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The Two Worlds of Engineering Student Teams

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The Two Worlds of Engineering Student Teams

Introduction

One common critique of the engineering curriculum is that students leave unprepared to connect the knowledge they learned in the classroom to the messy, open-ended work they face in engineering practice [1]. The study described in this paper was part of a broader institutional change initiative where we are attempting to address this issue. Shifting student activity from abstract decontextualized assignments to meaningful, consequential learning, we put students in the role of engineers working on teams [2]. We believe this shift will more effectively develop the next generation of engineering practitioners, innovators, and entrepreneurs. In these realistically situated tasks, students engage in activities that require them to activate disciplinary knowledge and practices to solve real world problems.

The change initiative has focused on shifting student activity in collaborative learning sessions, or "studios," that have been integrated into nine core undergraduate engineering courses at XXX University [3]. In the reformed studio, activities are designed to be "group worthy" in that they require multiple perspectives and often have multiple solution paths [1], [4]. To respond, students need to construct and organize knowledge, consider alternatives, and engage in analysis, inquiry design, and critique of their own and others' reasoning [5], [6].

Drawing on elements of research-based pedagogies that have been adapted by engineering educators including Problem Based Learning [7], [8] and Model Eliciting Activities [9], a realistic, situated studio activity was designed titled "Development of Microfluidic Device for Diagnostic Testing Using Polymerase Chain Reaction (PCR)." The task situated students as engineers for a startup company responsible for developing a scientific model and then using it to produce an engineering design. To test the ways this new studio task aligned with the goals set forth by the institutional change initiative, a clinical trial was performed to observe student teams as they worked through the activity in a controlled environment. We analyze video data to compare the ways that two student teams engage in the task, including the degree to which their activity resembles the work of engineers in an "engineering world" and the degree to which it mirrors students in a "student world."

Specifically, we seek to answer the following research questions:

1. To what degree do two student teams engage in engineering world or in school world as they complete the studio activity? Are there patterns in the differences between teams?
2. How do each of the worlds influence their engagement as they progress towards task completion?

Theoretical Framework

We are interested in activities and instructional practices that shift the engagement of students as they work on in-class activities in teams. The overarching framework we use is Productive Disciplinary Engagement [10], [11] but our thinking also draws from pedagogies of engagement [12] and consequential and critical engagement [13]. When students are in PDE, they use the concepts, language, and practices of engineering to "get somewhere" on a task (i.e., iterate on a design, streamline a process, develop better understanding of a system). PDE has been shown to result in deep learning of concepts and incorporation of practices [11].

We frame analysis in terms of overlapping “figured worlds” - the social systems of identities, relationships, and positions that participants take on as they work [14], [15]. The activity studied here asks students to step into "engineering world," where they use engineering principles and practices to make progress on a meaningful task. However, the activity also resides in “school world” where tasks have an exchange value: successfully completed work can translate into a desired grade. For student engineers, the two figured worlds co-exist but the skills and approaches that lead to success in each do not necessarily coincide. When an interaction draws on elements of both figured worlds, or the figured world cannot be determined, we label it “hybrid world.”

Often engineers engaged in complex tasks use models where they translate the problem into the language of mathematics, solve the governing mathematical equations, and then interpret the results [16]. Thus, they can spend considerable time working with abstract mathematical relations. One perspective is that they are in a different “space” when they do this work, which Prausnitz [17] has termed the “abstract world of mathematics.” Alternatively, we can take the perspective that mathematics is a tool that mediates activity [18] be it disciplinary activity in engineering world or student activity in school world [19].

Borrowing from Chi [20] and the literature on ambitious teaching [21], we identify three types of engagement: self-construction, interactive engagement, and facilitated construction. Self-construction occurs when a student presents ideas that go beyond the information presented, e.g., they may put forth an idea about how to productively move forward with the task. Collaborative engagement describes activity in which the student interacts with other students on their team in ways that influence the teams’ activity and approach. Finally, interactions with the instructor facilitating the activity in which students are provided substantial feedback and respond in kind is identified as facilitated construction.

In truly “group worthy” activities, complex tasks demand collaborative engagement. Such engagement can produce conflict and the resulting disequilibrium are essential to making progress. The bidirectional zone of development, where each student’s problem-solving abilities are elevated compared to their individual ability, results in re-equilibration [22]. In undergraduate engineering, collaborative engagement can take place in both engineering world and school world. We are interested in the disciplinary engagement of students including the ways they interact with each other around content and the reasons they select particular tools to achieve their objectives. Ultimately, we seek to understand the influence of their figured worlds on interactions and tool use, and the role of task design and instructor facilitation.

Methods

Studio Task

The task situates the students as engineers for a startup company designing a microfluidic device that automates the Polymerase Chain Reaction (PCR) process for point-of-care quantification of DNA sequences for small volumes of fluid. Critical to the design of a PCR device is the temperature profile of the process fluid. Hence students must apply principles from the course, Energy Balances, to undertake their engineering work. The fluid, which contains DNA, must be heated and cooled to specified temperatures to achieve proper DNA strand growth and the desired number of strand replications. This process a can be modeled as a continuous series of heating and cooling sections which must be sized appropriately in conjunction with the feed flowrate to achieve target temperatures. In the first studio activity studied here, each team is tasked with development of a mathematical model which could be used to predict the temperature at any given point in the flow path, while accounting for the temperatures required to denature then anneal primer-laden DNA. This studio task is open-ended in that the team is given a set of variables that must be included in the final model and Fourier's heat equation but are asked to reason through setting up the energy balance in differential form on their own.

