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Collaborative Design Between Industry Practitioners: An Interview-Based Study*

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This research describes and compares the interviews of practicing engineers and designers in industry regarding their collaboration on design projects with how academic textbooks teach design. An empirical study was conducted that centered around live interactions between the researcher and the interviewees to retrieve targeted information specific to collaborative design research that may be more difficult to attain in written documents. A total of ten interviewees from three companies volunteered to participate in an interview with topics related to design projects, processes, tools, and meetings. Interviews were then deconstructed to quantify results based on specific topics discussed (e.g., informal and formal meetings) and collaborative tools used throughout a project. Insights into when, why, and how the interviewees typically undertake design projects at their respective companies were elucidated. Results show that only one of the interviewees mentioned the benefits of a design tool, which they did not however use during their projects. This finding contradicts the textbook suggestions of using design tools as the means from which to collaborate. The purpose of collaborative design from the perspective of the interviewees is also discussed through formal and informal meetings. According to the interviewees, each meeting type employs a different set of needs when used in the design process. To better equip students for work outside of academia, preparation for meetings would be beneficial as they would begin to develop soft skills and project management skills required for industry. Such training is useful in concurrence with the teaching of design tools by enforcing student teams to compile meeting minutes, begin with stating the project problem statement, or limit meetings to a specified duration. These tips were useful in providing students with skills in managing meetings to ensure the ultimate success of the engineering design project. Additional research questions are posed for purposes of further study of other firms regarding their design practices and what resources academia can provide for individual designers.

Keywords: industry collaboration; practicing engineers; interviewing; interview-based study

1. Motivation for understanding collaboration between practicing engineers

This goal of this research is to understand how practicing engineers and designers in industry (practitioners) collaborate to undertake and complete design projects. In pursuit of this goal, engineering design textbooks were the subject of review to determine those tools and methods they describe as a means for practitioners to collaborate. Literature that discusses collaboration is also reviewed for its associated impact on industry, for a comparison of the various perspectives of academia and industry regarding collaboration.

1.1 Textbook review of collaborative design tools

While a design method is useful in helping a designer generate new solutions, manage the design process, and represent information and knowledge, a tool is a more specific exemplar of that method [1–5]. Used to physically or psychologically organize gathered information, design tools are used to create deliverables within a given format and gather results from mental exercises. These tools are software or hardware that are used to produce a specific outcome (e.g., solution concepts or prototypes [1, 5, 6].

Textbooks were reviewed to determine those tools used in both collaborative and individual projects (Table 1). For purpose of this research, a tool not described explicitly as requiring more than one person means that it is designed for individual use. Collaboration is defined as "the presence of mutual influence between persons, open and direct communication and conflict resolution, and support for innovation and experimentation" [7]. The most important aspect of this definition is that of requiring direct communication and conflict resolution, unlike the indirect nature of teamwork which is a parallel rather than a linear endeavor [8, 9]. A collaborative tool is also both concurrent and co-located. Note that the processes illustrated in each of these texts are simplified to product planning (PP), conceptual design (CD), embodiment design (ED), and detail design (DD) [10].

A total of 176 tool concepts (i.e. brainstorming, C-Sketch, requirement and requirement checklists) between the four phases of design were described by the textbooks. Note that these tools are not unique and are repeated between textbooks [10–18]. After categorization into product planning, conceptual design, embodiment design, and detail design, at totals of 59, 92, 23, and 2 respectively, it was

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Table 1. Number of collaborative (col.) and individual (ind.) tools recommended for use in each design process phase

	Product Planning (PP)		Conceptual Design (CD)		Embodiment Design (ED)		Detail Design (DD)	
	Col.	*Ind.*	*Col.*	*Ind.*	*Col.*	*Ind.*	*Col.*	*Ind.*
All Tools Recorded	43	16	59	33	13	10	0	2
Unique Tools Only	27	11	39	27	11	10	0	2

Table 2. Percent of tools discussed across multiple textbooks, based upon the phase(s) the tool was suggested for use

	PP		CD		ED		DD	
	Col.	*Ind.*	*Col.*	*Ind.*	*Col.*	*Ind.*	*Col.*	*Ind.*
Percent Repeated	22.85	18.52	20.41	10.00	0.00	9.09	--	0.00

determined that a third are used for product planning and half used for concept development, with detail design accounting for approximately one percent. These findings suggest a possible greater emphasis upon concept development than on the other three phases of the design process. The disparity in the number of tools also supports our hypothesis that the latter phases of the process require less tools to complete those phases and the possibility that the course may not address the embodiment and detailed design phases addressed in other engineering courses.

