STUDIES IN ENGINEERING EDUCATION

Understanding the Impact of Product Characteristics on Groups' Collaboration During a Dissection Task

EMPIRICAL RESEARCH

TAYLOR TUCKER
MOLLY HATHAWAY GOLDSTEIN
EMMA MERCIER

*Author affiliations can be found in the back matter of this article

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ABSTRACT

Background: Experiential design opportunities are valuable for helping engineering students realize three-dimensional implications of theoretical concepts taught in the classroom. However, research on effective hands-on task design in the context of undergraduate group problem solving is relatively limited. While some tasks may include three-dimensional representation of task content, there is still much to be understood about how hands-on tasks influence students' collaboration.

Purpose/Hypothesis: To understand the impact of product characteristics on learning outcomes for undergraduate engineering students during a collaborative dissection task, we observed 16 students for collaboration quality as they worked in groups of four to reverse-engineer products through physical deconstruction and modeling in computer-aided design (CAD).

Design/Method: We used a multiple-case study format to qualitatively analyze the groups. Ethnographic observations were recorded during three dissection sessions for each group. To understand groups' experiences during the task, we coded our observations for behaviors that included collaborating versus going off-task, tendency to interact verbally, dividing into subgroups versus working as a whole group, and engaging in dissection and other physical interaction with the product.

Results: We observed that dissection product characteristics impacted group collaboration, which in turn may have influenced the quality of their final modeling scores. These findings are supported by a positive relationship between participation in dissection and task scores.

Conclusions: The study indicates that task products can impact the quality of collaboration and, in turn, students' performance. More specifically, the nuances imposed by product characteristics can directly impact group interactions. Task products should be selected with attention to how characteristics may impact students' opportunities to engage and interact.

CORRESPONDING AUTHOR:

Taylor Tucker

University of Illinois Urbana-Champaign, US

tdtucke2@illinois.edu

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INTRODUCTION

Over the last three decades, we have seen an increasing shift in engineering education toward emphasizing learning through group work (Smith, 1995; Smith, 1998) and, in particular, collaborative design work (e.g., Freeman et al., 2014). Although individual and group learning can achieve the same content-based outcomes for students, these processes are inherently different in their characteristics—the former develops students' individual competency, while the latter has the added potential to develop students' interpersonal and collaboration skills (e.g., Dringenberg & Purzer, 2018). It follows that academic achievement, although a reliable measure of students' individual command of course content, does not necessarily capture the quality of interpersonal skillsets. Kamp (2016) found that some employers now tend to place more emphasis on students' skillsets and personal traits over academic achievements, making the development of a collaborative problem-solving skillset even more imperative for new generations of engineering students. Indeed, engineers in industry are often expected to work on team projects, which introduces challenges associated with teamwork (Meneske, Purzer, & Heo, 2019). Developing strong collaboration skills during their curricula can better prepare engineering students to transition into the workplace. Rich histories of research in collaborative, cooperative, and problem-based learning all indicate that neither successful group experiences nor the development of collaborative skills emerge without significant support from instructors or instructional material (e.g., Barron et al., 2009; Borge & White, 2016; Kaendler et al., 2015; Nokes-Malach, Richey, & Gadgil, 2015). Designing a task that successfully engages students in working collaboratively presents a complex challenge, as the difficulty and open-endedness of the task content and structure must be such that students need to rely on one another to effectively solve, while also providing enough structure to support students in developing collaborative problem-solving skills. Investigations of strategies for scaffolding these tasks (i.e., implementing structural prompts and processes that assist students in engaging in collaboration) have found that a variety of strategies can guide group members toward more productive interactions (e.g., Borge & White, 2016; Ge, 2001; Rummel & Spada, 2005; Tucker, Shehab, & Mercier, 2020; Tucker, Shehab, & Mercier, 2021). However, there is still a need to identify how specific components contribute to a successful collaborative task. Our study begins to address this by qualitatively evaluating the experiences of engineering students during a hands-on, collaborative dissection task.

POSITIONALITY

We are an interdisciplinary research team with backgrounds in engineering education, engineering mechanics, systems engineering and design, and educational psychology. We are focused on leveraging collaboration to develop effective, authentic group-level design opportunities in the classroom for undergraduate students. The first author conducted the data collection; the second author is the instructor for the course being studied. Our study is driven by the underlying desire to continue evolving task design in engineering education such that more connections can be made between classroom content and novel societal challenges. We envision having collaborative, experiential learning opportunities integrated and supported throughout undergraduate engineering curricula, which will contribute to generations of engineering graduates with a strong collaborative problem-solving skillset and a history of experiential design on authentic tasks.

THEORETICAL FRAMEWORK

Our study is grounded in collaborative learning research that indicates that high-quality interactions are necessary for successful learning outcomes (e.g., Barron, 2003; Järvelä & Hadwin, 2013; Roschelle, 1992) and, as such, ensuring that tasks are designed to foster high-quality interactions is essential. To define collaboration as a measurable quality, we relied on a framework that outlines characteristics of effective group problem solving. Furthermore, because engineers in industry solve complex, ill-structured problems that require collaboration among disciplines and fields, a common goal of engineering education is to develop students' competencies for solving this type of task—often through design experiences (Dringenberg & Purzer, 2018). Thus, we chose to focus on collaborative, ill-structured design tasks. Ge and Land's quasi-experimental study (2003) of task design scaffolds presented a framework of four problem-solving processes necessary for effectively solving an ill-structured task. These were representing the problem, developing solutions, making justifications, and monitoring and evaluating. The authors then examined the cognitive and metacognitive requirements of each process and presented a conceptual framework for scaffolding this type of task (2004). In previous work, we built on Ge and Land's study by developing a research framework that outlines the four necessary collaborative processes in the context of complex design work in engineering education (Tucker, Shehab, Mercier, & Silva, 2019). Our framework defines these processes as the following:

P1. Exploring the problem

P2. Planning how to solve

P3. Attempting to solve (iterating plans and making justifications)

P4. Evaluating the solution and considering alternatives

Implementation of the framework relied on interpreting effective verbal participation in each process, which were outlined for a STEM context primarily using Jonassen, Strobel, and Lee's (2006) study of characteristics of the collaborative engineering workplace. Exploring the problem (P1) includes constructing a model or diagram to demonstrate an understanding of the problem space. Planning how to solve (P2) includes considering multiple approaches, selecting an approach, and formulating the reasoning behind the selection. Attempting to solve the task (P3) includes generating solutions, conducting experiments, and iterating results. Evaluating the solution (P4) includes judging how effectively the group approached and solved the problem. In a complex design problem, groups who effectively collaborate will iterate among these processes until they have reached a complete solution. We used our framework to evaluate students' performances during collaborative tasks, finding that the extent to which they were able to participate in each of the four processes impacted their learning outcomes (Tucker et al., 2020). Thus, we have a model of how effective collaboration among group members should look for complex problem solving in undergraduate engineering education.

