Preparing Students for a Collaborative Engineering Design Work Environment: A Study of Practicing Engineers

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Abstract

Recent studies within design and engineering education have focused on better preparing engineering graduates to function within an industry design environment. Increased emphasis in this area is motivated by a growing concern that graduates are entering industry with little experience engaging in authentic cross-disciplinary design projects. While guidance from professors with industry experience and teaching techniques such as project-based and service learning are common approaches to supporting student preparation, there is continued need for design education to include a focus on the development of skills to support communication across disciplinary and team boundaries (e.g., shared language and clarity of narrative). These skills, which are frequently thought of as non-engineering work, are as critical to the completion of cross-disciplinary projects as skills associated with conventional engineering design work (i.e., design and technical practices). As a result, a multiple case study was designed to explore the practices of engineers at three different technology companies of varied size and within diverse product sectors. The study focused on how engineers working on cross-disciplinary design teams use artifacts to communicate and how those artifacts affect design decision making. Examinations of the artifacts practicing engineers use supported the development of design principles for instructors to create modules, assessments, and activities for engineering design classrooms. The educational design principles, presented in this paper as ‘how might we’ statements, include: (1) How might we encourage students to report honestly and accurately about status? and (2) How might we foster the use of documentation in student engineering projects? Findings from this study will be incorporated into an engineering design course in the coming year to further the overall goal of facilitating the preparation of engineering graduates for cross-disciplinary engineering design projects.

Introduction

Modern engineers and designers are increasingly faced with large-scale design projects such as designing transportation systems to meet future demand while reducing environmental impacts, updating urban infrastructure, or supporting increased access to clean water in developing countries\(^1\). These challenges cross disciplinary boundaries and many times require large, multinational teams. Over the last two decades, researchers and educators have explored approaches for designing educational experiences to prepare engineering students for the complex, cross-disciplinary problems they will face in industry\(^2\)\(^-\)\(^4\). In particular, these approaches aim to support the development of engineering graduates with broad knowledge across a variety of domains, more expertise in a specific domain, and an affinity for work on cross-disciplinary teams\(^2\)\(^,\)\(^3\)\(^,\)\(^5\). While on cross-disciplinary teams in industry, engineering graduates will also need to be able to communicate across disciplinary boundaries to support the work of the entire team\(^5\)\(^-\)\(^10\). While engineering curricula include courses and assignments dedicated to developing students’ communication skills\(^11\), many students tend to discount the role of these professional skills in their future engineering practice or lack understanding of how these skills will support them during their engineering career\(^12\)\(^,\)\(^13\).
To better understand the types of communication skills necessary for future engineering graduates, it is necessary to develop representations of engineering design practice that are inclusive of the communication practices used by engineers on these cross-disciplinary teams. Existing studies of engineering practice have furthered our understanding of “engineering design as a social process” (p. 161), the use of digital and paper artifacts to support engineering design, and the role of stakeholder considerations within a complex systems design. Nevertheless, additional research is needed to explore the communication practices among engineers on cross-disciplinary project teams. Communication within and among engineering design teams can be challenging due to epistemological and philosophical boundaries between the groups or differences in goals and values between the individual practitioners in a group. Existing research includes a variety of theoretical frameworks to describe strategies for communicating across, yet the context for most of this research focuses on non-engineering disciplines and practices.

To facilitate the preparation of engineering students for cross-disciplinary engineering design projects in industry, this research aims to examine how engineers working on cross-disciplinary design teams use artifacts to communicate and how those artifacts affect design decision making. A multiple-case study was designed to address two questions, one about the practices of engineers in industry and the other about the implications for engineering education:

I. In the context of large-scale, cross-disciplinary design projects, what are the characteristics and types of artifacts used by designers, and what roles do those artifacts play in the design decision-making process?

II. How can we better prepare engineering students for the communication and decision-making that take place in these cross-disciplinary design environments?

This paper begins with an exploration of existing research on the use of artifacts to support cross-disciplinary collaboration and design. Subsequent sections present preliminary results of this research with a focus on two distinct uses of artifacts as implemented by both engineering and non-engineering designers. These uses are then discussed in the context of existing engineering education curricula and particular educational design principles are identified. The resulting educational design principles from this study will be incorporated into curriculum within an engineering design course in the coming year.

