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Work in Progress: Exploring the Nature of Students' Collaborative Interactions in a Hands-on, Ill-structured Engineering Design Task

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WIP: Exploring the Nature of Students' Collaborative Interactions During a Hands-On Ill-Structured Engineering Design Task

Introduction

This work-in-progress paper explores the nature of engineering students' interactions during a hands-on design task. Engineering education is experiencing a shift in curriculum format toward more emphasis on collaborative design work; indeed, collaborative problem solving has become increasingly common in engineering courses [1]. Research has established the efficacy of ill-structured tasks for providing students with collaborative design experience authentic to industry [2], [3]. However, research on effective ill-structured task design in the context of undergraduate group problem solving is relatively limited. Studies have explored how to design and construct ill-structured tasks that effectively engage students and promote higher learning outcomes and group collaboration [4], [5], [6], but these tasks have primarily been limited to two-dimensional representations that lack opportunity for students to realize their design implications in the physical world. Transformative learning theory asserts that cognitive (head), affective (heart), and psychomotor (hand) processes are connected in transformative learning [7]. Ill-structured tasks already incorporate "head" and "heart" elements because they are cognitively demanding and support social interaction; it follows that a "hands" element should be incorporated for an effective immersive learning experience. Furthermore, as hands-on learning can provide experiential opportunities necessary for synthesizing theoretical concepts [8], it is necessary for a comprehensive engineering education. Some tasks may include three-dimensional content representation (i.e. in the form of a model or prop), which can effectively support students' more profound understanding of content [9]; other tasks may require the use of measurement tools. However, there is limited research on how engineering students interact with, and collaborate with, each other on a design task for which working with a physical artifact is central to the task. This WIP study seeks to address this gap by characterizing the nature of students' interactions as they worked in small groups on an ill-structured engineering design task centered around dissecting a physical product.

Previous work debuted a framework that outlines the four collaborative problem-solving processes necessary for solving an ill-structured task: exploring the problem (P1), planning solutions (P2), attempting to solve (P3), and evaluating the solution and considering alternatives (P4) [10], [11], [12]. This study adapts the framework to serve as the basis for measuring collaboration in the context of this task and uses mixed methods to evaluate behavioral and collaborative factors displayed by groups. The study explores the following research question: What are the characteristics of students' interactions during a hands-on ill-structured task?

Methods

Participants

Participants were 20 undergraduate engineering students (6 female, 14 male) recruited from a one-semester introductory Engineering Graphics & Design course at a large, public Midwestern university. The course, which had 102 enrolled students, was required for select engineering majors. Participants were pre-organized by the instructor into groups of four that worked together throughout the semester. Five different laboratory timeslots, totaling 74 enrolled students, were selected for the study based on scheduling limitations. Participant groups were selected based on complete group consent, with one per timeslot chosen by the researcher. In the event of multiple groups from the same timeslot providing complete consent, groups' dissection products were used as secondary criteria to ensure a variety of products in the study. Prior experience, identity, and other participant characteristics were not considered during the selection process. While all enrolled students took part in the class tasks, only participants were observed. Groups were observed throughout multiple 50-minute working sessions during which group members worked together to dissect their product. The groups were split among three pairs of TA and CA instructors. Data collection occurred during Spring 2020, but was completed before the university shut down face-to-face classes due to COVID-19. 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, but it is highly likely to have been a factor.

Design

Ethnographic observations [13], [14] and photographs were recorded in a face-to-face classroom environment. The observer did not interact with or otherwise disrupt participants during sessions. A protocol, developed using fieldnotes and memos from previous classroom observations in a similar environment, was consulted before 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.

Design Project

The semester-long design project [15] tasked students with the following: to dissect a commercially-available product, model the individual pieces using Autodesk Inventor™, and devise possible improvements to the design of the product. The dissection process, in which students reverse-engineer a product through physical deconstruction, provides experiential opportunity for practicing design [16], [17]. The final deliverables included an assembled CAD model and animation, a 3D-printed component, simulated stress analysis of a central component, and suggestions for improvements to the design. 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 breakdown of products is as follows: Groups A & D, Stirling engine desktop model; Group B, Nerf™ gun; Group C, wooden calendar puzzle; Group E, desktop gumball machine.

Analysis

Thematic analysis, a process that identifies recurring ideas in the data, consolidates those ideas into codes, and uses the codes to identify patterns that evolve into themes [18], was used to identify preliminary themes emerging from the observations. Among others, these included individual roles (Table 1), which were self-assigned by group members either subconsciously or purposefully during the dissection process. Themes were developed by the observer and then discussed with fellow researchers. Future work will discuss the thematic analysis process in more detail.