LITERATURE REVIEW

BENEFITS OF ILL-STRUCTURED TASKS

Traditionally, engineering material has been taught in a way that supports grading, heavily focused on rote methods in which students "plug and chug;" that is, plug values into existing formulas and chug through the equation to solve (e.g., Agogino, Sheppard, & Oladipupo, 1992; Douglas at al., 2012; Jonassen et al., 2006). "Plug and chug" tasks allow instructors to easily compare a student's process and solution to an answer guide to identify mistakes. This type of work falls into the category of well-structured tasks, which define a clear path to a single correct answer (Dym, 1994). In his characteristics of well-structured tasks, Simon (1973) notes that these problems have "a definite criterion for testing any proposed solution, and a mechanizable process for applying the criterion" (p. 183). While this method supports quick, reliable feedback on the implementation of formulas and mathematical problem solving, it does not necessarily support the growth of students' collaboration skills.

In contrast, ill-structured tasks are typically designed to require collaboration, which stimulates problem-centered interactional activity (Kapur & Kinzer, 2007). Unlike well-structured tasks, which are designed to be solved by the individual, the ill-structured format inherently motivates teamwork. Furthermore, Jonassen (1997), building on work by Schön (1990), notes that well-structured tasks require a search for a pre-determined solution, whereas ill-structured tasks can be thought of as a design process. In general, ill-structured tasks are also harder to grade because the grader must validate students' unique solutions; from a resource standpoint, well-structured tasks place less load on instructors' time and efforts. Thus, it is necessary for engineering educators to implement a balance of well-structured tasks, which can quickly measure students' content-related competency, and ill-structured tasks, which more closely resemble authentic design work (Dym et al., 2005; Jonassen & Hung, 2008).

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COLLABORATION IN ENGINEERING EDUCATION

Complex group problem solving, like that supported by ill-structured tasks, allows students to expand their learning beyond "drill-and-practice"-type problem solving and engage in higher-order thinking and co-construction of knowledge (Hung, 2013). Additionally, collaboration is significant for engineering students because engineers typically do not work alone, and rely on input from other engineers and experts in various fields to arrive at an informed solution (Jonassen et al., 2006). Moreover, engaging in ill-structured design tasks early in undergraduate education is beneficial to students' interest in the field of engineering (Dym et al., 2005) and to their self-efficacy (Michael, Booth, & Doyle, 2012). Thus, the collaboration skills fostered by ill-structured tasks are directly relevant for students' practices in the workplace and might improve the undergraduate learning experience.

In this article, we focus on collaborative learning—the co-construction of knowledge through social interaction—rather than cooperative learning, which is more often associated with tasks that can be partitioned within a group (Dillenbourg et al., 1996). Cooperative learning tasks are typically designed with a focus on 1) positive interdependence such that the success of each group member is tied to the success of other group members, and 2) individual accountability such that everyone has a specific role in the task (Johnson & Johnson, 2009; Slavin, 2009). In contrast, collaborative tasks require group members to co-construct an understanding of the problem space. While we make this distinction to focus on the need for co-creation of knowledge, it must be noted that not all definitions of these forms of learning agree, many use the terms interchangeably, and students may often move between activity that can be classified as cooperative and activity that would be classified as collaborative in a single task (e.g., Hmelo-Silver et al., 2013). Designing tasks for the different interaction types requires different approaches, and while there is much to be gained from studying task design in cooperative learning, it is also necessary to attend ways in which tasks can scaffold knowledge co-construction.

Successful collaboration has been recognized as associated with a process that leads to successful outcomes and high-quality learning experiences by all group members (e.g., Barron, 2000; Mercier & Higgins, 2013; Roschelle, 1992). While a group may come to a reasonable solution without engaging in successful collaboration, effectively designed tasks will require students to engage in productive interactions in order for the outcome to be positive. Research indicates that interactions that build on one another's ideas, particularly developing and expanding on ideas rather than merely accepting them, are important (e.g., Barron, 2003). Additionally, groups who create a shared representation of the problem (either a physical representation or through common language or gesture; Mercier & Higgins, 2014; Roschelle, 1992; Schwartz, 1998) are more likely to have successful learning experiences and productive outcomes. Finally, groups who pay engage in all problem-solving processes tend to demonstrate more substantial learning outcomes than those who only focus on select processes (e.g., Tucker et al., 2020; Tucker et al., 2021).

DISSECTION IN ENGINEERING EDUCATION

Research has shown that hands-on learning, or learning by doing, can be more effective for learning outcomes than merely listening to lecture content (e.g., Deslauriers et al., 2019). In dissection, a hands-on task often employed in engineering education, students work to reverse-engineer a product through physical deconstruction. This type of task provides an experiential opportunity for practicing design (Lamancusa, Torres, & Kumar, 1996). Also known as "disassemble, analysis, assemble" (D/A/A), dissection has become a common pedagogy for providing students with practical experience in the classroom (e.g., Calderon, 2010). Literature has established that experiential design opportunities are meaningful for a rich engineering education. Indeed, Lamancusa et al. (1996) characterized pre-digital age engineers as "tinkerers" who "developed an instinctual, common sense feeling for engineering" (p. 1). The overview of a product dissection-type course by Lamancusa et al. (1996) showed that students' exposure to physical products improved their design awareness by supporting visualization skill development and a more common-sense aptitude for engineering.

Furthermore, in making a case for dissection tasks to be integrated in virtual classrooms, Ragonese and Starkey (2020), building on work by Huerta-Wong and Schoech (2010), noted that "listening to lectures on theoretical concepts without the experiential opportunities to put these concepts into application does not benefit a student as well as an experiential, hands-on approach" (p. 1). When considering a task that is fruitful for collaboration, we often consider ill-structured tasks to be most effective (Kapur & Kinzer, 2009) because they allow teams to engage in discussion about how to frame the problem, what sort of solution they are seeking and the path they will take within the "problem space" that they have defined (Simon & Newell, 1971). Because product dissection typically has more than one solution path and provides an opportunity for engineering students to engage in engineering practices, it demonstrates ill-structured task characteristics. It is, therefore, an ideal activity for students in CAD focused courses to use to learn both skills such as modeling and representation and collaboration skills.