Participants and Setting

The 13 clinical trial participants were volunteer undergraduate engineering students at a large public university who had just completed their second or third year in the curriculum. All participants had passed the required core sophomore level course, Energy Balances. The participants were placed into 3 teams of three and 1 team of four. Nine of the participants were male and four were female. In teams of three, homogenous gender and mixed gender groups of two females and one male tended to perform better on physics problems [23]. To the extent possible, teams were gender balanced with this study in mind. Participants were seated at square tables, one to two per side to encourage interaction. Teams were then given the microfluidic energy balance task handout, asked to read the detailed activity description thoroughly, and to make sense of the tasks over the course of 80 minutes. Resources available to the teams were the Energy Balances course textbook, laptops to access the internet for pertinent information, and two facilitating faculty members with content and pedagogical expertise. Use of resources was at the discretion of the team. In this way, we attempted to mimic elements of a studio classroom setting but in a more controlled environment to minimize extraneous variables. This research was approved by the Institutional Review Board and all participants provided informed consent.

Data Collection

Each of the four teams were video recorded while they engaged in the microfluidic energy balance task. Separate camcorders focused on each table and were placed close enough to record clearly spoken dialogue but distant enough to not be obtrusive. At the beginning of the trial the camcorders were turned on and remained unattended for the remainder of the trial to minimize distraction. This study focuses on the externalized outputs of collaborative engagement in the task, including verbal utterances and non-verbal overt activities. Each team's utterances were categorically coded for analysis, with transcripts of interesting interactions used as the cornerstones for our hypotheses. In some instances, non-verbal overt activities were used as supporting data. Of the four teams, two were selected for this in-depth comparative case study due to the distinctly different figured worlds they appeared to enact towards making sense of the task. The other two teams showed behaviors intermediate, so the two teams analyzed represent the extreme cases among the four teams recorded.

Analysis and Codes

The video data was coded using multiple passes with utterances coded by speaking turn and time of task. The research team iteratively developed an emergent set of categorical codes for the turn-based data. Three sets of data are reported in this paper: which student (labeled S1, S2, S3, and S4) or facilitator (F1 and F2) was talking; which figured world the talk represented; and what broad type of engagement was observed.

Table 1 presents the code categories for figured worlds, their description, and an example excerpt. The figured worlds were classified according to engineering world, school world, or hybrid world. Each of the codes were distinguished by the reasoning involved at times of uncertainty in the problem-solving process. When students were working on mathematical manipulations a separate category called Abstract Math was identified.

Table 1: Code categories used for figured worlds and math activity

Category	Description	Example
Engineering world	In engineering world, reasoning is anchored in accountability to science and engineering disciplinary norms; it is defined by a transferrable set of skills that are regularly used by engineers in practice such as making meaning of systems and processes.	“So… a certain amount of power is going into the water at all times along the coil that’s in the water, and so we can assume there’s a constant amount of energy going into the water….”
School world	In school world, the student uses the context of their school experience to identify what to do. They learn to recognize patterns to problem solving in a course context and form preconceived notions of what solutions should look like. Dialogue in School World can be identified by modifiers like “in this class”, "always", and "have to.”	“Yeah I’m trying to…I was totally prepared for the heat loss to just say ΔT log mean and call it good.”
Hybrid world	In hybrid world, the thinking and reasoning utilized by students cannot clearly be categorized into either Engineering World or School World as it has elements of both. It is most clearly identified by students reading and reasoning through information that is available (online, textbook, memorandum).	“I think they [memo authors] only said this [Fourier] applies during the heat loss.”
Abstract math	Here students project their progress in the engineering world and school world into mathematical or thermodynamic abstractions where they apply the tools they believe necessary for a solution. Dialogue classified with this code is rife with variables, mathematical manipulations, and unit checking.	“We have another Joule unit in that…we do want another Joule…oh this should be flipped. Joules per kilogram…err…Kelvin, kilogram, Joule.”

In the engineering world example from Table 1, the student uses an understanding of constant supplied power to the heater system to assume constant energy transfer into the process fluid. The student reasons through the physical system in his/her mind, a useful tool for practicing engineers. Engineering world codes tended to persist longer in the broader dialogue as it calls upon a deep understanding of processes. The school world example stands in contrast to this physical system reasoning. Representativeness resulted in students forming an idea of what the solution should look like early in the problem-solving process. The example in Table 1 mentions ΔT log mean, a common solution to undergraduate heat transfer problems. School world codes tended to be short and require less dialogue. Hybrid world codes were often identified in combination with non-verbal overt activity. Specifically, a student reading directly from the task memorandum or textbook. Abstract math was given a separate code as without context this category of speaking turn is difficult to attribute to a figured world. Abstract Math dialogues tended to be long-lived, making up significant uninterrupted portions of team discourse.

Table 2 presents the categorical codes for engagement including self-construction, collaborative engagement, and facilitated-construction.

Table 2: Code categories used for type of engagement

Category	Description
Self-construction	Dialogue by a student which produces useful outputs which serve as a catalyst for discussions, without team member contribution or guidance from a facilitator. Overt activities include: connect or link, reflect and self-monitor, planning, predicting outcomes, and generating hypotheses [20].
Collaborative engagement	Students' dialogue substantively on the same self-constructed idea vocalized to the team. They can accept the ideas presented to the team, little conflict is caused, and dialogue serves to continue the current course of discussion. Or, ideas are questioned or misunderstood, disequilibrium leads to students trying to bring the course of discussion to their understanding. Overt activities include: building on a team member's contribution, argue, defend, confront, or challenge [20].
Facilitated-construction	Dialogue anchored in scaffolding or feedback offered by a facilitator. Discussions by team that continue for a time without direct input from the facilitator, but were anchored in facilitation, are coded as facilitated-construction.