Collaborative tools used for product planning, conceptual design, and embodiment design were more numerous that detail design indicating the possibility that collaboration is used more extensively in these phases than in detail design, in which the designers of a given specialty are specific autonomy on a facet of a project. Consider the author's experience in a capstone design in which a group of undergraduate engineers collaborated to solve a problem requiring the insertion of filler material into a hollow tube. The collaborative methods of brainstorming, the morphological chart, and the gallery were all used to develop these final solutions. Once the concept groups were completed, each was analyzed for their overall feasibility via separation into two subgroups and constructing high-level prototypes. One solution was selected with those prototypes constructed and improved throughout the remainder of the project by the single group. This phase of product design required that everyone assumes responsibility for a specific subsystem, thus completing the project through concurrent, dislocated collaboration. This process is like those presented in textbooks.

Although Table 1 shows the total number of tools described in each phase of the design process with respect to collaborative and individual use, duplicates of the tools described in each textbook were included. Therefore, it is beneficial to eliminate those duplicates to determine the number of unique tools used in the reviewed design textbooks to remove potential bias from such duplicates. The percent change of the number of unique tools discussed in each design process phase was also calculated, and those results are presented in Table 2.

Although there were decreases in the total number of tools presented for product planning, conceptual development, and embodiment design, the number of unique collaborative tools continues to outnumber the individual tools described in each phase. It is thus possible that prior research emphasized the use of tools for collaborative rather than for individual use. Therefore, understanding how designers use these tools while designing products is necessary. Note that collaborative tools under detail design was signified with a "–" given the initial lack of collaborative tools. Thus, including a 0% change could be misleading.

1.2 Collaborative design

The importance of collaboration throughout the design process is well established [19–23]. More specifically, multi-disciplinary collaboration is most beneficial in that greater efficiency and a broader range of products are addressed that consist of more than a single designer or engineer [21]. The inclusion of a variety of designers that bring their core competency to the group ensures that business remains responsive to both customer satisfaction and manufacturing concerns [22, 24].

Collaboration also assumes the form of design reviews, a notable of example of which is how group familiarity and information sharing among that group affects a design review [19–21]. In particular, greater common knowledge within the group leads to the greater dissemination of information, which is external to the purpose of design reviews [19]. Also, group familiarity is a potential factor of design review effectiveness, with "groupthink," a high level of group familiarity and pressure to reach a decision, the prime example [19, 25].

Project structures are also discussed and subdivided into five categories: functional, functional matrix, balanced matrix, project matrix, and project team [26]. All five encompass a variety of functional or specific multi-disciplinary groups where assignments are project-specific with each of relevance to specific project types or to specific project phases. While the observations of such collaborative groups in industry is well known, little data is available regarding how the individual engineering or design professional evolves a design.

2. Empirical investigation via interviewing

The use of interviews to collect data from participants has evolved to encompass both social and cultural occurrences within a given workplace [29, 32]. Researchers use the phone, Internet the individual meeting as the conduit to ask specific and targeted questions regarding a specific subject of research, thus making it imperative that the questions be targeted to the specific subject at hand [29–33]. These techniques all permit the use of overall questions that then yield more specific questions and answers. As such, the research retrieves the information they need directly from those involved in a project. In-person interviews also allow for the collection of a richer data set through nonvisual or nonverbal cues, which can affect the intent of a statement [29, 32, 34, 35]. The use of other techniques regarding project history reviews is often limited by the information the original participants recorded instead of the live interaction of an interview. Both qualitative and quantitative data can be derived from the interview process, such as the instances in which either individual participants or the group as a whole repeat the same phrase can determine patterns across a specific population [29, 33, 36]. Moreover, such a strategy is repeatable across various unique groups to determine similarities and differences, a topic expanded upon in the next section.