RESEARCH QUESTIONS

Investigations of tangible characteristics (e.g., tactility, complexity, accessibility) of task products have been limited in collaborative learning literature, which tends to focus more on pedagogical methods and design strategies (such as scaffolding) that support students' learning outcomes. Simply engaging students in the dissection process does not necessarily ensure strong performance, making it necessary to investigate and characterize the nature of students' work during a collaborative dissection task. Our study investigated the following research questions:

1. How do engineering student groups allocate their time during a collaborative dissection task?
2. How might characteristics of the task product impact groups' task performance?

METHODS

RESEARCH DESIGN

We applied a qualitative multiple-case study format (Yin, 2018) to investigate students' experiences while collaborating on a design task for which a physical product was a major focus. Figure 1 describes the logic model for our study. Our first iteration of this study was to collect ethnographic observations and artifacts for five groups (Tucker, 2021). This iteration served to gain an initial understanding of students' experiences during the collaborative, hands-on task. We then iterated our format to dive deeper into connections between product characteristics and group collaboration and the implications that follow. We chose the case study format because it allows us to explore, in depth, groups' experiences within a bounded context (their dissection sessions) (Yin, 2018) while also drawing on artifacts created outside of the sessions. Due to our small sample size, we used descriptive statistics to tabulate trends in the data and highlight relevant patterns, and individual reflections as evidence of group dynamics. To explore connections to task performance, we included groups' modeling scores.

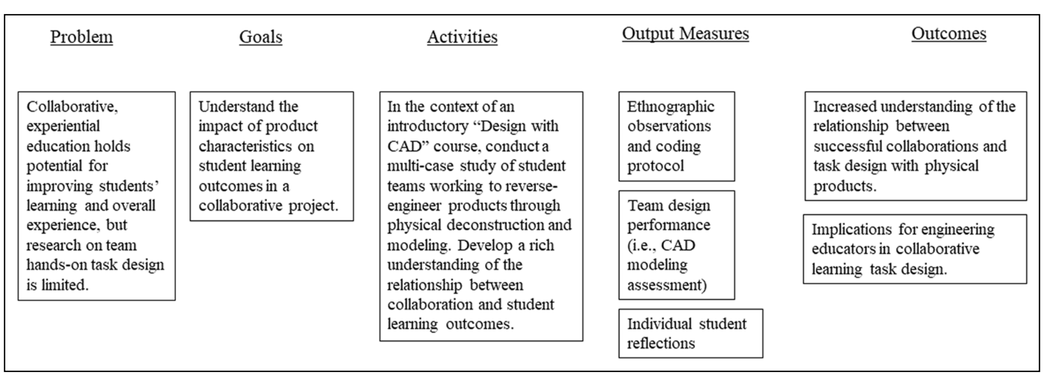

Figure 1 Study logic model.

Although the dissection task constituted one element of the semester-long design project, which was more heavily focused on CAD modeling, we recognized that the early stages of a design project have important implications for groups' overall performance. Thus, this study focuses on the impact students may have experienced as a result of their engagement during dissection sessions specifically.

RECRUITMENT

We received approval from the university's Institutional Review Board to observe and analyze consenting students in the course. An email with information regarding the study's purpose, procedures, and consent process was sent to all students enrolled in the course. A researcher then visited each section to discuss and obtain consent from interested students. Consenting students also expressed preferences regarding the use of photographs and artifacts in publications.

PARTICIPANTS

Participants were 16 undergraduate engineering students (4 female, 12 male) recruited from a one-semester introductory "Engineering Graphics & Design" course at the University of Illinois Urbana-Champaign. The course was required for agricultural & biological, industrial, and systems engineering majors. All students were organized into groups of four at the beginning of the semester using team formation software (CATME, 2021) that grouped based on 1) previous CAD experience and 2) similar available worktime while 3) not isolating female students. Each group worked together throughout the semester. The whole class of 102 students met for two weekly lectures, with weekly laboratory classes for smaller groups of students. For this study, four different laboratory timeslots were selected based on scheduling limitations. Because ethnographic observations were performed in real-time by a single observer, one participant group was selected for observation in each timeslot based on complete group consent. In the event of multiple groups from the same timeslot providing complete consent, we used groups' dissection products for secondary criteria—as the course offered a limited selection of product types, we chose to avoid repeats of the same product where possible to ensure a variety of products in the study. No other group characteristics were considered during the selection processes. Groups were observed during three 50-minute working sessions where group members worked together to dissect and model their product. The groups were split among three pairs of teaching assistants such that group A corresponded to one pair, groups B and C to another, and group D to a third. Data collection occurred during the spring 2020 semester; observations were completed before the university shut down face-to-face classes due to the Covid-19 pandemic. Additional data in the form of students' individual reflections span the entire semester. Post-spring break, the class switched to an online format and all further team communication became virtual, with final presentations delivered to the class via Zoom; there is no way to know how this impacted groups' final scores.

OBSERVATION

The observer, who was not affiliated with the course or its grading procedures, took photographs and recorded ethnographic observations (Hoey, 2014) by typing in word-processing software in a face-to-face classroom environment. The same observer attended all sessions and did not interact with or otherwise disrupt participants. These sessions took place midway through the 16-week semester during three consecutive weeks prior to spring break. We developed a protocol using field notes and memos from pilot data collections held during a previous semester (Table 1); this was consulted before observation sessions to guide the observer's focus. All observations were written freeform and the protocol was not present during sessions. Observations were recorded with corresponding timestamps. A change in notable participant behavior and/or the passing of roughly one minute constituted a new timestamp and corresponding entry. For purposes of analysis, each entry constituted one unit regardless of content. For rapidly changing behavior within a one-minute span, multiple observations were recorded under the same timestamp; these were later treated as individual units during analysis.