To clarify the coding of self-construction, we define useful outputs as outputs which serve as a catalyst for discussions that assist the team in gaining a better understanding over time. The first italicized line of Figure 1 below serves as an example of an utterance coded as self-construction. To be Self-construction, the utterance must produce some useful output and the idea must appear to originate with the speaker. It is often difficult to tell where an output originated without context; fortunately, the utterance "I had a thought" communicates clearly the idea originated with S1. Considering S2's response in line two it is evident that there is some confusion on the usefulness of differentials, making the discussion inherently valuable.

> *S1: I had a thought. Are we going to have differential temperature within the differential length?*
> S2: I'm not sure…why we need a derivative this way? This [current equation] seems accurate, because…
> S1: If you have a differential length are you concerned with the temperature within that…at that length? Because this temperature is dependent on the length, right? So, I guess it'll be just dT/dl…but then…
> S3: Yeah but then…
> S1: Think about the physical system and what's going to be happening and how the heat transfer is going to change…as the temperature inside the pipe increases to our target… Q out is going to increase because your temperature gradient is getting larger. Right?
> S2: I think it'll go…I think it'll actually go the opposite way, it'll come down because there will be less of a temperature gradient.

Figure 1: Examples of self-construction and collaborative engagement in team dialogue

Analyzing the remaining lines of dialogue in Figure 1, S1 must defend his hypothesis to his teammates who are questioning its validity. The dialogue is laden with engineering world reasoning, leading to substantive exchange of ideas between all three members of the team. Referring to the coding definitions in Table 2, the discussion is coded as collaborative engagement since the talk builds upon a team member's contribution and disequilibrium has led to the exchange of ideas. All underlined turns are then coded as collaborative engagement. In this analysis, collaborative engagement codes persist until the course of the conversation changes either by a new self-constructed hypothesis or facilitator input.

Facilitated-construction utterances are identified by interaction with the facilitator that contain substantive input. The dialogue in Figure 2 shows an example of scaffolding provided by the facilitator in line 1, with subsequent facilitated-construction upon this scaffolding. Talk that is anchored in facilitator input will continue to be coded as facilitated-construction even with little input from the facilitator, provided the team dialogue concerns the scaffolding/feedback offered by the facilitator and the facilitator is still present at the table. In this manner, coding for facilitated-construction include both facilitator utterances and the student responses.

> F: Yeah...so you're thinking about this over an integral length. What's another way to think about it?
> S2: Well if we don't assume that the amount of power going in to the water is constant then...I don't even know how you would do that. I mean I can accept that...the heat lost wouldn't be constant. I can accept that. But like if we don't assume the amount of power going into the heater is constant...
> F: No, no…yep that's all good. But if the heat lost isn't constant then this is changing as you flow.
> S2: Yeah.
> S3: That's [why] we will have...somehow [a] derivative term.
> F: Yeah...so rather than doing it across the whole thing, what's another way to draw this?
> S2: Over a very small length?

Figure 2: Examples of facilitated-construction in team dialogue

Results

The two teams had noticeably different physical positioning as they completed the task. Team 1 had four participants who sat two per side on opposite sides of a table. Three participants had a laptop open and each student had their own scratch paper as a workspace, which each continued to use for the duration of the task. They visually appeared to each be doing individual work in parallel, similar to completing individual homework. Occasional attempts to engage through a shared common object were quickly rebuked. Team 2 consisted of three participants, two on one side of the table and the third on the shorter perpendicular side directly adjacent. This team did not use laptops, but rather used the physical textbook from the course as their primary reference source. Each member began with scratch paper as individual workspaces, but they shifted to working with a shared object workspace about 15 minutes into the task. Unlike Team 1, there was noticeable non-verbal communication as team members appeared to be looking for reactions of the others when they put forth conjectures or responded to them. Team 3 tended to defer to one dominant member, limiting collaborative engagement. Team 4 collaboratively engaged often but tended to "hop" between figured worlds and topics of discussion. Thus, Teams 1 and 2 were selected for the comparative case study. Teams 3 and 4, interesting in their own respects, will be the topics of future analysis.

Discourse Timelines

Figures 3 and 4 show discourse timelines that were constructed for Teams 1 and 2, respectively, using the code categories defined in Tables 1 and 2. These figures graphically depict how the team members engaged one another while making progress on the task, including how the talk was distributed, what type of engagement was identified and the social context of the discourse. The top rows show who was talking with the blue markers representing each of the team member utterances and the green markers the facilitator utterances. Markers in close proximity appear as lines; e.g. for blue markers lines most often represent closely spaced speaking turns between team members and less frequently long individual dialogues. The next three rows denoted by orange markers represent engagement codes including facilitated-construction, collaborative engagement, and self-construction. The bottom four rows indicate the social context of engagement with the red markers representing codes of the three figured worlds (school world, engineering world, and hybrid world) and yellow markers representing math activity/tool use.