Background

Boundary Objects

While studying the collaborative effort among three groups (i.e., amateurs, professionals, and administrators) of differing viewpoints to create a museum exhibit, Star and Greisemer noticed how the ‘objects’ used by the groups inhabited ‘several intersecting social worlds’ and provided a ‘means of translation’ among groups (p. 393). These boundary objects helped enable successful collaboration among the diverse groups and individuals. Several permutations of boundary objects have been studied in a variety of disciplines, and many modifications and expansions to Star and Greisemer’s original concept have been proposed. Some examples include intermediary objects, prototypes, and mediating and commissioning artifacts. Although these examples often retain the label of boundary objects, Lee argues that many of these modifications do not fit the requirements of boundary objects as artifacts which fulfill the
informational requirements of a particular group or community of practice, as defined by Star and Greisemer.

In her study of cross-disciplinary collaborative design of a museum exhibition, Lee introduced the concept of Boundary Negotiating Artifacts (BNAs) for situations in which different communities of practice must collaborate while on unsteady ground and/or lack standardized structures to support their collaboration\textsuperscript{19}. Lee\textsuperscript{19} defines BNAs as artifacts that:

- Surround a set of practices that all members may or may not agree upon;
- Facilitate the crossing of boundaries (transmitting information);
- Facilitate the pushing and establishing of boundaries;
- May seem “effortful” as opposed to effortless;
- Are fluid: (1) a BNA can change from one type to another when the context of use changes; and (2) a BNA can sometimes simultaneously be physically incorporated or transformed into another artifact;
- Can be largely sufficient for collaboration;
- Are possible predecessors of boundary objects.

In the context of a design process, early phases of the design can motivate the use of these BNAs as engineers are completing non-routine work to conceptualize the task at hand\textsuperscript{23}. As the work becomes more routine, the artifacts used, while still facilitating cooperative work, are the result of now more standardized practices. Pennington (2010) defines these artifacts as Boundary Specifying Objects (BSOs), physical or virtual objects which,

- Facilitate the crossing of boundaries;\textsuperscript{19,22}
- Need little or no explanation regardless of prior knowledge;\textsuperscript{19}
- Are reusable or part of established practices or standards\textsuperscript{23}.

Pennington considers both BNAs and BSOs to be sub-classifications encompassed in the broader term, \textit{boundary object}, which can be used to describe any material object used to facilitate the crossing of boundaries\textsuperscript{23}. Within this study, the BNA and BSO definitions and associated tangible and digital artifact categorizations were used to facilitate the data analysis process and to situate the artifacts observed within an existing framework.

Lee introduced and defined BNAs in a cross-disciplinary, non-engineering environment, identifying several categories of BNA based on function (Table 1), including \textit{inclusion} and \textit{self-explanation}\textsuperscript{19}. The original categories of BNAs were defined in the context of a museum exhibit design. In the context of engineering practice and education, Beddoes and colleagues applied two of the BNA categories, inclusion and compilation artifacts, to explore cross-disciplinary teamwork among graduate engineering students, post-docs, and faculty\textsuperscript{19,27}. That study highlighted the value of employing BNAs as a theoretical construct for describing how team members collaborated and provided a foundation for exploring the creation and evolution of BNAs and BSOs within engineering practice. Still, additional research is necessary to understand the extent to which cross-disciplinary teams within engineering utilize artifacts to support communication and how that practice can support the development of engineering students. In particular, studies of artifacts used on teams could support student preparedness to communicate effectively on projects in complex, cross-disciplinary work environments\textsuperscript{12}. 
Table 1: Overview of Boundary Negotiating Artifact Framework (Adapted from Lee 2007)

<table>
<thead>
<tr>
<th>Type</th>
<th>Purpose</th>
</tr>
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<tbody>
<tr>
<td>Self-Explanation</td>
<td>Created for and used by an individual or small group of people to expand knowledge and understanding</td>
</tr>
<tr>
<td>Inclusion</td>
<td>Used to propose new concepts or forms to other team members</td>
</tr>
<tr>
<td>Compilation</td>
<td>Used to bring multiple communities of practice into alignment on a problem long enough to develop a shared and mutually agreeable understanding of a problem and to pass critical information between the groups</td>
</tr>
<tr>
<td>Structuring</td>
<td>Used to allocate resources, align the values of a population, and/or organize the activity of individuals</td>
</tr>
<tr>
<td>Borrowing</td>
<td>Taken from one community of practice and used in unanticipated ways by people in another community of practice</td>
</tr>
</tbody>
</table>