The authors began by studying the various interview type where the purpose of the research was exploratory and to develop a general understanding of industry collaboration [31]. The evolution of this research then involved the use of verification interviews with multiple personnel at the same company and at different companies to verify and potentially triangulate responses. Interviewing was conducted until a "knowledge asymptote" was obtained [31].

2.1 Interview structure and triangulation

A fully developed interview must provide questions that require the interviewee to think about their response to thus avoid the trap of a simple series of yes/no answers. For this research, questions were formatted into four topics and presented in a semi-structured manner to structure the setting as that of a free-flowing conversation rather than a rigid sequence of events from the interviewee's perspective. Given the difficulty in predicting the nature of the interviewees response, a semi-structured interview was used to gather both peripheral and relevant data in this free-flowing conversation [29, 31]. The four topics of the interview provided an alternative to ensure the relevancy of the subject at hand during this interview. Triangulation checklists and matrices were most effective in determining the relevancy of the interview questions to ensure that they provided an internal validation of the research tool [31]. Through this process, the interviewer can listen to the responses to then ask relevant follow-up questions based upon the direction of the interview. Topics also produce opportunities for triangulation while ensuring a comfortable constancy in the interview process.

Triangulation is the process from which a research related issue or study is at least twice observed to determine a level of consistency between sources, to credibility to participant statements by ensuring that the answers are as complete as possible [29, 33, 37, 38]. Triangulation can be i) horizontal across organizations where individuals with equivalent responsibility in a firm participate, or ii) vertical within an organization such that employees of various levels answer the same question [31]. Fig.1 shows a series of questions used to generate triangulation. These questions are provided as example of the methodology behind our research.

The basis of the first question is to understand the resources (e.g., individuals, hardware and software) available to the designer throughout their project. The posing of this question however expands the concept of resources so that the interviewee can provide an initial, unbiased response of all resources at hand. Follow-up questions may focus on the software used, (e.g., CAD modeling, word processing, email). For example, expanding upon email use could entail the frequency of that email to colleagues. This triangulates with the first two questions in that emails are sent to a software client while also providing the basis of more questions regarding communication frequency and type.

This research, in part, uses the sources triangulation method to examine the consistency of data sources within the same method [38]. While the data collection method through interviewing

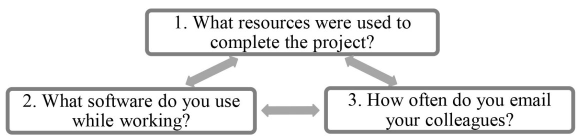

Fig. 1. Example of triangulation questions during an interview.

Table 3. Interview participants, experience, and highest education completed

Participant Identifier	"Name"	Total Experience (Yrs.)	Position	Corporate Hierarchy	Education Completed
A.ME.1	Amelia	6	Manufacturing Eng. Manager	2	BSME
A.ME.2	Bridget	16	Lead Manufacturing Engineer	3	MSME
A.ME.3	Charlotte	14	Manufacturing Engineer II	3	MSME
A.ME.4	Danielle	15	Manufacturing Engineer Manager	2	BSME
A.IE.1	Emma	5	Manufacturing Engineer I	3	BSIE
B.ME.1	Felicia	6	Engineering Manager	2	BSME
B.ME.2	Grace	3	Project Engineer	3	BSME
B.EE.1	Harper	33	VP of Engineering	1	BSEE
B.ID.1	Isabella	35	Industrial Designer	2	BSID
C.ME.1	Janice	2	Computational Analyst	3	MSME

remains constant, responses from interviewees with different backgrounds and companies is used for triangulation to further elucidate engineers and designers collaborate in industry across a broader population instead of focusing solely on manufacturing.