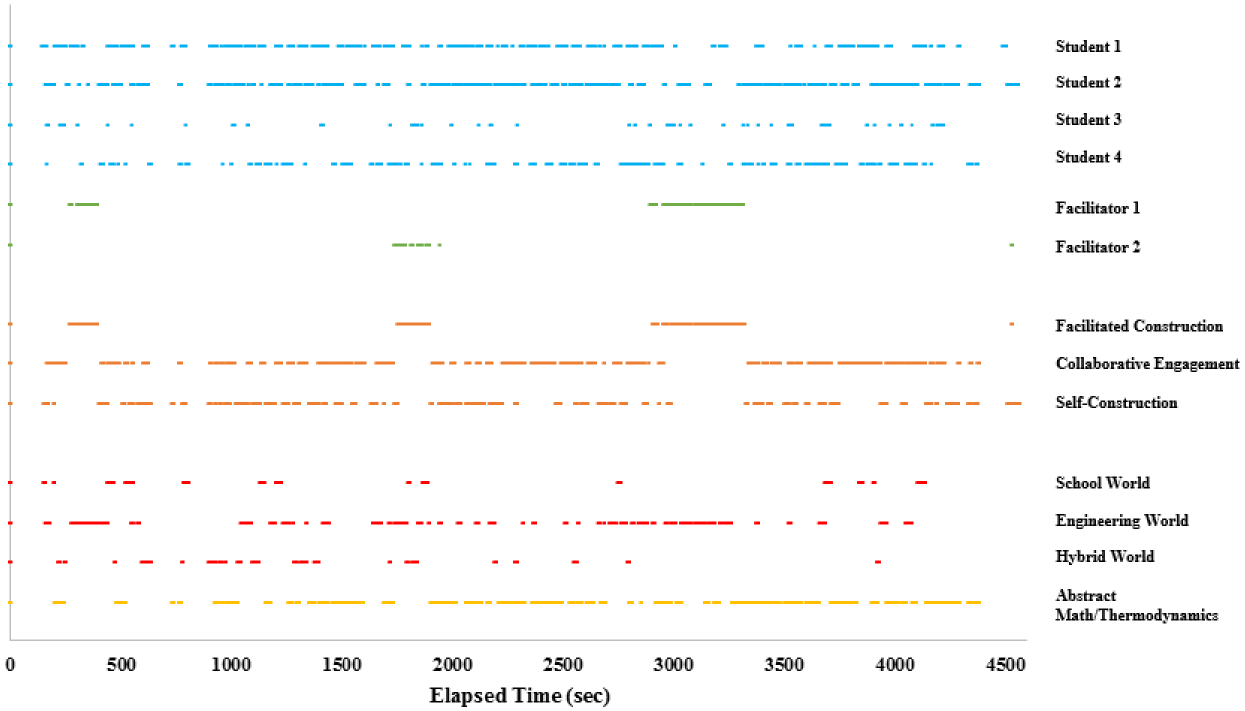

Figure 3: Team 1 discourse timeline with figured world, abstract math, and engagement coding

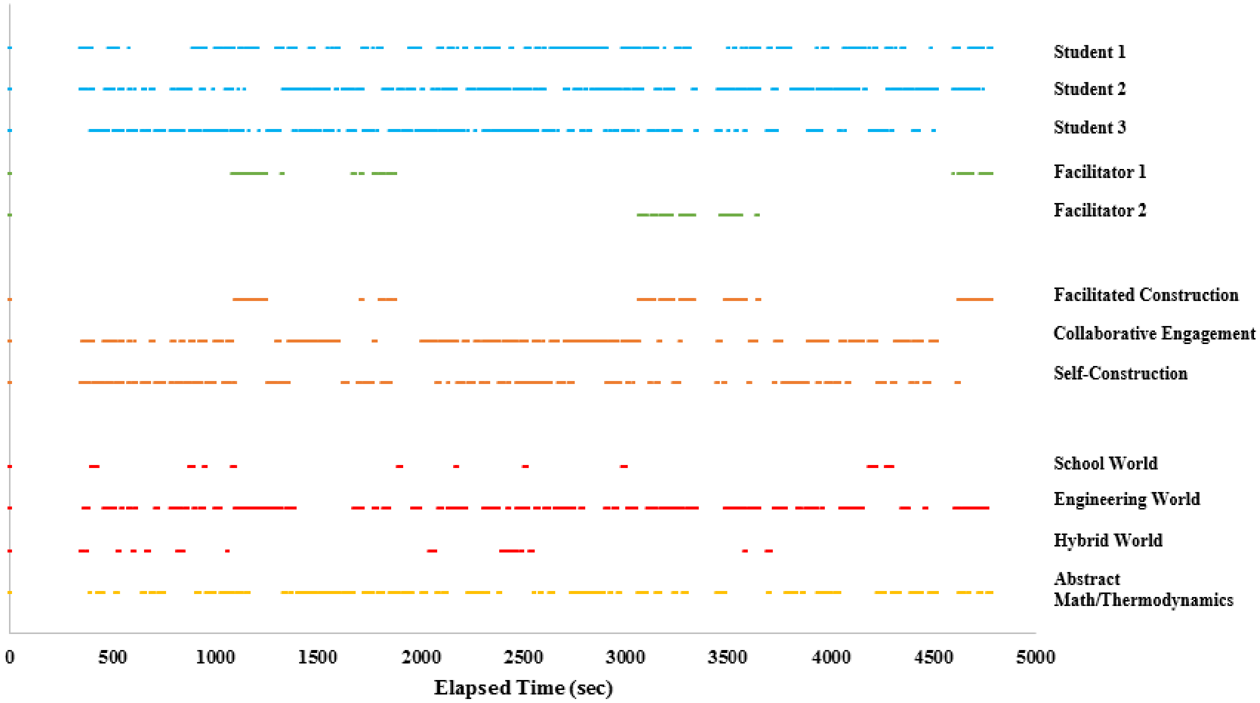

Figure 4: Team 2 discourse timeline with figured world, abstract math, and engagement coding

Tables 3-5 summarize the talk time for each of the student participants and faculty facilitators (Table 3), the time each team spent in the three coded forms of engagement (Table 4) and the time each spent in each of the figured worlds (school world, engineering world, or hybrid world) as well as the time engaged in working on abstract mathematics (Table 5).