Interdisciplinary Projects and Industrial Preparedness
Boundary objects have been studied almost exclusively on cross-disciplinary projects where communities of practice must cross boundaries regularly, with few studies of boundary objects occurring in a setting of practicing engineers. Star and Greisemer first developed the idea of boundary objects while studying “a somewhat routine and fairly simple” project19,22. Engineering projects are becoming increasingly more cross-disciplinary in nature, which suggests that artifacts that transcend boundaries would be helpful to these projects; however, these projects may vary in scale and complexity across different organizations12. By studying the uses of BNAs and BSOs, the concept of boundary objects can be extended for use in cross-disciplinary and complex projects, such as those commonly found in industrial design environments.

Strauss28 categorizes projects along two axes. One axis ranges from simple to complex, where complex projects include many workers of many different disciplines, a complicated division of labor, many possible project goals, and a complex organizational context for the project. The other axis ranges from routine to non-routine, where routine projects have frequently-traversed path, clear steps, experienced workers, stable resources, and clear strategies in place. Non-routine projects are much less predictable and can be unstable28. Unlike Star and Greisemer’s study, Lee’s study is characterized by the use of artifacts in a cross-disciplinary environment, where “unsteady ground” in design problems necessitated the development of artifacts that support collaboration in non-routine and complex projects19,23,27. Further research has shown that BSOs can also help facilitate collaboration in complex projects23. Thus, the larger and more complex a problem is, the more BSOs and BNAs may be necessary27.

As most engineering design work requires that engineers engage in cross-disciplinary interactions, a key component of preparing future engineers is helping them to develop the skills to succeed in these interactions. Previous research began exploring the use of BNAs and BSOs in a range of engineering and non-engineering environments. Yet there is still a need for deeper understanding of the uses of BNAs and BSOs in an authentic work environment and their particular functions and characteristics. Additionally, as BNAs are ideally suited to complex projects27, there is a further need to study how BNAs and BSOs interact across disciplinary boundaries on large and complex problems, with multiple stakeholders and team members. Therefore, this study will support the design of strategies to develop students’ communication...
skills by exploring practicing engineers’ use of BNAs and BSOs to communicate and make decisions on complex projects.

Methods

To support development of student communication skills involving the use of artifacts, a multiple case study was designed, consisting of meeting observations and semi-structured interviews at three sites. All participation was voluntary and anonymous, and all collection processes were approved by the research team’s Institutional Review Board prior to the start of the study. Data was then analyzed using qualitative analysis methodologies, including collaborative code development, to deeply explore the characteristics and uses of various artifacts in the context of engineering practice.

Research Sites and Sample

Data collection consisted of three research sites at engineering companies, who design, produce, and support product lines in the consumer and business markets. Each company designs, manufactures, and distributes a different style of product, and they vary in size, age, and management model. To maintain the confidentiality of the study participants, pseudonyms for the companies and their employees were used.

The research sites were Henning Devices, a mid-sized (approx. 12,000 employees) international consumer electronics company; Martin Inc., a large (approx. 160,000 employees) international vehicle design and manufacturing corporation; and Cizus, a small (less than 100 employees) cloud-based software start-up. Each company employs engineers with a range of backgrounds and expertise, and participants in the study were self-selected from this base. Most participants were engineers or project managers for engineering design teams. Several executives also elected to participate. Researchers spent between two and five days at each research site conducting interviews and observations and shadowing engineers and project managers. At each site, researchers conducted five interviews with participants and attended five to eight design and coordination meetings.

Data Sources

Data were collected through meeting observations and semi-structured interviews with voluntary participants. The purpose of observing meetings was to gather information about the use of artifacts in authentic work environments. Given that meetings were routine for the engineering design teams at each of the companies, the meeting observations provided an opportunity for the research team to learn how the artifacts were created and utilized in practice. For each meeting, two to five researchers took handwritten notes to capture characteristics of the meeting (e.g., purpose, attendees, speakers, room layout, artifacts present, artifact characteristics) and the communication practices of the attendees (e.g., use of artifacts).