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Thematic Episodes	Record brief description of the type of *group* work students are doing. This may include reading task material, discussing the object, working individually, or assigning tasks. Mark description with time stamp. Record new description and time stamp when nature of work transitions to different type. If students are working individually, note each role.
Individual Roles	Using assigned codes, take note of the occurrence of students' individual roles (e.g., emerging leaders, bystanders, organizers, etc.). Were these roles self-assigned? Note changes in roles and include timestamps when possible.
Verbal Interaction	Record nature of interactions including episodes of P1, P2, P3, and P4, as well as off- task talk and any TA interactions. For TA interactions, record the nature of the interaction (e.g., Did students initiate with a question?). Take note of talk that explicitly includes the object.
Influence of Object	Record nature of students' interaction with object; use timestamps when possible. How is the object being used or manipulated? Is it being passed among multiple students? How many group members have touched the object? Do different members use or interact with it in different ways?

Table 1 Observation protocol for recording fieldnotes during in-person dissection sessions.

DESIGN PROJECT AND GROUP CHARACTERISTICS

The semester-long design project (Leake & Borgerson, 2008) tasked students with the following: to dissect a commercially-available product, model the individual pieces using Autodesk Inventor™, and devise possible improvements to the product's design. Our study focuses on collaboration taking place specifically during the dissection portion of the project. The project's final deliverables included: 1) an assembled computer-aided design (CAD) model and animation, 2) a 3D-printed component from the modeling of the product, 3) stress analysis of a central component, and 4) a written report detailing the overall design approach and suggestions for improvements to the product. Students also evaluated their CAD model's accuracy by comparing its projected total weight to the measured total weight of their physical product; teams were required to justify discrepancies. The model and animation were assessed by two members of the course grading team using a rubric (Table 2).

CATEGORY/SUBCATEGORY	SCORING BREAKDOWN	SCORE	TOTAL POSSIBLE POINTS
Modeling Effort			**18**
Modeling effort—part count, complexity (6 = A, 5 = B, 4 = B, 3 = C)	**/6**		
Modeling accuracy, attention to detail (6 = A, 5 = B, 4 = C)	**/6**		
Use of lighting, texture, backgrounds, translucency (5 = A, 4 = B, 3 = C)	**/5**		
Rendered section view of assembly	**/1**		
Animation			**9**
Quality, complexity, clarity of animation (6 = A, 5 = B, 4 = C)	**/6**		
Focus on product function (3 = A, 2 = B, 1 = C)	**/3**		

Table 2 Modeling assessment rubric.

All students enrolled in the class were exposed to the same bank of commercial products that were selected by the instructor. Students had the opportunity to indicate their top three product choices with the guarantee of receiving one of their choices for the project. The instructor selected a variety of products that had the following criteria: assemblies of 10–30 parts, moving parts to allow student to learn CAD animation and motion analysis, relatively easily disassembled by hand or with simple tools, and easily portable. The rationale for allowing students to rank their top three product choices was to increase their intrinsic motivation and allow for a variety of projects throughout the class (Wankat & Oreovicz, 2015). Of the four groups, two had the same commercial product (these have been numbered "I" and "II"). All reported results will reference the groups by the products they dissected, which are as follows: Stirling engine I; calendar puzzle; Stirling engine II; gumball machine (Figure 2). All products in the study were of similar scale, meaning that they were easily held with two hands and could roughly fit within 1 cubic foot of space.

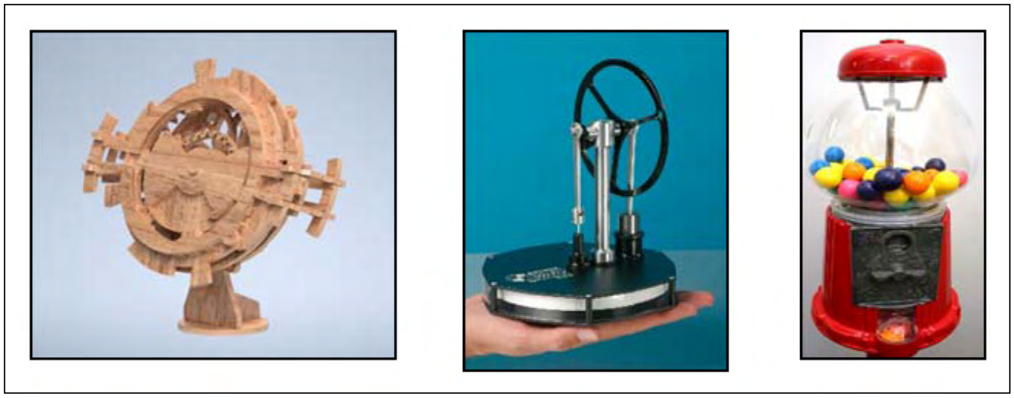

Figure 2 Task products assigned to groups in the study. These included (from left): a calendar puzzle, Stirling engine model, and desktop gumball machine. Calendar puzzle reproduced with permission; Stirling engine and gumball machine reproduced under Creative Commons license.

Two groups had all-male participants and two groups had two female and two male participants in each; this breakdown roughly reflected the gender distribution of the class. During the first observation session, three of the four groups began dissecting their products; one group did not yet have their product available and used the time for planning. During the second observation session, all groups worked on dissecting their products for all of the time allotted. During the third observation session, groups that did not finish dissecting during the second session did so; other groups began planning for the modeling portion of the project. Across the three observation sessions, all groups had ample time to both complete their dissection task and plan for other parts of the project. Because the dissection task was self-paced, discrepancies in groups' activity during these sessions were not measured.

EMERGENT THEMES

We used thematic analysis (e.g., Braun & Clarke, 2006) to identify preliminary themes emerging from our observations. Our group-level codes included type of product, divide-and-conquer, collaboration, physical interaction with the product; and physical collaboration through the product (Table 2). Furthermore, students were observed to individually engage in documentation, active dissection, active observation, and passive observation (Table 3). Codes were applied to data entries using Excel.

Table 3 Initial themes that emerged from analyzing dissection session observations.

THEME	DESCRIPTION
Type of Product	Characteristics related to the product itself, such as purpose, target audience, difficulty to dissect, and amount of available information.
Divide-and-conquer	Episodes in which group members divide into subgroups, either subconsciously or by choice, to tackle multiple aspects of the dissection process simultaneously.
Collaboration	Episodes of collaborative behavior as characterized by P1–P4 processes.
Physical Interaction with Product	Group members' physical interaction with the product.
Physical Collaboration through Product	Group members' physical collaboration with one another through manipulation of the product.

The observer developed initial themes and then discussed with fellow researchers to reach a consensus. Based on discussion and feedback, themes were revised and finalized. Tables 3 and 4 reflect the themes we implemented for the analysis presented in this paper.