Table 3: Quantitative summary of talk time for the two teams analyzed

		Students					**Facilitators**	
		S1	**S2**	**S3**	**S4**		**F1**	**F2**
Team 1	Talk Time (sec)	905	1151	142	606		302	56
	Percent*	29%	36%	4%	16%		10%	2%
Team 2	Talk Time (sec)	854	1115	1142	-		235	172
	Percent*	24%	32%	32%	-		7%	5%

*Calculated as a percentage of cumulative talk time.

Table 4: Quantitative summary of type of engagement codes for the two teams analyzed

		Facilitated-construction	**Collaborative Engagement**	**Self-construction**
Team 1	Talk Time (sec)	556	1424	993
	Percent†	19%	48%	33%
Team 2	Talk Time (sec)	635	1327	1146
	Percent†	20%	43%	37%

†Calculated as a percent of talk time coded with the three types of engagement. Not all utterances coded.

Table 5: Quantitative summary of figured world and abstract math codes for the two teams analyzed

		School World	**Engineering World**	**Hybrid World**	**Abstract Math**
Team 1	Talk Time (sec)	234	847	216	1492
	Percent‡	8%	30%	8%	53%
Team 2	Talk Time (sec)	187	1563	214	1366
	Percent‡	6%	47%	6%	41%

‡Calculated as a percent of talk time coded with the three figured world and math codes. Not all utterances coded.

As shown by the blue markers in Figures 3 and 4 and the percentages in Table 3, it is evident that the interaction patterns in the two teams are different. When compared to Team 1, Team 2 has a relatively even distribution of discourse between team members. While Student 1 in Team 2 talked a little less, he often was visibly working through an idea or calculation on his own which he then shared with the group. Team 2 members' verbal participation changed with time. Student 1, while quieter at the beginning of the task, serves a crucial role in the course of discussion near the middle. Student 3, who begins the task quite talkative providing ideas about how to formulate the problem, participates less to the dialog at the end. We assert this relatively even dialogue distribution, but where contributions shift with time, is consistent with productive disciplinary engagement in the task. Each member brings different strengths, inclinations, and perspectives. As their work unfolds on this complex, open-ended task, it provides opportunity for each to contribute in ways that they can best. In contrast, Team 1's dialogue was largely concentrated among Student 1 and Student 2 who both sat on the same side of the table, accounting for 65% of the total talk time. However, even here we see a shift in participation with Student 1 participating less and Student 4 more at the end of the task.

On the other hand, inspection of the orange markers in Figures 3 and 4 and the summary data in Table 4 shows no obvious differences between the coded types of engagement among Teams 1 and 2. For facilitated-construction, this is a manifestation of facilitator efforts to allocate time evenly between the study teams, with the facilitator talk time accounting for 12% of the total talk time (Table 3), and the team members responding in the remaining 7-8% of the time reported as facilitated-construction in Table 4. Collaborative engagement represents about 45% of the total coded talk time for both teams, indicating that the task appeared to be sufficiently "group worthy" to require input from multiple team members. However, it does not necessarily mean that all group members were involved in discussion as evidenced in the discourse timeline of Team 1. Self-construction represents about 35% of coded engagement in the task, indicating active generation of ideas which served as catalysts for collaboration. Inspection of the self-construction markers in Figures 3 and 4 show that self-construction was well distributed throughout the task. We assert this even distribution of self-construction indicates a sufficiently complex task to require individual outputs throughout, without causing too much frustration.

Table 5 summarizes coded talk time in the three figured worlds: school, engineering, and hybrid, as well as abstract math, which was coded distinctly from the figured worlds. School world represents a relatively small percentage of the codes for both teams. It is suspected that school world reasoning does not require much justification or elaboration, and thus leads to little dialogue. In hybrid world, talk typically focused on information gathering from the task statement or other reference sources, which also required relatively little open discussion. Time spent in engineering world represents a large proportion of the figured world codes for both teams, and the amount is variable. Team 1 spent 30% of their time in engineering world, while Team 2 spent 47%. In contrast, Team 1 spent 53% of their time in abstract math compared to Team 2's 41%.

The studio reform effort hypothesizes that tasks situated in authentic engineering experience result in self-construction and subsequent collaborative engagement in engineering world, and that these interactions promote deeper learning of principles and greater take-up of practices. The distribution of the team engagement codes (Table 4) show that the two teams show similar frequency of self-construction and collaborative engagement, but they showed significantly different time in engineering world (Table 5). To unpack the social context of the collaborative engagement, we next analyzed how much of that talk time occurred in each of the figured worlds and abstract math. As Table 6 shows, while both teams spent a similar proportion of their time collaboratively engaging one another, the social context of this engagement was different with Team 1 spending only 190 seconds in engineering world while Team 2 spent 562 seconds. Collaborative engagement in engineering world almost always represents desired talk where team members are arguing, defending, explaining, and elaborating using reasoning based in engineering norms and practices.

Table 6: Figured world coding filtered for collaborative engagement utterances

Collaborative Engagement Talk Time (sec)					
	School World	Engineering World	Hybrid World	Abstract Math	No Code
Team 1	159	190	76	878	121
Team 2	106	562	109	519	31

To help explain the large differences in the social context in which two teams collaboratively engaged in the task, discourse timelines were analyzed for patterns in the transitions between social contexts. Figures 3 and 4 show that team dialogue oscillates between figured worlds over time as they attempt to make meaning of the task. Each member brings their current understanding, perspectives, and beliefs to the discussion as they work towards a shared understanding. To better understand this dynamic, we investigated transcriptions of the moment of shift between worlds, as described next.