To gather information about types of artifacts frequently used at each site and individual subject perspectives on those artifacts, two or more researchers conducted semi-structured interviews using a six question semi-structured interview protocol. The protocol aimed to uncover participants’ common interactions with different communities of practice within the company and the extent to which they use artifacts in communication. Focus was given to interactions
across different communities of practice, because boundaries are more likely present when individuals have dissimilar values, needs, and experiential backgrounds. Sample interview questions included:

- Could you briefly describe your current position?
- Could you describe one of your current projects?
- Could you briefly describe your last meeting with other teams involved on this project?
- Could you briefly describe the last major decision made?
- Could you describe an instance when you had difficulty exchanging information with other members of a team?

Follow-up questions were asked for clarification and to expand upon relevant opinions or anecdotes. Each interview was audio-recorded and transcribed, and most were with a single voluntary participant. After being scrubbed to maintain subject anonymity, interview transcriptions were sent to individuals for review and were analyzed after approval. After each site visit, notes from individual researchers were compiled electronically and researchers recorded a verbal debrief to capture biases and points of interest.

**Data Analysis**

For each interview and meeting observation, the team identified artifacts as they were discussed or used, as well as important characteristics and functions of those artifacts. A coding scheme was iteratively and collaboratively developed for each artifact function and characteristic using category development and content analysis methodologies. This coding scheme was also compared with the existing BNA and BSO frameworks, during and after code generation, to test code suitability and align codes with existing literature as appropriate.

Eleven functions and fourteen characteristics were identified and defined. Functions were identified by examining the use and apparent intended purpose of each artifact in context, see Table 2. Example functions identified include persuasion, artifacts which were used to convince another party or community of practice of some argument, and dissemination of information, artifacts which were used to spread or make information available to different communities of practice. Artifact characteristics such as audience size, artifact format, and authorship were also identified. One such characteristic described the artifact as either static or fluid. Static artifacts were considered to have a format that remained unchanged over multiple uses. For instance, a PowerPoint presentation given during a meeting could be considered static, while a Computer-Aided Design (CAD) model that is actively being modified could be defined as fluid. Each artifact was then examined in depth within each case, across cases, and with regards to existing literature frameworks. Overarching trends in artifact use were examined and four contextually influential artifacts were chosen for further analysis. From these artifacts and trends, educational design principles were extracted in the form of “how might we?” statements.
Table 2: Artifact Functions

<table>
<thead>
<tr>
<th>Function</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Persuasion</td>
<td>Artifact designed to influence the opinions of the audience</td>
</tr>
<tr>
<td>Dissemination of Information</td>
<td>Artifact informs audience about work and/or background information</td>
</tr>
<tr>
<td>Dissemination of Information with Status</td>
<td>Artifact informs the audience about the progress of work</td>
</tr>
<tr>
<td>Dissemination of Information with Risk/Status</td>
<td>Artifact informs the audience about the progress and the potential obstacles to progress of work</td>
</tr>
<tr>
<td>Planning and Coordination</td>
<td>Artifact organizes people and/or outlines time/resource allocation</td>
</tr>
<tr>
<td>Translation</td>
<td>Artifact used to cross boundaries in language</td>
</tr>
<tr>
<td>Self-Explanation</td>
<td>Artifact generated by small population to gain new understanding for themselves</td>
</tr>
<tr>
<td>Education</td>
<td>Artifact prompts and facilitates new understanding of concepts and/or development of skills in audience</td>
</tr>
<tr>
<td>Gathering of Information</td>
<td>Artifact used to discover or compile information previously unknown to a population (e.g. scientific discovery or group opinion)</td>
</tr>
<tr>
<td>Facilitation of Decision Making</td>
<td>Artifact used to facilitate decision making</td>
</tr>
<tr>
<td>Generation of Ideas</td>
<td>Artifact used by small population to generate or compile new concepts</td>
</tr>
</tbody>
</table>

Limitations
This data is limited by time and participation: Site and sample were limited by a single point of contact at each site, and interviewees included only engineers, managers, project managers, and executives who were available during each visit. Despite this, the team was able to gather a large breadth of data from each site, and there are a total of three sites, resulting in a comparatively large dataset. Each case was visited for a maximum of five days, granting a snapshot of company processes and communication techniques. While a longer longitudinal study could be used to further enrich this exploration, the use of authentic work environments for this study provides preliminary results that can support future research and educational practice. Individual biases of the research team were identified in debriefs and field notes. Limitations were generally mitigated by researcher vigilance in identifying bias and collecting a large breadth of data.