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ROLE	DESCRIPTION
Documentation	Student documents dissection process by taking notes (e.g., in a Google doc), making labels, etc. This includes organization of parts (such as separating into labeled bags for storage).
Active Dissection	Student actively works to dissect product. May include following directions from the active observer.
Active Observation	While not actively dissecting the product, student assists in dissection process by retrieving necessary tools, helping to hold parts, making suggestions for what dissector should do, etc. May include following directions from other students.
Passive Observation	Student observes dissection but does not assist, interact with the product, or make suggestions.

Table 4 Individual activities observed during dissection sessions.

DATA CODING

We used our themes to develop a coding scheme (Table 5) intended to capture behavioral and collaborative trends as recorded in the observations. The observer and a second researcher then iterated the coding scheme to a workable version that was applied to observations from all groups. We applied all applicable codes to every entry (i.e., each unit). Inter-rater reliability averaged 92.3% agreement (with the lowest agreement being 82% and the highest being 98.4%); discrepancies were discussed to reach consensus when necessary. Table 5 reflects all codes used for the data analysis presented in this paper.

CODE	DEFINITION
Subgroups	0 = No division (either all working together or all working separately)
	1 = Presence of subgroups
Collaboration (includes non-verbal signals; multiple codes may be applicable)	0 = N/A (no collaboration observed)
	1 = Students are working together on task. Includes episodes of actively measuring loose pieces (no dissection).
	2 = Students are exploring the scope of the task (P1). Examples include asking what they need to do or discussing the type of task ("So are we just taking this apart?" "I think we need to take pictures today"). This can also include exploring supporting materials.
	3 = Students exhibit planning behavior, such as verbally planning what to do (P2). ("Someone needs to document while we do this," "We should start by removing this piece.")
	4 = Students discuss the dissection itself, such as commenting on difficulty; students quietly work to dissect the product (P3). ("It's hard to get this piece off," "Can you help me do this?" "I think we now have to look at this.")
	5 = Students evaluate their work. This may include identifying errors or suggesting changes to their method (P4). ("We should've taken this part off last," "Maybe we should label these instead.")
Off-Task	0 = No off-task talk/activity noted
	1 = At least one student is behaving or talking off task
Verbal Interaction	0 = None specified
	1 = Verbal interaction is occurring among at least two group members (i.e., dialogue or narration, whether as a full group or in subgroups)
	2 = Group is specified as working quietly
Dissection	0 = Dissection is not taking place
	1 = Dissection is taking place (i.e., product is being disassembled; parts are being removed, often through tool use)
Physical interaction with object	0 = Students are not physically interacting with product
	1 = Students physically interact with product through touch. Can include inspection, manipulation, and handling, but does not include removal of parts (i.e., dissection).

Table 5 Coding scheme for analyzing observations from dissection sessions.

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To account for limitations associated with capturing ethnographic observations by hand in real-time, we made several assumptions in the implementation of this coding scheme; namely, that a group displaying interactive behavior was also interacting verbally unless otherwise specified; that group behaviors persisted until noted as changed; that in episodes of questionable engagement, the benefit of the doubt would be given to the group interacting or remaining on task; and that events within the group that occurred outside close proximity to the observer (i.e., away from the worktable, out of earshot or vision) would not be captured.

We present all tabulated codes in two forms: proportional and raw values, where raw values are shown in parentheses. Proportions were calculated by tabulating each code across all observation sessions per group and then dividing by each group's total number of timestamps. A low value indicates that the groups engaged in the coded behavior for a lesser duration, whereas a high value indicates that they engaged in the behavior for a larger duration. The raw numbers indicate the magnitude of groups' participation in each code; the proportions allow for easier comparison across groups. The number of units produced per group varies; group's individual densities of behavior and participation in observation sessions was not controlled.

ADDITIONAL DATA SOURCE: INDIVIDUAL REFLECTIONS

At the end of the semester-long project, all students were instructed to compose individual, open-ended reflections regarding their teamwork and design experiences. Reflections were published in students' online portfolios, which were hosted by a university-supported platform. We used thoughts and ideas from students' reflections as evidence to triangulate our interpretation of the observation data.

ANALYSIS RESULTS

OVERVIEW

Our four cases can be summarized as follows: 1) a group whose product required no dissection (calendar puzzle); 2) the lowest-scoring group (Stirling engine II); 3), a group with the same product as the lowest-scoring group (Stirling engine I); and 4) the highest-scoring group (gumball machine). Relationships among any and all members of the four groups outside of the classroom were not known to the researchers. Additionally, this analysis only looks at product dissection sessions and does not take into account any later semester CAD modeling or activity. To understand how well groups performed on their design projects, their modeling scores are presented as percentages (Figure 3). The order of groups from highest to lowest performing is as follows: gumball machine (100%), Stirling engine I (88.9%), calendar puzzle (85.2%), Stirling engine II (81.5%).

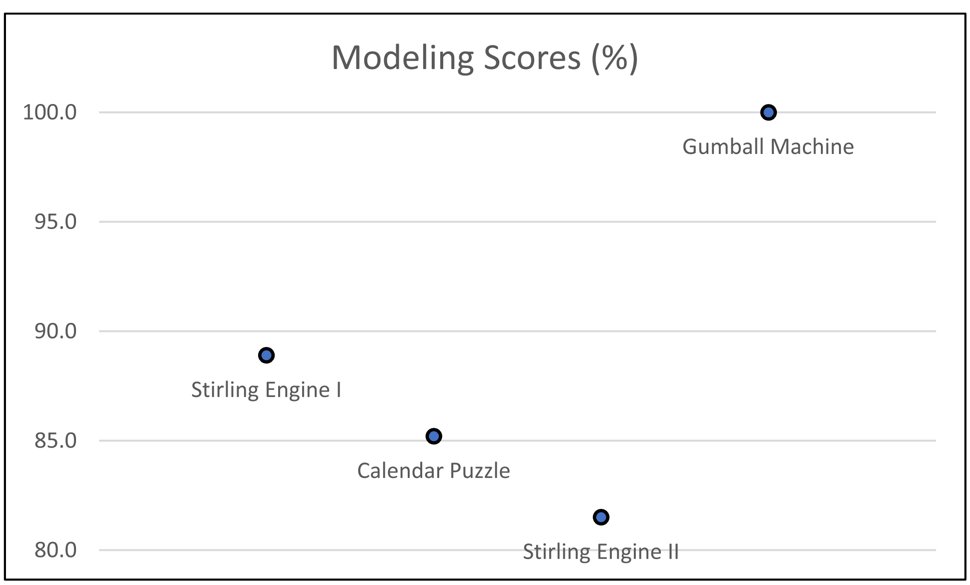

Figure 3 Modeling scores per each group in the study are presented as a percentage out of 100.