Collaborative Engagement: Shifts between Figured Worlds

We hypothesize that shifts from engineering world to school world draw upon problem solving techniques that are less transferable to engineering practice. Moreover, the moment of shift from engineering world to school world and vice versa is often apparent in transcriptions, making this shift useful for analysis. To understand how different transitions draw upon different skills, we first analyzed instances where the team does not change figured world when engaging a self-constructed utterance. Figure 5 shows a case for Team 2 where S3 responds to S1's self-construction which serves to encourage more discussion on the engineering world social context at hand.

> S1: I was just thinking what our mathematical model looks like and what the physical system is going to behave like graphically…and if this [graph] is going to represent our conceptions.
> S3: So yeah...we agree that the graph should be something like that [graph]? This is indeed dT/dl?
> S1: I don't know if it…Is it going to be linear? Or is it going to be…I don't… like the heat loss is it…
> S2: It's not going to be linear, this [Fourier] is not a linear function.

Figure 5: Example of a non-shift in figured world from self-construction to collaborative engagement

The ability to connect physical systems with their mathematical models, and if those models when plotted fit expectations for how the physical system will behave is an important engineering practice. Through the input of all three team members, the dialogue in Figure 5 shows a solid reasoning progression in engineering world. In contrast, Figure 6 shows a case for Team 1 where S3 and S1 respond to S2's self-construction in a manner which serves to shift the social context from engineering world reasoning to school world "what is expected" reasoning.

> S2: So I guess what I'm saying is, is it gonna be at 95 degrees C for like half of this chamber or like right when it gets to this point before it hits the anneal space?
> S3: Do we need to know that?
> S1: I think that that might be overcomplicating the situation. This is...this is a class where [indiscernible] ok it goes into the heater and is at that [target] temperature now.
> S4: I think we could probably like assume that it's completely mixed and the temperature is uniform in the heating area…because that's what we assumed in Mass Transfer [class] usually.

Figure 6: Shift from self-construction in engineering world to collaborative engagement in school world

Student 1's response to the engineering world sizing question involves reasoning that no longer fits into engineering world. The modifier "this is a class where" is typical of school world dialogue where students seek to identify where the task fits within a curricular context. Here, S1 and S4 use their experiences in the Energy Balances and Mass Transfer courses to identify a problem-solving technique that worked in those classes (rather than for the physical engineering system). This response uses the heuristic of where content is placed in the curriculum to identify an assumption and move forward to abstract math. However, this type of school world reasoning is unlikely to be useful in professional practice where work is not positioned. Shifts antithetical from school world to engineering world were also observed, such as the dialog of Team 2 in Figure 7.

> S2: This is where we would use log mean temperature in Heat Transfer [class].
> S3: I guess if you are going to use it with Heat Transfer [class] it may be easier...but I'm not sure.
> S1: Well...if we just...if we're breaking it into chunks all we're doing is heating it right? So, we're gonna have our heating element...which is gonna be our Q right? And then we just have Q = mCpΔT…
> S3: mdot so "m" is the mass flow rate...so it is a function of flow rate.

Figure 7: Shift from self-construction in school world to collaborative engagement in engineering world

We assert that while school world utterances account for a relatively small amount of talk time for both teams, each utterance can significantly alter the course of progress on the task for a team that is not collaborating openly among all members (Team 1, Table 3) and not collaborating often in Engineering World (Team 1, Table 6). This open collaborative engagement in engineering world offers opportunities to “simplify” while still using transferrable practices. S1’s response achieves steering the course of discussion away from Heat Transfer and log mean temperature back to the scope of the Energy Balances course using reasoning based in the process.

Projection and Translation

From Table 5 it is evident that both groups spend a significant amount of talk time in abstract math. We next explore the social context in which a team is engaged just prior to and just after mathematical activity (“bookending”). To determine what social context each team framed their mathematical activity, we analyzed the data for changes from figured world to abstract math and from abstract math to figured world, as shown in Figure 8. The data used is talk time coded as both collaborative engagement and abstract math. This talk occurs when students are collaborating with one another using mathematical tools. The categories in Figure 8 represent the context in which each team was interacting just prior to, and just after such collaboration. The data show the degree that each team contextualized abstract math (AM) by using engineering world (EW), school world (SW), or hybrid world (HW). For example, EW-AM-EW (engineering world to abstract math to engineering world) represents the case where the team both accesses their mathematical work and interprets the results in terms of engineering world. We see a 24% difference in abstract math talk time between the two teams for this case.