Results
Initial analysis showed that the majority of artifacts used across all three sites were digital in nature, rather than physical. In particular, more than 50% of the artifacts at each individual site were digital, with Cizus showing the largest percentage of digital artifacts at 82%. Henning Devices and Martin Inc., as larger and older hardware companies, had both more physical artifacts and more static artifacts (i.e., artifacts whose formats remain unchanged over multiple uses). At Cizus, 72% of the artifacts were fluid (non-static) in composition compared to 36% and
41% at Henning Devices and Martin, Inc., respectively. The following sections focus on two preliminary findings:

I. The success of fluid Boundary Negotiating Artifacts (BNAs) due to increased interaction between engineers

II. The adoption and adaptation of Boundary Specifying Objects (BSOs) by engineers in industry.

To illustrate these findings, the subsequent sections present examples of artifacts across each site. While these findings could be illustrated using a variety of artifacts, the selected examples include artifacts with two different functions, which are the focus of this paper, particularly: (1) to facilitate documentation and (2) to communicate status.

Promoting Social Interaction and Producing Impactful Artifacts with BNAs as Living Documents

BNAs were found to be used across sites, frequently acting as “living documents” that are updated and modified by users to better meet their goals. BNAs frequently promoted social interaction, particularly face-to-face, between designers, engineers, and management who each needed to modify and use the artifact. This face-to-face dialogue appeared to facilitate open communication and the crossing of disciplinary and functional group boundaries more effectively than electronic or presentation-style communication might, see Figure 1. Overall, the increased social interaction caused by the development of a BNA was seen to lead to the generation of an impactful artifact ideal for the intended purpose.

**Figure 1:** BNAs were found to promote social interaction. Through that social interaction, the team members created impactful "living documents" for use by the organization.

**Code Process Document.** Paul, a software engineer working at Henning Devices created an artifact for archiving old work in a format that would allow him to return to and understand that work at a later date. He had become frustrated because he was often unable to execute old scripts he had written for past projects since it had been so long since he had used them. When he returned to a project after months of working on another, he frequently could not decipher his past work and did not know the proper configuration of resources. Even with commented code,
he still spent considerable time re-learning how to implement the project, leading him, at times, to nearly restart entire projects.

To avoid wasting time in the future and save important information for himself, Paul created a document to accompany his code that outlined program set up and operation. These fairly informal documents had no standard format and differed depending upon the important aspects of a project. For Paul, this document served as, what Lee calls, a *self-explanation* artifact, allowing him to expedite decisions and more efficiently continue work on projects when he returned to them. While some self-explanation artifacts support only the author, this artifact was eventually discovered by other engineers on Paul’s projects. These engineers came to rely on the notes and updated them as they modified a project. Paul was eventually made aware that others were using the artifact when another software engineer called him to discuss his documentation of a past project and ask permission to modify it. This unexpected development prompted Paul to work with the current developers face-to-face.

> I actually got an email from a software engineer. I had no idea who he was. He found my document when they were assigned a product I had worked on, used it, and asked me for permission to check-in changes to the document to indicate the newer version of a tool now being used. I had no clue who he was, but he was completely self-sufficient.

The original developer of this artifact intended it to be a static personal archive, yet it supported social engagement between engineers and eventually produced a powerful tool for his peers. It was adopted by many software engineers at the company, and it is now common practice for people to create their own similar documents when starting a project.

**Workflow Management Software.** Cizus uses a workflow management software package, Athena, to assign work to individuals, track the progress of projects, and store process documentation. Athena is used by employees at every level of the startup as a crux of communication and organization. Athena’s role at Cizus was similar to Lee’s *compilation* artifacts, bringing people from different teams together to see the whole picture of what the company was working on at a given time. As one manager explained,

> We use it as an issue tracking system and project planning system. We try to put everything in [the workflow management software].