2.2 Interview design

Three companies participated in this research (two large and one small). Observations and results were evaluated after each interview and each company. A saturation approach was used to determine when to stop seeking new interviewees and organizations based on when no new observations or results are found. The dissimilarities in company function and sizes were intentional to more thoroughly understand the differences and similarities between each. The following criteria was used to define the size of the company: small (<50), medium (50-499), and large (>499) [39, 40]. Two large companies (A and B) and one small company (C) were chosen to conduct interviews.

To ensure participant confidentiality, company data was abstracted to provide a basis of comparison to triangulate responses. Company A based in Washington State, manufactures specialty products for large corporate customers. Company B, headquartered in Hong Kong, manufactures products for general consumers for local retail purchases. Company C, based in North Carolina is a research and development firm that creates software code used to optimize and verify a design with specified requirements. Their client base is that of government entities. The data of the various functions and customers for each company were used for the triangulation across a broader range of engineers and designers employed by industry to expand and validate the results. Interviews for employees of Company A were conducted in a South Carolina based facility that manufactures electricity meters for energy utility companies. Interviews for employees at Company B were conducted at a second South Carolina firm, one that designs power tools, outdoor products, and home appliances. Lastly, Company C interviews were held on-site at that firm. The functions and customers for each company were used to as data for triangulation across a large scope of engineers and designers currently employed in industry

Interviews were conducted with ten engineers and industrial designers with varying degrees of experience, education backgrounds, and corporate hierarchical levels (Table 3). All were specifically selected because of their professional differences for purposes of triangulation across multiple domains, job titles and against firms performing different functions, thus giving multiple sources to determine findings. The opinions of our participants which are informed by their experience and levels of education were also naturally included.

The participant identifier is formatted such that the first letter represents their employer, the next two letters represent the major for their highest completed education degree, and the final sequential number based upon the order of interview within the same company and education. The name listed is a pseudonym substituted for their actual name for ease of comprehension and to provide empathy toward the results. The pseudonyms, which were generated in alphabetical order based on the order of the participant identifier, are all the same gender to reduce potential bias. The years of experience and level of education are provided to showcase the variety of participants considered in this research. Lastly, the person's position and level in corporate hierarchy are provided to help illustrate differences in perspectives between the practitioners. Hierarchy of one is the highest level interviewed of a vice president, two is management level, and three is entry-level.

All interviews with Company A and B participants were performed in-person and on-site with their choice of locale in either meeting rooms reserved by the participant or in their personal office. Most interviews were held on weekdays, typically around lunchtime. Company C's interview was conducted on a workday evening and over the phone.

The participants were asked a total of 27 questions on the following topics: introduction, design process, design meetings, and project description. More specifically, participants were queried as to whether they used design tools in their projects, and how and when they collaborated on a typical project. The questions developed prior to the interviews were constantly refined during the evolution of the project. Specific questions regarding major milestones were not posed as the purpose of these interviews was information gathering rather than to validate any preexisting understanding of collaboration in industry.

3. Interviewing results and discussion

Results collected from the transcribed interviews are represented and discussed in tabular form to provide an analysis of how practicing engineers in industry collaborate or work individually.

3.1 Design process and tools in industry

Each interviewee's responses were analyzed to detect patterns in the interview. Table 4 shows designers using specific processes provided to them, using their own process, or if they use a combination of the two.

The results from row 1 of Table 4 show that the mechanical engineers with Company A all work on fixture design, an expected result as these professionals are a resource on the production floor particularly in the context of either new or modified fixtures. In her interview Emma, a manufacturing engineer with five years of experience charged with improving the process said that "*Most of my projects are on process improvements to improve efficiency . . . with work instructions and line changes.*" All Company B and C personnel are engaged in product design, except for Harper, who in the role as VP of engineering supervises the engineering teams and provides administrative support. Here we provide our triangulation to understand how engineering support staff across multiple industries collaborate.

Regarding the design process (rows 2 and 3), all our participants developed a design process that is a simulacrum of that presented in the textbooks, thus clearly indicate how their undergraduate classroom training informs their design process, even if it dissimilar to their experience in college. We must also consider either the presence or absence of a formal design process affects the resulting product. For example, in the case of Company C, a relatively recent start up, Janice, a computational analyst "*Want[s] to stress the informality of [Company C]*," indicating a possible absence of a conventional hierarchical structure combined with an ethos of independence through which an employee will undertake and complete an assigned project. In other words, collaboration is an option rather than a requirement.