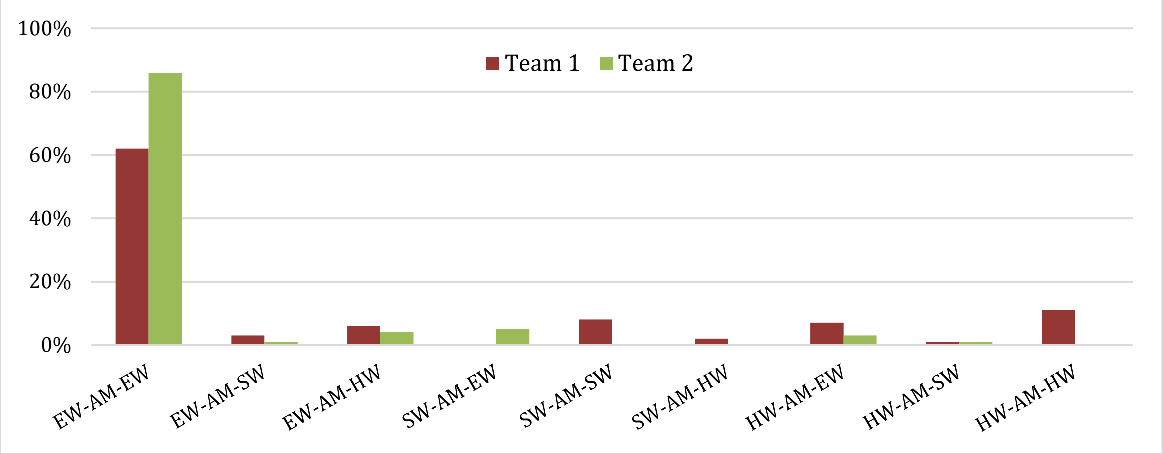

Figure 8: Bookending of collaborative engagement in abstract math with the three figured world codes

Discussion

The studio reform effort set out to design and implement group worthy, open-ended tasks situated in a realistic engineering experience. The hypothesis is that students who work with teams that exhibit self-construction and subsequent collaborative engagement in engineering world achieve deeper learning of principles and greater take-up of practices. This study analyzed a microfluidic energy balance task in a clinical setting to compare the socio-technical processes utilized by two teams as they made progress on the task, and how these processes changed with time. Our goals in this analysis were to learn how to encourage collaborative engagement in engineering world, better understand movement between figured worlds, and where abstract math fits within the process from problem to answer.

Reflecting on Tables 3-5 it becomes apparent that focusing entirely on type of engagement or social context of engagement is insufficient to explain the disparity in talk time between Team 1 and Team 2. Holding that complex “group worthy” tasks produce conflict that leads to disequilibrium, and that engineering world context calls upon transferable to practice skills, productive disciplinary engagement in studio tasks should manifest itself in collaborative engagement in engineering world. Such engagement almost always represented desired talk where team members were arguing, defending, explaining, and elaborating using reasoning based in engineering norms and practices. Our data indicate that when compared to Team 1, Team 2 accessed their mathematical work and interpreted the results in terms of engineering world more often (Figure 8) and collaboratively engaged in engineering world as they reasoned through the physical system and process more often (Table 6). We assert that the well distributed dialogue of Team 2 (Table 3) with individual contributions that change with time as students offer their strengths and perspectives (Figure 4) is characteristic of teams that are collaboratively engaging in engineering world. Thus, instructors need to get students talking in ways that use disciplinary ideas and are grounded in the systems and processes they are working on to promote symmetric and dynamic team discourse. But what of the significant portion of time both teams spend in abstract math?

Expertise with mathematical modeling is an essential skill for a practicing engineer. Modeling of processes clearly requires skill with mathematical manipulation, and both teams spend a significant amount of time in abstract math (Table 5). However, modeling is more than just being able to solve equations, it also involves ways the mathematics connects to the engineering work at hand. Looking only at transcript excerpts coded with “abstract math,” it is difficult to identify the purpose that the students bring when they are engaged in mathematics itself; it could be to solve a real problem or get a correct answer for the points.

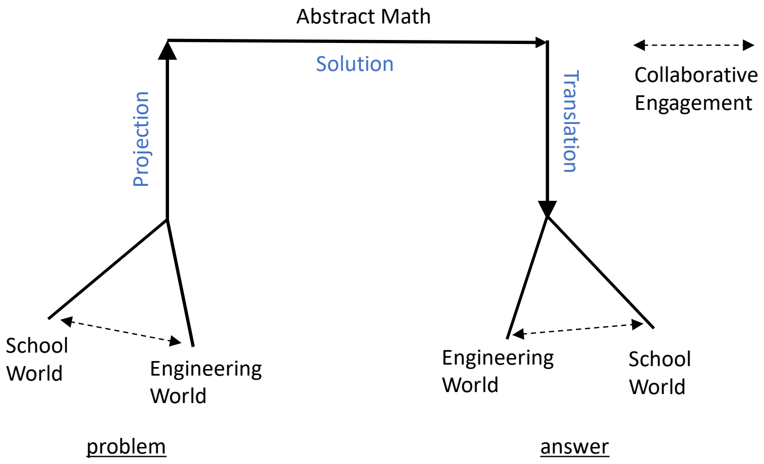

Figure 9: Paths from figured worlds to abstract math

Figure 9 represent the different possible paths we identified from the two teams (see Figure 8). In the task, teams collaboratively engage in a figured world and project this social context onto their mathematical activity. Once in abstract math, the team utilizes the mathematical tools at their disposal to arrive at a solution using dialog that rarely provides an indicator of which figured world they are in. They then attempt to translate the abstract solution back to a figured world. Both the projection of the problem and the translation of the answer can be framed in terms of engineering world (e.g. expected physical behavior of the system), or school world (e.g. expected solution in the course).

Our data show the projections and translations between figured worlds in Figure 9 are not equivalent. When a team member catalyzes a discussion with self-constructed output, team members appear to react to the discussion utilizing reasoning heuristics based in their figured world (Figures 5-7). However, the characteristics of the reasoning process widely differ. In engineering world, students frame their arguments in terms of physical and chemical processes of the systems or processes at hand. In school world, they tend to be based on what is expected from the instructor or appropriate for the class. The reasoning in engineering world directly connects to the ways of reasoning that will be useful in professional practice; the reasoning in school world much less so.