Researchers observed Athena used during the biweekly planning meeting, where managers used Athena for a purpose that it wasn’t necessarily designed for originally. Specifically, the managers were exploring the previous and upcoming tasks for each individual in the company. During the meeting, each manager gave updates on each project and employee and assigned work for the upcoming few weeks. Athena was presented on a screen that everyone could see during the meeting. The narratives and schedules presented on Athena were the focal point of discussion not only during the meeting, but also outside the meeting when managers were making changes as needed. By having a place where the work plans were visible and adaptable, different managers from different groups were able to facilitate discussion about project priorities and individuals’ work plans.
Adaptation and Optimization of Existing BSOs for New, Specific Problems

BSOs acted as standard forms of communication at all sites and were commonly used for documentation, decision-making, disseminating information, and onboarding of new employees. A common progression for development of some of the more impactful BSOs emerged from the interviews and observations through which BSOs, originally created by an organization external to the company, supported the development of BNAs from which new BSOs were generated, see Figure 2. Pennington noted how a new and undefined BNA can become a BSO, as the artifact is specialized for a need and becomes more widely used within a population, ultimately assuming a static format. In addition to this linear development, a more cyclic process was observed by the engineers and managers across all three sites.

Figure 2: Development process for highly utilized BSOs at these sites. BSOs, originally developed externally from the company, were the foundation for the development of a BNA that ultimately resulted in a new BSO.

Often, when a need is recognized, an existing BSO, sometimes already in use elsewhere in the company, is borrowed and implemented. Many times, this BSO fulfills the need imperfectly and requires modification. Groups then iterate upon the BSO, causing it to temporarily assume a fluid format and/or composition and become a BNA. These groups may choose to a range of features of the artifact, including the content captured, the style of presentation, or the definition of a rating scale. The BNA is then adapted several times with input from multiple individuals and groups until it resolved into a BSO uniquely suited to meet the intended need. Artifacts may undergo this process repeatedly, and thus related artifacts adapted from similar roots may exist across an organization.

The Status Room. Project status is information about the development of a project with reference to an established timeline. Across sites, a project or task status was found to be primarily represented through color labels: green, no help required; yellow, may need additional resources; red, in need of help. At Henning Devices, researchers attended a weekly status meeting in a room designated exclusively for status updates. Charlie, a program manager participating in this study, realized that many managers and engineers in his group avoided labeling projects as red, for fear of being seen as incompetent. Charlie explained “as status moves upward [on the executive ladder], reds become yellows, and yellows become greens”. The poor communication was a significant problem, leading to delayed product release dates because
project teams were neither asking for nor receiving the support necessary to accomplish their goals.

Researchers observed this problem in multiple teams across all sites. To address this issue, Charlie adapted a whiteboard to implement a SCRUM board in an extra room. SCRUM boards are a standard format for coordinating team activities that organizes workflow into 3 categories: future work, work in progress (WIP), and work backlog. Like a traditional SCRUM stand-up, Charlie asked all the project managers and executives who attended to stand throughout the meeting, and each reported their project status aloud in succession. Unlike a SCRUM board, the work was organized on a calendar rather than sprints (two-week project timelines) with backlogs and WIP. Charlie also implemented additional company-specific labels and projections for future work that team members can add as needed.

By discussing their decisions openly with their peers, participants were assured of their choices and given useful feedback. Similarly, by making the status board a physical object and updating it weekly, Charlie was assured that every team member agreed on the content posted and could adequately justify their claims. The board and the associated meeting now serve as an integral part of product development at the company. A standard Scrum board (BSO) would not have properly served the purpose intended by Charlie, but by modifying the format through a cycle of experimentation and reform (BNA), the artifact became a powerful tool around which people can frame their communication (BSO).

**Status Boards.** This cycle of BSO adaptation was also present at Martin, Inc. in a newly formed team. This team similarly implemented a SCRUM status board to manage their workflow and projects because the team members felt overwhelmed by the number of tasks assigned to them. The team had multiple projects for each member, rather than a few projects for the whole team. Thus they used the board primarily to project how much work each individual had, irrespective of an overarching schedule. The team modified the categories and color-coding on the board to display the effort and time involved in a task and to show where team member efforts were being focused. The team’s managers saw the board and began assigning tasks to individuals based upon self-reported availability.

Soon, many teams in the division had a similar board posted on the walls in the same room where the initial board was hung. Each board was distinct, and was modified to best serve the team that had created it. The categories and focus of each board were different depending upon the goals and workstyle of the team. Researchers observed that the standard BSO of a workflow management board was adapted several times into different artifacts to be used by adjacent populations, and that each iteration served the needs of its designers.