Table 1. Observed Self-Assigned Student Roles

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 active observer
Active Observation	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
Emergent Leadership	Student takes leadership of the group. This can include delegating tasks to others, making plans on behalf of the group, giving instructions, and making organizational moves
Investigation through Tools	Student interacts with product through tool use. This includes taking photographs, sketching traces or diagrams, taking measurements, etc.

Themes were used to develop a coding scheme used to capture behavioral trends as recorded in the observations. The coding scheme was developed by the observer with input from fellow researchers. The observer and a second researcher then iterated the coding scheme to a workable version applied to observations from all five groups. 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.

Results

Table 2. Proportions of Codes per Group

Code	A	B	C	D	E
Off-Task	.155	.083	.208	.071	.013
Subgroups	.293	.117	.125	.190	.088
Verbal Interaction	.672	.900	.653	.762	.838
Dissection	.466	.450	.278	.357	.525
Physical Interaction	.466	.600	.208	.810	.563
Physical Collaboration	.224	.117	.125	.024	.088
Use of Supporting Materials	.000	.067	.514	.952	.513
P1	.015	.077	.154	.175	.038
P2	.106	.192	.212	.100	.076
P3	.591	.481	.404	.325	.544
P4	.030	.038	.038	.000	.076
Scores (%)	88.9	88.9	85.2	81.5	100

Table 3. Proportions of Student Roles per Group

Role	A	B	C	D	E
Documentation	.534	.333	.153	.429	.263
Active Dissection	.448	.367	.278	.357	.538
Active Observation	.466	.483	.042	.286	.500
Passive Observation	.172	.300	.000	.262	.325
Emergent Leadership	.017	.067	.181	.214	.125
Investigation through Tools	.552	.217	.250	.738	.438

Table 2 summarizes the observations recorded per group and each group's score on the final product model. Scores were assessed by a TA using a rubric provided by the instructor. Values are provided as proportions out of the total timestamps recorded for each group. Table 3 provides the breakdown of proportions of student roles observed in each group.

Discussion

Although the groups had different approaches regarding use of supporting materials, such as reference guides and supplementary videos related to their product, all final scores were between 80-100% with an average score of 88.9%. The uniformity of scores suggests that these materials' presence does not necessarily impact students' approach to working with the object. It follows that while supplemental resources may help in navigating the product, they do not necessarily impact students' understanding. This may be because students derive more meaning from the dissection process itself, which provides them with experiential opportunity for synthesizing theoretical concepts in a hands-on setting [19]. Indeed, the highest-scoring group participated the most in dissection, while the group whose product came pre-dissected (C; calendar puzzle) not only experienced the least verbal and physical interaction and the most off-task behavior, but also had one of the lowest scores. This suggests that the lack of experiential opportunity may have impacted the latter group's motivation to interact with the product or collaborate with one another, thus limiting their collective understanding of the product.

All groups experienced more P3 (attempting to solve) than any other collaborative process, reflecting the same trend revealed in historical data of engineering students solving non-scaffolded ill-structured design tasks [10]. Indeed, the group with the highest P3 also had the most physical interaction with the product, suggesting that the other three problem-solving processes were not as inherent to hands-on learning. As ongoing research has since found that more balanced participation among the four processes can improve students' learning outcomes by increasing opportunities for them to engage in more complex cognitive processes (pending publication), future work should investigate the implementation of scaffolds that provide opportunity for students to enter each process during dissection tasks. Furthermore, the group that participated most frequently in verbally evaluating their work (P4) achieved the highest score (100%), while the lowest-scoring group did not participate in P4. This trend is supported by prior research that showed a significantly positive relationship between participation in reflection and task scores [6]. Strategic scaffolding may support more profound engagement with the product, which could lead to higher learning outcomes.

Conclusion and Limitations

Five groups were observed working to reverse-engineer a product through physical dissection during a one-semester ill-structured engineering design task. Trends from groups' behaviors suggest that, while the experiential nature of dissection supports group members' collaboration and engagement with the product, strategic scaffolds are necessary to allow groups to enter all collaborative processes necessary for effectively completing the task. In particular, groups who found an opportunity to reflect during the dissection process seemed to build understanding with less reliance on investigation of the product through tools, meaning that they were able to engage with the product through multiple levels of cognition.

The university-wide shift to an online curriculum format mid-semester due to the pandemic impacted the study. Although groups had already completed their dissection processes, the disruption and subsequent challenges may have impacted their final work quality. Future work will more deeply investigate groups' behaviors during the task. Findings from this study and ongoing work support more effective task design.

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