Such autonomy may be unsuitable for proper communication, however. For example, Danielle, a manufacturing engineer manager with 15 years of experience employed by Company A reproduced in detail a design process used by her firm, while her colleagues were unable to do so. This obviously lack of communication between hierarchies regarding the design process may well characterize a specific departmental culture. Specifically, Bridget, a lead manufacturing engineer with 16 years of experience employed by Company A , stated that "*A process or tool should not be too restrictive . . . to discourage creativity.*" Here creativity is not encouraged via management conveying a specific process to the designers but rather through the actual withholding of those processes to allow designers to pursue their own concepts to complete the project, if it proceeds apace.

Except for computer-aided design (CAD), the established design tools detailed in rows 4 and 5 (i.e. that from the reviewed textbooks from this paper), were not used by any of our interviewee. Although CAD was used on occasion in design meetings and by the individual no other tools were

Table 4. Designers' use of the design process or tools

Row #	Topic	Amelia	Bridget	Charlotte	Danielle	Emma	Felicia	Grace	Harper	Isabella	Janice
1	Project types	F	F	F	F	Prc	Prd	Prd	--	Prd	Prd
2	Personally developed (informal) procedure used?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3	Company provided (formal) procedure used?	N	N	N	Y	Y	Y	Y	Y	Y	N
4	Collaborative design tools used? *	N	N	N	N	N	N	N	N	N	N
5	Individual design tools used?	N	Y	N	N	N	N	N	N	N	N
6	Assigned with others of the same specialty?	N	N	N	N	N	N	N	N	N	N
*Except for computer-aided design (CAD)											
Legend: F – Fixture/Tooling, Prc – Process, Prd - Product											

used. Note that the semi-structured interviewing allowed the interview to further elucidate on methods such as brainstorming, QFD, and method 6-3-5. Most strikingly our interview with Isabella, an industrial designer with 35 of experience the interview became light-hearted when asked if she or if anyone in her group used design tools; her response was *"[Laughter] no, we do not use any tools like [brainstorming] here."* Her response is noteworthy as our reviewed text details design tools as a primary point of collaboration among designers in industry, which is not the method through which they collaborate. Only Bridget ever used a checklist as her individual design tool. Although she provided no formal name regarding her use of a checklist, she did mention that "*A tool would be useful, such as one that would list out what is generally needed to complete a project*" and her specific use of it to complete projects.

Also, in terms of collaboration, none of our respondents stated they would be paired with another of the same specialty (row six). Each would assign a specific project to an individual or be assigned a project. For those projects requiring the addition of specialists from different disciplines, it was determined that those assigned would have the opportunity to retrieve data external to their discipline to complete the project, supporting the established concept of collaborative specialization.

3.2 Industry meetings and collaboration

To understand the efficacy of the meeting process, questions were formed around both informal and formal meetings. Informal meetings were those deemed unscheduled in which team members could informally discuss the project (e.g., in the office). Formal meetings were naturally those scheduled in advance to which the entire team was invited. A pattern matrix showing informal meetings is shown in Table 5.

Regardless of project type, the purpose of all informal meetings was that of discussing the subject problem at hand and to get design critiques (rows 1 and 3). Although Emma was the only one of our respondents to state that design critiques were not a subject of informal meetings, her definition of a concept as related to fixtures in a manufacturing facility could have influenced her understanding of the formal meeting in that she does not design fixtures. However, she did host design critiques with those in her group external to the formal process to ensure that her team would complete the project accordingly. Aside from Isabella's group who would occasionally, "*Use a whiteboard to generate concepts*," rarely was concept generation a subject of discussion.