**Resulting Educational Design Principles**

Many engineering institutions seek to prepare their students for professional engineering work through curricula which simulate authentic work experiences. Students are meant to solve problems using strategies they might see in industry, and focus is often given to the development of technical skills within the students’ field of study. However, recent research has shown the importance of developing professional skills alongside technical proficiency, and this paper
aims to identify and explore core professional proficiencies used by engineers. Within engineering design curricula, there is an opportunity to apply educational strategies that will build these skills and prepare students for professional engineering design environments. Researchers working on this study generated educational design principles based on the best practices, the overarching challenges, and experiences of engineers observed at site visits. Principles were largely distilled from examples of artifacts that participants viewed as especially successful for their intended purpose and the two emerging themes discussed in the previous section. By considering the benefits of these communication tools and the challenges inherent to an engineering design classroom setting, these resulting principles can guide implementation of status and documentation artifacts in the classroom. These principles are formatted as “How Might We” statements to capture intent and limitations. In this section, four examples of successful status and documentation artifacts used by practicing engineers participating in the study are highlighted as well as the associated educational design principle. Educators can use these principles to generate educational designs (e.g., assignments, assessments, activities, projects, tools) for their particular context that can help students develop these professional skills.

**Documentation**

Documentation artifacts used by engineering design teams act as archival tools to record processes and strategies. They can be used to inform future decisions made on the same or similar projects, which can save a team time and resources, expediting the decision making process. Similarly, documentation artifacts which record technical processes, like Paul’s Code Process Document, guide engineers upon returning to a project or beginning similar work on another product. Artifacts used for documentation were seen across all sites and were quite varied depending upon the authors, intended audience, and archival purpose of the artifact. Some were generated by populations for internal use and reference, while others were adopted from industry standards. There were significant differences between artifacts as a result of their origin. Most successful cases of documentation not only tended to increase social interaction, but also were generated to fulfill a specific need and did not disrupt the design process. This motivation is in contrast to the motivation for student documentation in engineering and design courses, where documentation is commonly completed after a project or is pursued during the project in a way that detracts from work that would be done on the project itself.

Paul’s Code Process Document, for example, was successful because it was designed for a specific need. Paul found remembering how to execute old scripts difficult and thus, created a document to accompany his code that outlined script operation, effectively solving this problem. Other engineers began using and updating the document, which then became part of the process of software development at Henning Devices.

The development and evolution of the Code Process Document was quite different from how documentation is presented in an educational setting. Students are often advised to document project processes and development, but only after the project is complete. There is rarely a need for them to refer back to any documentation while working on a project. If students’ successes in a course were directly impacted by the quality of the documentation they kept, they may find the process of documentation more valuable.
At Martin Inc., researchers encountered documentation in the form of archived PowerPoint presentations. The large size of the company and the tendency for major design decisions to be made at the higher levels of the managerial structure caused PowerPoint presentations to be crucial in capturing increased level of detail, relative to the other sites. By having project specifics presented on slides, the material can be easily passed to team leaders and executives. After they were presented at a design meeting, these detailed slides were saved in a common location to be referenced when similar decisions were made.

While this system of documentation has limitations around availability of materials, clarity of narrative, and proper cataloguing, it is wholly non-disruptive to the progression of a project. In order to move forward and make design decisions, the information in the slides must be recorded and presented. It is then both logical and simple to save this information for future use. This consideration for the time expended on documentation is important when incorporating documentation into design engineering curriculum.

Overall, most successful documentation artifacts seen across the sites were BNAs created to fulfill a specific need and led to increased interaction between engineers. However, there are several challenges to successfully implementing documentation artifacts into an academic setting. For example, students often find that writing documentation takes time away from working on the project itself. They also may not see the reason to document projects if the documentation takes place after the project is complete or if they don’t plan to look back at the documentation after the course. In addition, students tend to not understand how these types of documents may be used in a professional context. Given the challenges surrounding successful documentation in engineering education and the discrepancies between the use of documentation in industry and education:

How might we foster the use of documentation in engineering projects that encourages iteration and reflection but does not take away from the quality of the project itself?

Status
Artifacts that disseminate status inform the audience about the state of an activity. When these artifacts are successful, they enable the author to report the progress of a project accurately and honestly. Most successful status documents seen across sites are living documents that foster discussion and many of these artifacts were adaptations of existing artifacts, most originating external to the companies. They were originally adopted to fill a need and were updated and optimized over time to fit their users’ intended purpose. Often in an educational setting, there is no overt or implicit requirement for engineering students to clearly articulate their project’s status, as there is little to no need to inform others of necessary resources or to coordinate between teams.