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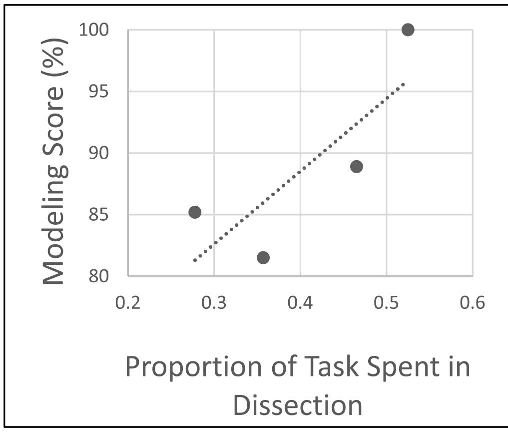
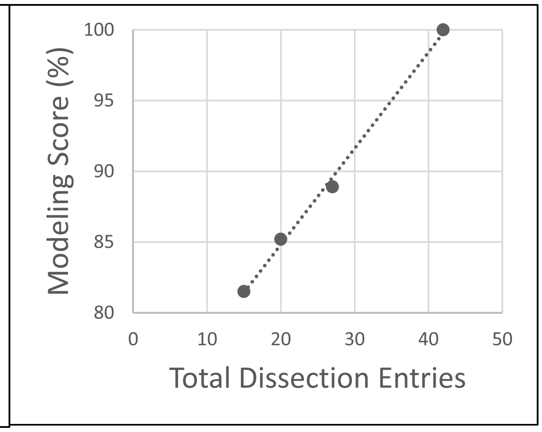
To visualize how groups' engagement with the hands-on nature of the task may have impacted their performance, groups' participation in dissection is plotted against their modeling scores (Figures 4, 5).





Figures 4, 5 Modeling scores versus dissection proportions (left) and total dissection entries. In **Figure 4**, the dots represent the calendar puzzle, Stirling engine II, Stirling engine I, and gumball machine from left to right. In **Figure 5**, the dots represent the Stirling engine II, Stirling engine I, calendar puzzle, and gumball machine from left to right.

Visual inspection of the data shows a positive linear relationship between groups' participation in dissection and modeling scores, with the two higher-scoring groups participating more in dissection than the two lower-scoring groups, and the highest-scoring group participating the most.

CASE 1: CALENDAR PUZZLE

Figures 6, 7 Group members work on the calendar puzzle (left). The finished puzzle (as shown in group's CAD model) can be set manually.

The calendar puzzle group was comprised of two female and two male students (Figures 6, 7). Most groups in the study were tasked with dissecting a finished product to learn about its design. However, this group was assigned a wooden puzzle that came in pieces. When assembled, the puzzle would create a three-dimensional calendar that could be manually "set" to display a chosen date. The puzzle pieces arrived in pre-cut wooden sheets, allowing the user to pop out pieces of their choice while working on the puzzle. Additionally, the puzzle came with a step-by-step assembly manual. Although any group could choose to search online to find resources related to their product, the calendar puzzle was the only product to provide explicit assembly instructions out of the box. Where other groups were taking apart their products and discovering individual components (and relationships among them), this group had their pieces in front of them with instructions on how to fit the pieces together.

While all members appeared friendly with one another and showed consistent enthusiasm for participating in the dissection sessions, they tended to refer to the assembly manual when working with their pieces in lieu of "blindly" exploring the puzzle. Compared to other groups, this group participated the least in working together on assembling their puzzle, often working individually on different sections. They also spoke to one another about the task the least of any

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group. Furthermore, this group had the least physical interaction with their product (Table 6). In fact, the group did not fully assemble the puzzle during the observed periods. Instead, the majority of their efforts focused on measuring and documenting their pieces in preparation for modeling. They also strategized how to divide modeling efforts among themselves. This group received the second-lowest modeling score of all groups in the study (85.2%).

Table 6 Case 1: Calendar Puzzle. Proportion of time spent in each behavior.

CODE	RESULT
Total observation timestamps	72
Verbal interaction	.653 (47)
Dissection	.278 (20)
Physical interaction	.208 (15)

Note. Proportions for tables 6–9 were calculated by dividing the frequency of each code by the total amount of observation timestamps. For each table, the raw data (in parentheses) reflects code frequencies.

In their individual reflections, which were written at the conclusion of the project, members of this team reported that they increased their communication efforts as the project progressed because they experienced obstacles while navigating virtual components due to the Covid-19 pandemic. At times, they struggled to coordinate design specifications for individual CAD components while working separately from one another. While this group had the most individual components to model of any group in the study, the experiences and struggles they reported are on par with those reported by other groups. During dissection, the observer noted that members of the group tended toward different roles; for example, two members tended to measure components collaboratively, while another assumed the responsibility of documentation.

The striking characteristic setting this group apart from others in the study is the uniqueness of their product and its impact on their engagement with the task. Theirs was the only product that essentially arrived pre-dissected; instead of learning through open-ended disassembly, the group learned through step-by-step assembly. The lack of opportunity to learn about their product's design through collaborative, hands-on dissection may have negatively impacted group members' engagement with the task by compromising their opportunity to collaboratively reverse-engineer, and thus co-construct knowledge around, their product.

CASE 2: STIRLING ENGINE II

Figures 8, 9 Group members explore their product (left). The assembled Stirling engine desktop model has moving components that mimic the internals of the full-scale engine (as depicted in the group's CAD model). Images reproduced with permission.

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The Stirling engine II group was comprised of two female and two male students (Figures 8, 9). Although identical Stirling engine models were used, these groups were located in separate sections and thus did not confer with or advise each other during the observed dissection periods. Any collaboration between groups outside of observation sessions is unknown.

Both groups were assigned a working desktop model of the Stirling engine, which uses a temperature differential to power a piston-driven wheel. The base of the model contained riveted metal plates and spot-welded components that could not be further dissected without destruction, which was outside the scope of the dissection tools provided. Thus, group members found a natural stopping point in their dissection process when they reached the base assembly.

