusion artifacts? These are a few of the questions that explorations of inclusion artifacts may begin to provide answers to.

Furthermore, in teaching teamwork practices, faculty could use the concept of BNAs to teach communication skills by demonstrating how inclusion artifacts can help them explain their ideas to other team members and other relevant stakeholders. Prototypes, sketches, and CAD drawings—all of which could be boundary negotiating artifacts—are significant parts of engineering work, and their importance should not be downplayed. When such objects are assignments for interdisciplinary teams, they can be conceptualized as BNAs and used to call students' attention to communication and a team mental model. However, drawing concrete teaching recommendations from our data at this point is difficult because precisely what and how inclusion artifacts are optimally used, and therefore taught, will necessarily vary depending on the type of team in question (e.g. in one undergraduate course or as part of graduate research), how long that team has been working together, and the type of project they are working on.

In addition to the inclusion artifacts*, compilation artifacts* were employed in the form of tables and charts, drawings on white boards, and reports. These were also often posted on the wiki. Recall that compilation artifacts are meant to produce alignment and shared understanding between the different groups involved. Perhaps the most significant compilation artifact observed during our study was the summary report on version 1 of the system. While we were conducting our observations, the team was at the beginning of their efforts to design a second version of the system, the first version having been developed and tested in previous years. Before beginning to design version 2, however, it was important for everyone – both the continuing and the new team members – to understand how the first version had worked and what had been learned from testing it. Therefore, the students who had worked on version 1 developed a report that included data tables and charts to present the information that was collected, and to summarize what had been learned about the system and its users thus far. They presented this information to the entire team at a group meeting. One faculty leader explained that this was important because everyone needed a "common understanding" of what challenges the team faced before they could move forward. The meeting in which this information was presented lasted over two hours, and the students to whom the artifacts were presented had many questions regarding what the data in the tables and charts meant or represented, and why the information had been organized in some particular format or "representation scheme" as opposed to another. In part, the lack of clarity was due to the fact that data had been generated in some cases by someone from computer science or engineering and needed to be explained to others with different disciplinary backgrounds. It became clear that without the presenters there to explain the artifacts, the students who had not worked on version 1 would not have been able to interpret all of the information that the artifacts were intended to convey.

Thus, compilation artifacts can provide information regarding ways to successfully facilitate alignment and communication between team members. For instance, which artifacts facilitate a shared understanding of a problem? Which do not? Which most successfully lead to alignment, or a team mental model? Which artifacts get saved and are easily accessible, under what circumstances, and to what effect? How do compilation artifacts shape team members' actions? Conversely, if it is found that team members lack shared understandings or coordination, then it may prove useful to examine what artifacts they are and/or are not using in their own work. Although these kinds of issues are also faced by mono-disciplinary teams, interdisciplinary and multidisciplinary teams face additional challenges in successfully creating and using artifacts to produce alignment and shared understanding among members who may have much wider variations in background knowledge and skills.

In addition to the presence of boundary negotiating artifacts, their absence and lack of use also deserves discussion. One source of the challenges we observed was that ideas and plans were discussed verbally and no artifact was produced. This caused problems when team members either were not at those discussions or came away with different understandings of what the plan was. Another issue – which led to similar challenges – was that when artifacts were produced, not all members were made aware of or felt obligated to look at the artifacts produced by other team members. For example, during one meeting it became evident that students had been working with different assumptions about the kind of sensing feedback mechanism that would be built into the system, and this caused tensions. Making more effective use of inclusion and compilation artifacts prior to this point could have prevented such tensions.

While the examples discussed here are necessarily specific to the unique, innovative graduate team we observed, the framework of BNAs could also be useful for other kinds of teamwork in engineering education, including undergraduate teams in individual courses as well as multidisciplinary teams. However, it is likely that the types of and uses for BNAs will vary depending on the kind of team in question, as well as how long a team has been working together. For example, teams that have been working together longer may use fewer compilation artifacts because they already have a shared understanding of their goals and problems, especially as compared to a more recently formed team. Therefore, there is much room for engineering education researchers and faculty to develop, explore, and refine typologies for BNAs in ways that are most helpful to understanding and facilitating different kinds of teamwork, including across levels of education and types of graduate research. Additional research on different kinds of teams is also likely needed before more specific implications for how to teach students about BNAs can be identified. The types of BNAs discussed here, as well as the larger set identified in Lee's study, should be taken as a helpful starting point for those investigations, but not necessarily as the only types or as sufficient for describing all teamwork.

Conclusions and Future Work

We found evidence that boundary negotiating artifacts offer a useful theoretical framework for studying interdisciplinary engineering teamwork. They provide information on, and sites of analysis for, interactions and practices that remain underexplored in engineering education research. Our findings suggest that BNAs deserve more consideration within engineering education because of the increasing significance the field is placing on teamwork, interdisciplinarity, communication, and project management skills.

The purpose of this paper was to introduce the concept of boundary negotiating artifacts and present preliminary data on their use in one interdisciplinary graduate research team. We will continue this work during a second, similar study at another site in the Fall of 2011. This will allow more data collection to shed light on the ontologies of BNAs. Others can also develop the concept of BNAs in their own research and start using this knowledge to help them facilitate their own teams. Helping students learn about BNAs is yet another way in which faculty could use the concept. Improving our understanding of what BNAs are and how they are integral to interdisciplinary teamwork could help students manage and negotiate their interactions with team members. Finally, we again note growing interest within STS and Engineering Studies in the objects, inscriptions, and representations employed in scientific and engineering work, as well as the long history of studying those objects. In light of these observations, we propose that studying boundary negotiating artifacts in engineering education settings offers particularly promising opportunities for collaboration between engineering education researchers and scholars in STS and Engineering Studies.

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