Another example of a status artifact seen at all three sites, outside of status boards or walls, is a demonstration, used to show the functionality of a product at specific stages of development. The integral facet of demonstrations is that they act as proof of a claim or concept, which eases doubt among the audience and ensures that the presenter is held accountable for their work. Any claims made by the presenter must be validated and demonstrated by the product shown in its current stage. This approach ensures that material is not embellished and setbacks are not hidden from
collaborating parties. Additionally, larger scope discussions can occur because basic questions concerning functionality are easily answered by viewing a demonstration.

This strategy is becoming more widely implemented in educational settings. For example, students in engineering design classes are often required to demonstrate functionality of a device to faculty and other students. This can take the form of a video or live demonstration. However, on a cross-disciplinary project that requires the design of a product with multiple functions and components, students often do not provide a holistic overview of their progress, choosing instead to present progress of individual, non-integrated parts. As faculty and audience members are often not fully informed about the intended vision for the project, the presenting students may portray an embellished representation of progress to appear successful.

At two sites, engineers and project managers used status artifacts attached to walls of designated rooms meant for status meetings. As discussed in the previous section, Charlie at Henning Devices recognized that he had difficulty keeping abreast of cross-team activities, so he created a designated room for status with a large community board hanging from the wall. Similarly, at Martin Inc., a team leader noticed his supervisor was not aware of the large volume of work his team was struggling to complete, so he created an artifact to show project status and workload for each team member. In both instances, the creators had a specific need to introduce more transparency across teams or team members, which was addressed by the creation of specific artifacts. These artifacts were accompanied by routine meetings in which all team members were present, which fostered open negotiation and transparency. At both sites, it was important that active negotiation take place before artifact content was updated, which helped mitigate miscommunications between team members. Additionally, these artifacts could be viewed at any time, by any team member, because the space containing the artifact was used solely for this purpose. At Martin Inc., the artifact was also adopted and adapted by other teams in the shared space.

In a classroom setting, students may present the status of their projects to team members, but informing individuals outside of their team is not always necessary. Unlike the projects across all three industry sites, where the teams and individuals worked on projects that were directly connected to projects of other groups. It was crucial that status be clearly communicated both laterally and upward in the company’s structural hierarchy. This communication allowed for better planning and coordination between individuals and teams, as well as proper allocation of resources, including capital and labor, to ensure that projects met deadlines with few road blocks.

In general, most successful status artifacts across the sites started with the adoption and adaptation of existing frameworks to make reporting project status more honest and transparent. Reporting status honestly and accurately is also a challenge in engineering design education. For instance, when completing a new project students may not know if they are progressing well. As novice designers, they may not be aware of the challenges that are likely to arise, especially when they do not have a lot of experience scoping and structuring projects. When students approach new design projects or problems, they may set broad goals that they do not know how to achieve or begin generating solutions before understanding the task completely, which can lead them to underestimate, and thus inaccurately report, the time and effort it will take for them
to complete their project. Given the challenges faced by engineers and students working on cross-disciplinary design teams:

*How might we encourage students working on cross-disciplinary projects to report honestly and accurately on the status of different project components?*

**Conclusion and Future Work**

This study explored the communicative tools, more specifically Boundary Specifying Objects and Boundary Negotiating Artifacts, of practicing engineers and designers working on projects in industry in order to understand how to better prepare engineering students for the challenges of working on cross-disciplinary teams. By analyzing the different functions and characteristics of BSOs and BNAs used across three industry sites, researchers observed that many successful BNAs were living documents that facilitated social interaction to produce impactful artifacts. In addition, they identified artifacts adapted from outside sources that then became BSOs. This paper focuses on artifacts used to communicate status and document project progress and information. Both creating documentation and reporting status are important for engineers and designers in industry, but are not always addressed in education. Through investigation of authentic engineering design environments, researchers identified principles that can be utilized to better prepare engineering students for cross-disciplinary projects in industry. Future work will focus on the development of educational designs (e.g., activities, assessments, projects, tools) based on these principles that will be incorporated to an engineering design course in the coming year.

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**References**


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