The student teams we observed both oscillated between figure worlds as they negotiated a path forward (Figures 3 and 4). Since shifts from engineering world to school world draw upon reasoning processes that are less transferrable to engineering practice, to the extent possible, students should be encouraged to collaboratively engage with one another to frame mathematical projections and translations in engineering world. Understanding the aspects of activities and instructional practices that influence the way student teams talk and reason is an important area for further research. Importantly, when working on complex group-worthy tasks, reasoning processes are not static but dynamically fluctuate as new ideas and information become salient. Moreover, for the very reason that school world thinking is undesirable – that it is more superficial and shorter lasting – makes it harder for a facilitator to catch in the moment. Therefore, ways to make students thinking visible and practices where facilitators ask students to justify the choices they have already made are important to this type of instruction to better prepare students for practice.

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References

[1] National Academy of Engineering, *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington, DC: National Academies Press, 2005.

[2] M. D. Koretsky, D. Montfort, S. Nolen, M. Bothwell, S. Davis, and J. Sweeney, “Towards a stronger covalent bond: pedagogical change for inclusivity and equity,” *Chemical Engineering Education*, vol. 52, no. 2, 2018.

[3] M. D. Koretsky, “Program Level Curriculum Reform at Scale: Using Studios to Flip the Classroom,” *Chemical Engineering Education*, vol. 49, no. 1, pp. 47-57, 2015.

[4] R. A. Lotan, “Group-worthy tasks,” *Educational Leadership*, vol. 60, no. 6, pp. 72-75, 2013.

[5] B. Barron, and L. Darling-Hammond, “Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning,” *Powerful Learning: What We Know about Teaching for Understanding.* pp. 11-70, 2008.

[6] L. Deslauriers, E. Schelew, and C. Wieman, “Improved learning in a large-enrollment physics class,” *Science*, vol. 332, no. 6031, pp. 862-864, 2011.

[7] D. R. Woods, *Problem-based Learning: How to Gain the Most from PBL.* Waterdown, Ontario: Donald R. Woods, 1994.

[8] D. R. Woods, A.N. Hrymak, R.R. Marshall, P.E. Wood, C.M. Crowe, T.W. Hoffman, J.D. Wright, P.A. Taylor, K.A. Woodhouse, and C.G.K Brouchard, “Developing problem solving skills: The McMaster problem solving program,” *Journal of Engineering Education*, vol. 86, no. 2, pp. 75-91, 1997.

[9] R. Lesh, M. Hoover, B. Hole, A. Kelly, and T. Post, “Principles for developing thought revealing activities for students and teachers,” *Handbook of Research Design in Mathematics and Science Education*, A. Kelly and R. Lesh, Mahwah, NJ: Lawrence Erlbaum, 2000, pp. 591-645

[10] R. A. Engle and F. R. Conant, "Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom," *Cognition and Instruction*, vol. 20, pp. 399-483, 2002.

[11] R. A. Engle, “The productive disciplinary engagement framework: Origins, key concepts, and continuing developments," *Design Research on Learning and Thinking in Educational Settings: Enhancing Intellectual Growth and Functioning*, London: Taylor & Francis, 2012.

[12] K. A. Smith, S. D. Sheppard, D. W. Johnson, & R. T. Johnson, “Pedagogies of engagement: Classroom-based practices,” *Journal of Engineering Education*, vol. 94, no. 1, pp. 87-101, 2005.

[13] M. Gresalfi and S. Barab, “Learning for a reason: Supporting forms of engagement by designing tasks and orchestrating environments,” *Theory into Practice*, vol. 50, no. 4, pp. 300-310.

[14] D. Holland, W. Lachiocotte, D. Skinner, and C. Cain, *Identity and Agency in Cultural Worlds*, Cambridge, MA: Harvard University Press, 1998.

[15] M. D. Koretsky, D. M. Gilbuena, S. B. Nolen, G. Tierney, and S. E. Volet, “Productively engaging student teams in engineering: The interplay between doing and thinking,” in *Proc. Front. Educ. Annu. Conf., Madrid, Spain, 2014*, pp. 1–8.

[16] R. A. Lesh and H. M. Doerr, *Beyond Constructivism: Models and Modeling Perspectives on Mathematics Problem Solving, Learning, and Teaching*, Mahwah, NJ: Lawrence Erlbaum, 2003.

[17] J. M. Prausnitz, R. N. Lichtenthaler, and E. G. de Azevedo, *Molecular Thermodynamics of Fluid-phase Equilibria*, London, England: Pearson Education, 1998.

[18] J. V. Wertsch, “The primacy of mediated action in sociocultural studies,” *Mind, Culture, and Activity*, vol. 1, no. 4, pp. 202-208, 1994.

[19] W. C. Newstetter, “Of green monkeys and failed affordances: A case study of a mechanical engineering design course,” *Research in Engineering Design*, vol. 10, no. 2, pp. 118-128, 1998.

[20] M. Chi, “Active-Constructive-Interactive: A Conceptual Framework for Differentiating Learning Activities,” *Topics in Cognitive Science 1*, pp. 73-105, 2009.

[21] M. Windschitl and A. Calabrese Barton, “Rigor and equity by design: Locating a set of core teaching practices for the science education community,” *Handbook of Research on Teaching*, N.L. Gage, Ed. Chicago: Rand McNally, pp. 1099-1158, 2016.

[22] A. Lumpe and J. Staver, “Peer collaboration and concept development: Learning about photosynthesis,” *Journal of Research in Science Teaching*, vol. 32, no. 1, pp. 71-98, 1995

[23] P. Heller and M. Hollabaugh, “Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups,” *American Journal of Physics*, vol. 60, pp. 637, 1992.