These students tended to stay on task and speak quietly to one another, choosing to work together for the majority of the observation period. At times when members worked on separate tasks, they made efforts to keep track of one another's progress. They fell naturally into roles as time progressed, with two members physically orchestrating the dissection process. For Stirling engine II, another member facilitated the dissection verbally while the fourth member tended to work on self-assigned tasks.

This group received the lowest modeling score (81.5%) and participated the least in dissection. In contrast, the group was highly active in documenting and the most active of all groups in collaboratively measuring the product. This was also the only group that did not participate in reflecting on their task or outcomes during the observation period (Table 7).

Table 7 Case 2: Stirling Engine II. Proportions of time spent in each behavior.

CODE	STIRLING ENGINE II
Total observation timestamps	42
Dissection	.357 (15)
Measurement collaboration	.381 (16)
Documentation	.429 (18)
P4: Evaluating work and considering alternatives	.000

In their individual reflections, members of this group echoed the sentiments of others, reporting the need to adapt to the changing learning environment as the project progressed. Students also reported an initial struggle with communicating asynchronously and noted the strategy of assigning work roles for outside the classroom early on, such as a project coordinator who would check in with other members consistently.

The striking characteristic for this group is its means of engaging with the task. Stirling engine II members differed from the tendencies of other groups in the study because they focused more on documentation and measuring than actually dissecting their product. Furthermore, this group did not engage in evaluating their work during the dissection task. The focus on non-dissection elements during the task, combined with the lack of reflection on their work, may have hindered this group's ability to co-construct knowledge around their product's design.

CASE 3: STIRLING ENGINE I

The Stirling engine I group had four male students (Figure 10). Similar to Stirling engine II, students in this group tended to stay on task and chose to work together for the majority of the observation period. At times when members worked on separate tasks, they made efforts to keep track of one another's progress. These students also fell naturally into roles, with two members physically orchestrating the dissection process while one member focused on measurements and documentation and the remaining member assisted this process verbally.

Despite the natural stopping point presented by the product's characteristics, the Stirling engine I group managed to spend more time in dissection than did Stirling engine II (Table 8). In their

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final presentations, the two groups also demonstrated different approaches to classifying and tabulating components.

Figure 10 Group members record product dimensions. Image reproduced with permission.

CODE	STIRLING ENGINE I
Total observation timestamps	58
Dissection	.466 (27)
Measurement collaboration	.258 (17)
Documentation	.534 (31)
P4: Evaluating work and considering alternatives	.034 (2)

Table 8 Case 3: Stirling Engine I. Proportions of time spent in each behavior.

In their individual reflections, these members noted the importance of staying on top of the workload. The notable characteristic for this group is its ability to persist in dissection—and the impact that that persistence may have had. Combined with their willing to reflect as a group, Stirling engine I's drive to participate more in dissection may have positively impacted their modeling score.

CASE 4: GUMBALL MACHINE

Figures 11, 12 Group members dissect the gumball machine (left). This group's CAD rendering of the gumball machine cross section displays its internal components (right). Images reproduced with permission.

The gumball machine group was comprised of four male students, two of whom were exchange students from the same foreign country (Figures 11, 12). These two students spoke their shared native language to each other during sessions and their behavior suggested a connection outside of the classroom.

This group was assigned a functional, desktop-sized gumball machine that was constructed from metal with a glass globe. The outer shell could be disassembled and the globe removed to access the inner workings of the machine, which were actuated mechanically using a spring-loaded mechanism operated by an exterior lever. Although desktop-sized, the gumball machine had a robust design intended for thousands of cycles. Of the four groups, this group collectively displayed the most emotion and frustration during the dissection process, often struggling to work components apart using the tools provided. Indeed, these students tended to struggle together, having the least instances of divide-and-conquer behavior. They also had a high level of verbal interaction as compared to other groups (Table 9).

Table 9 Case 4: Gumball Machine. Proportions of time spent in each behavior.

CODE	GUMBALL MACHINE
Total observation timestamps	80
Verbal interaction	.838 (67)
Dissection	.525 (42)
Subgroups	.088 (7)

This group not only participated the most in dissecting their product, but was also the only group to receive a perfect score on their CAD model (100%). In their individual reflections, group members recognized the difficulties they experienced in coordinating the modeling of complex parts while working remotely. They also described the emphasis they placed on consistent, clear communication, both of which were common themes for all groups in the study. These students tended to frame the challenges they faced as opportunities to grow stronger as a group.

The striking characteristic for this group is its strong performance on the task, which coincides with the highest participation in dissection of any group in the study. These students relied heavily on whole-group collaboration and became engaged in productive struggle due to unforeseen difficulties dissecting their product. Thus, the product's characteristics combined with students' tendency to engage in group-level dissection may have supported this group in co-constructing knowledge around the product's design, which in turn could have influenced their performance.

DISCUSSION

We observed four undergraduate engineering student groups that each worked collaboratively to dissect and document an assigned product as part of a semester-long design project. Studies such as Calderon's (2010) and Sheppard's (1992) have advocated for dissection as an effective experiential design opportunity for students. Indeed, we know that students' hands-on engagement with content during a design task can support stronger learning and design outcomes (e.g., Lamancusa et al., 1996; Sheppard, 1992). Furthermore, research has shown the efficacy of collaboration for improving students' learning outcomes. However, effective collaborative, hands-on task design in engineering is still relatively unexplored. While some tasks may include three-dimensional representation of task content, there is still much to be understood about how hands-on tasks influence students' collaboration. Research in other STEM fields has investigated strategies for leveraging hands-on learning in task design; for example, Anderson et al.'s problem-based learning study (2021) explored strategies for designing hands-on activities that could increase feelings of interest and self-efficacy in chemistry. Although there are similar studies in engineering education, such as Ma, Tucker, Okudan Kremer, and Jackson's (2017) investigation of employing hands-on learning to teach engineering design, *collaborative* task design in engineering has not yet established task elements or directives for students' learning outcomes. Our study serves to address this need by exploring the impact of the task product on groups' performance during the task. We used case studies of four groups, combined with descriptive statistics and classroom artifacts, to characterize trends experienced by students as they worked on the task. We observed that task product characteristics had substantial impact on groups' interactions, including their decisions regarding allocating time for task activities. In turn, this impact may have influenced the quality of their final modeling scores.

RQ 1: HOW DO ENGINEERING STUDENT GROUPS ALLOCATE THEIR TIME DURING A COLLABORATIVE DISSECTION TASK?