Generalists employed by the firm often attended these informal meetings, primarily because of the project assignee requesting the assistance of their resource (row 5). Questions regarding the overall design of a concept, its machinability, the ergonomics, or the direction are typically asked in these informal meetings. Therefore, the primary purpose of these meetings is to gather information from specialized resources to verify and further an existing understanding of the project. Moreover, these resources can include suppliers or catalogues to assist in data collection.

A pattern matrix for formal meetings is shown in Table 6. A review of the interviews of each participant clearly shows that the purpose of the formal meeting is to critique and provide updates on the

Table 5. Intent and content of informal/unscheduled meetings

Row #	Topic	Amelia	Bridget	Charlotte	Danielle	Emma	Felicia	Grace	Harper	Isabella	Janice
1	Discussion about understanding problem	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2	Concept generation performed	N	N	N	N	N	N	N	N	Y	N
3	Concept critique	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
4	Used at stage gates?	N	N	N	N	N	N	N	N	N	N
5	Attendees from outside engineering?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 6. Intent and content of formal/scheduled meetings

Row #	Topic	Amelia	Bridget	Charlotte	Danielle	Emma	Felicia	Grace	Harper	Isabella	Janice
1	Discussion about understanding problem	N	N	N	N	N	N	N	N	N	N
2	Concept generation performed	N	N	N	N	N	N	N	N	N	N
3	Concept critique	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
4	Project updates	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	Used at stage gates?	N	N	N	Y	Y	Y	Y	Y	Y	N
6	Attendees from outside engineering?	N	N	N	N	Y	Y	Y	Y	Y	Y

status of a given project, rather than to discuss the problem or generate design concepts. Also, this overlap between the formal and informal meeting in terms of design critiques is due to the overlap of the personnel in attendance.

Regarding the formal meetings, Harper, the VP of engineering in Company B, specifically iterated the differences between each meeting in the context of the stage gate design process used in their firm. Typically, the first stage gate would include vice presidents, industrial designers, and project engineers of various disciplines. The second stage gate would then include those same project engineers, industrial designers, and include members from quality with the occasional presence of a vice president. In the third stage gate, in which the concept was 'frozen,' the efforts of the industrial designers were then supplanted by that of the international engineers would become more involved in the detailed project design. The fourth and final stage gate meeting would be attended by the project engineer in charge, the product manager, the safety/risk qualifier, regulatory, and quality professionals and all the vice presidents. Each participant then approves the final documentation before production.

This method of collaboration in terms of product updates permits the substantive, high-level involvement of employees from a broad range of disciplines to ensure the successful completion of a project at the desired level of efficiency. Also, Company B's level of collaboration within formal meetings were primarily used for updates, for project review and to ensure the appropriate level of progress prior to proceeding to the next gate. This level of detail is quite possibly the result of the primary consumer market of Company B, which is to the public rather than highly the trained technical specialist. Additional regulations may also characterize this process given the final target audience of the public rather than the skilled technician.

Unlike the professions of product or process design, manufacturing design is an insular process, perhaps because of the limited customer base who will use such sophisticated products. Further, although Emma, the industrial engineer with Company A, works in a manufacturing environment, her process designs are subject to a greater level of scrutiny from others in the firm. This enhanced scrutiny is perhaps due to the broader affect that her designs have upon the entire manufacturing operation, in terms of production, quality, suppliers and the ultimate profit and loss from the finished product (i.e. the bottom line). Moreover, the manufacturing process is not characterized by the "stage gate" concept as is typical in Danielle's firm. While a formalized system does exist, Emma's team often deviates from those specified process, likely because manufacturing is characterized by retroactive rather than proactive processes (i.e. correcting design flaws when the product is in use as opposed to preventing problems prior to occurrence).

4. Discussion

Industry practitioners primarily collaborate in both informal and formal meetings, with the latter occurring either weekly or monthly with correlations to specify project type. For example, whereas process projects require more formalized meetings, fixture and manufacturing projects tended to revolve around informal meetings. For example, process projects require more formalized meetings, but fixture and manufacturing projects tended to revolve around informal meetings. Moreover, Company B's formal stage-gate structure necessitates a series of signatures at each gate to ensure the forward progression of the project. These meetings occur less frequently than informal meetings, which typically occur sporadically throughout the workday or week. The importance to industry through this collaboration via informal meetings entails providing project updates and verifying concepts prior to the formal meeting, which is more important than the use of design tools.

Practicing engineers typically collaborate when a specific aspect of their project requires specialized assistance from another resource. While these engineers collaborate in design, they either usually assume primary responsibility for a project or either assign it to an engineer or designer in a different discipline who can provide the specific input. For example, a manufacturing engineer in the manufacturing department of Company whose specialty is in mechanical engineering may partner with a test engineer who is either an electrical or computer engineer. Although there is some overlap, the inclusion of these discrete disciplines will ensure timely completion of the project. A similar construct was also observed in Company B in which a project engineer would be assigned to a project with various mechanical and electrical components. While they could retrieve information on other existing products of the company, specific requirements, such as the power source, must be satisfied by requesting the assistance of the power-sourcing department. This sharing of specialization between each group ensures that individuals may be engaged on several projects at once rather than working on a single project to completion.

During the development of a product through the design process, meetings primarily occur informally across all three companies. Informal meetings (those not scheduled in advance) were held to

Table 7. Areas of potential application for research conclusions based on company type

Group "Function"	Conclusions Apply	Conclusions May Apply	More Research Required
Manufacturing	X		
Development		X	
Research			X
Consulting			X
Contractors			X
Novel Design Development			X

discuss the problem to understand and seek data upon a given design prior to the formal presentation to a group of engineers. Such feedback was sought from operators using the product, shop machinists responsible for machining parts for the project and engineers with a greater depth of experience on a similar project or within different disciplines. Formal meetings, held to convey updates on a project, were usually about five to ten minutes, with some exceptions. No formal meetings were held to collaborate regarding concept generation, which adds credence to the differences of collaboration in industry compared with that in existing texts.

Although every text reviewed covers the instance of collaboration via teams none of the interviewees specifically mentioned that criteria. Specifically, each interviewee would mention meetings or a group, but not a team, which is indicative of the fact that collaboration in industry differs from that described in textbooks. Although collaboration is a multilevel process, for our companies A, B, and C, collaboration is reserved for use in conveying regular project updates to management and for informal meetings with colleagues to discuss ideas. Formal tools are used for neither concept generation nor evaluation, the instance of which was prevalent across multiple project domains. More research should be performed to determine the exact nature of these conclusions, however given that these conclusions are only relevant for the three companies analyzed in this research (Table 7). Further, while meetings were the primary source of collaboration in industry, none involved the use of tools, in direct contrast to the texts, which discussed tools as an option to bring designers into collaboration. Clearly, our results indicate a very real discrepancy between how a practicing engineer collaborates peers compared to that which is in the texts.

5. Conclusion

Collaboration between industry practitioners, particularly if within the same specialty, was limited in terms of direct collaboration in a specific project. Textbooks were used as a basis from which to understand how academia teaches a form of collaboration and to compare with how industry currently collaborates. Collaborative design tools in textbooks, described as a means from which collaboration occurs, were not used by the interview participants, clearly indicative of how academia perceives collaboration in industry with how industry undertakes such collaborations. To better align the teaching of collaboration in academia with what occurs in industry, classroom work must entail training students to collaborate in teams that are characterized through actual meetings characterized by project updates and the actual peer critiques of design decisions. While those collaborative design tools taught in academia are useful in the applications suggested, a greater emphasis should be placed upon the creation of social and inter-team skills.

6. Future work

The authors recommend recruiting of additional firms to expanding upon this existing research data set presented here, particularly those firms that design specialty or novel products to understand their design process. The expectation is that this new data will be used to better understand true collaboration through this larger triangulation of data so that academia can develop better pedagogies to improve the efficiency of students in completing actual engineering design projects. This enhanced understanding of how industry professionals collaborate in the design process is transferrable into the teaching of design courses

Some courses are taught in groups of students from a single discipline where they all work on the same project throughout its completion. Multidisciplinary collaboration could become the standard since this provides a more realistic scenario that the students would encounter in industry.

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