We found that the highest-scoring group worked in collaboration the most of the four observed. They were vocal as they worked, which opened up the opportunity to co-construct knowledge around the product. The gumball machine presented some difficulty to dissect because it had robust, tight-fitting parts that were tough to remove with the provided tools. This caused the group to work together to find a solution, sometimes using tools in a creative way. Group members expressed their frustration with the product and relied on one another for support.

In contrast, the calendar puzzle group simply followed their user manual and focused the majority of their attention on modeling their pieces. They spoke less to one another and, essentially having nothing to dissect, spent less time collaboratively interacting with the product, instead dividing up the pieces and transitioning into individual assignments. Indeed, a similar trend was observed between the two Stirling engine groups—Stirling engine I, which dedicated more time and effort to actively dissecting their product, achieved a better modeling score than Stirling engine II, who participated the least in dissection and received the lowest modeling score of the observed groups. It is important to note that this group also did not engage in reflecting about their process, which sets them apart from other groups in the study. Furthermore, they spent the most time measuring their product, which indicates that they were trying to engage with the product beyond dissection.

It seems that the amount of time spent in collaborative interaction with the product has an impact on the quality of students' interaction, especially their discussion. This finding is supported by Brereton, Cannon, Mabogunje, and Leifer's study of engineering students working in teams on a seven-month design project (1996), which concluded that "the content of the evolving design depends heavily upon negotiation strategies and other more subtle and ubiquitous social processes that shape design work" (p. 339). Brereton et al.'s study emphasizes the impact of effective social interaction on design outcomes; thus, the reduced social interaction among these group members may have had the opposite result. Indeed, Barron's study of 6th graders working in small groups showed that the quality of interaction is important for the outcomes of collaboration (2003). It is not enough for students to simply be skilled at the individual level; their learning outcomes are impacted by individual factors and group-level experiences. Furthermore, we know from individual reflections that students valued communication throughout the design task, which tells us that dissection-related opportunities to interact with one another hold inherent value for group members.

RQ 2: HOW MIGHT CHARACTERISTICS OF THE TASK PRODUCT IMPACT GROUPS' TASK PERFORMANCE?

We observed some notable differences among the products in the study. The gumball machine, although fully dissectible, presented difficulty to dissect without specialized tools due to its robust structure, tight-fitting parts, and complex internal mechanisms. These features caused group members to struggle with the dissection process, which led them to work together to devise creative ways to move forward. Because the gumball machine is a well-known item, it was reasonable for the students to make assumptions concerning the product's internals. A visual and tactile inspection of the product also informed them that the metal components were robust and well-formed, which may have boosted their confidence in seeking creative solutions. In other words, they could guess enough about the product to devise a plan for moving forward with dissection, and they were confident enough in its design to try innovative tactics without fear of destroying components. These features may have supported students in engaging in effective collaboration, which in turn may have impacted their performance.

In contrast, the calendar puzzle was not conducive to dissection. Although group members spent time interacting with the pieces, they did so primarily on an individual basis. In other words, especially with the help of the manual, students did not need to rely on one another to move forward with the task. Instead, they were able to divide pieces and begin individually modeling components. In turn, this lack of collaboration may have impacted their performance during the task.

The Stirling engine's characteristics were similar to that of the gumball machine, with the main difference being that its construction presented a natural stopping point that made for a shorter dissection process than that of the gumball machine. We observed that the two groups responded differently, with Stirling engine I making more of an effort to be thorough in their dissection. The Stirling engine II group transitioned from dissection to measuring product components and were the most active group in this activity. It is unclear whether this behavior impacted the quality of their collaboration; future work can investigate the impact of activities other than dissection on group collaboration during a hands-on task.

Given these observations, we find that a desirable hands-on task product should be robust enough to withstand stresses and forces caused by handling and dissection, but not to the point that students are unable to remove or work with components. The product should have sub-assemblies or internal mechanisms and components that present multiple layers of dissection in order to complete the task. Furthermore, it may be helpful for students to work with a familiar product for which they can reasonably apply background knowledge to guide their process. However, the product's design should not be overly simple, as students would ideally still engage in productive struggle. The need for productive struggle with physical products, which typically needs to be scaffolded to be effective, is supported by Martin and Schwartz's study of middle school-aged children in a math class (2005), which found that manipulating physical pieces facilitated participants' interpretation of fractions. In turn, increased physical interaction with the task product can lead to increased interaction among group members, which is desirable for group collaboration (Barron, 2003; Dringenberg & Purzer, 2018). Thus, close attention to the characteristics of task products can impact groups' performance during the task, which in turn indicates that their learning outcomes could also be impacted.

LIMITATIONS

While we embedded validation considerations into our study design and implementation, we also have limitations in our study design and the generalization of our results. Observation protocols are commonly used in the study of collaborative learning; however, the presence of an observer might have had an unintended consequence on student behavior. In addition, because this study was set in an existing course context, products were chosen with a primary learning goal of CAD modeling proficiency. Results presented in this study may only be generalizable to similar course contexts, student populations, and similar products dissected. In addition, race and ethnicity information was not collected from students, and our sample over-represented female students, limiting the generalizability of our results.

CONCLUSION

This work expands the body of literature investigating the ways in which engineering student teams collaborate during ill-structured tasks. We observed four undergraduate engineering student groups working collaboratively to dissect a product as part of a semester-long design project for which computer-aided modeling was a major component. Our case studies demonstrated the characteristics of a group that received a perfect score on the task as well as groups that received less than perfect scores. Our studies, which included tabulated data from our observations, suggested that the task product has an influence on students' collaboration, which in turn can impact their performance. Product characteristics including structure, internal complexity, and cultural relevance, may have an impact on groups' behavior and experiences during the task. These findings are meaningful to dissection task design because they demonstrate tangible task elements that may be strategically implemented to support students in stronger task performance, which may impact their learning outcomes. A natural next step for this research is to perform a comparison study between the two groups who worked on identical products. Future work should also more deeply investigate the effect of task products on group outcomes.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR AFFILIATIONS

Taylor Tucker orcid.org/0009-0005-3311-7795
University of Illinois Urbana-Champaign, US

Molly Hathaway Goldstein orcid.org/0000-0002-2382-4745
University of Illinois Urbana-Champaign, US

Emma Mercier orcid.org/0000-0002-9301-5142
University of Illinois Urbana-Champaign, US

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