How do students experience the problem-solving studio?

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Abstract— **Student-centered learning environments, including flipped classrooms, are becoming increasingly common in engineering education. Numerous advantages have been ascribed to these approaches, including that they increase student engagement and achievement. Unfortunately, not all students respond favorably to student-centered courses. To understand why, we are studying how students perceive their experiences in the Problem-Solving Studio (PSS). PSS is a cognitive apprenticeship learning environment that heavily emphasizes student-student interactions. In this work-in-progress paper, we describe the results of the first phase of a two-phase mixed-methods study that seeks to answer the question "How do students perceive the various features of PSS, and how do these perceptions affect their motivation and approach to learning?" The purpose of this phase of the study was to identify participants whose perceptions of PSS varied widely. We prompted students in an entry-level biomedical engineering course that used the PSS approach to reflect on their motivation for the course and their approach to learning. We coded the students' responses, quantized them, and used cluster analysis to identify groups of students with similar response profiles. We identified four groups of students whose perceptions of their experience in PSS differed with respect to their motivation and approaches to learning, but whose demographics (with respect to age, gender, grades, and minority-status) were similar. We used these results as a guide to determine who to invite to participate in the second phase of our study. We successfully recruited thirteen participants with proportional representation from each group, which supports our phase two goal of interviewing students with a wide range of perceptions and experiences in PSS. Phase two of the study is currently in progress.**

Keywords—approaches to learning, motivation, flipped classrooms, Problem-Solving Studio, mixed-methods

I. Introduction

Students often struggle in analytical engineering courses [1, 2]. Some struggle because they come to these courses with a well-practiced algorithmic problem-solving approach [3]. They search for previously solved problems with similar surface features and insert numbers into the equations that were used to solve these similar problems [4]. This "plug-and-chug approach" often fails because most engineering problems, even in entry-level courses, involve multiple processes or events that require the problem-solver to employ more than one deep conceptual principle at a time. For students to move beyond the plug-and-chug approach, they may need to adopt a more effective approach to learning. Marton and Saljo found, through a series of studies that began in the 1970s, that students adopt one of three approaches to learning: deep, strategic or surface [5]. Students who take a deep approach, when challenged with a task, work to relate ideas, look for unifying principles, use evidence, examine the logic of arguments, and actively monitor how well they understand things [6-8]. Students who adopt a strategic approach are interested in learning the content of the course, but their primary focus is on monitoring and responding to how their work will be graded [6, 9, 10]. Students who adopt a surface approach tend to see the course topics as bits of unrelated information that need to be memorized [11].

Deep approaches generally lead to better learning outcomes [12, 13]. Several studies have shown that the learning approaches students take are context-dependent and can be influenced by specific features of the learning environment [5, 14-16]. Learning environments that are teacher-centered, involve large lecture halls, and assess students using a single final exam tend to promote the surface approach [17, 18]. Courses that are student-oriented, supportive, employ cooperative learning, ask students to assume responsibility for their own learning, and model metacognitive approaches to studying and learning tend to promote the deep approach [17, 18]. One increasingly common approach to promote deep learning approaches is to flip the classroom. To flip a classroom means to post lectures online for students to watch outside of class, which frees up class time for a range of student-centered, active-learning strategies such as problem-solving, conducting research, or working on projects with classmates. In addition, instructors can use the class time to provide feedback and support that is targeted to the needs of individual students [19]. Unfortunately, students in these kinds of courses do not always adopt a deep approach to learning [14]. There is a need to understand why this is the case.

One reason may be that students perceive learning environments in significantly different ways [20]. Several theories have been developed to explain how the external environment interacts with students' cognition and affect [21, 22]. The MUSIC Model of Academic Motivation, which integrates several theories of motivation, provides a useful framework for assessing and understanding students' perceptions of their learning environment [23, 24]. The MUSIC model identifies five types of motivation. These refer to the degree to which a student perceives they control the learning environment (empowerment), the coursework is useful to their future (usefulness), they can succeed at the coursework (success), the instructional methods and coursework are interesting (interest), and the instructor cares about whether they

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can succeed and about their well-being (caring).

The purpose of this project is to explore the idea that students taking the same course can vary widely in how they perceive its learning environment, leading to a range of student motivations and approaches to learning. To accomplish this, we chose to study a specific kind of student-centered learning environment: the problem-solving studio (PSS). PSS is a student-centered cognitive apprenticeship environment that heavily emphasizes student-student interactions [25]. Students learn best when they interact because they prompt each other to engage with the coursework, provide feedback to each other, and leverage each other's different understandings and perspectives [26]. Our research question is: "How do students perceive the various features of PSS, and how do these perceptions affect their motivation and approach to learning?"

II. Methodology

Participants for our study were recruited from an entry-level biomedical engineering course, taught in our department using the PSS approach, called "Conservation Principles in Biomedical Engineering". The intent of the course is to introduce students to a systematic approach to solving problems that includes breaking a system into its components, establishing the relationships between known and unknown system variables, assembling the information needed to solve for the unknowns, and then obtaining the solution. The primary textbook for the course is "Bioengineering Fundamentals" by Saterbak, McIntire, and San (SMS) [27]. Forty-five students were enrolled in the course.

To answer our research question, we conducted a mixed-methods sequential explanatory design in two phases [28]. The first, quantitative, phase identified participants whose perceptions of PSS varied widely. Thirty-six students completed this phase of the study. We do not know why nine students chose not to complete this phase of the voluntary study. The second, qualitative, phase used a phenomenological interview approach to capture the full range of students' complex experiences in PSS [33]. Thirteen students completed this phase of the study. In our analysis of the data, we will heavily prioritize the second phase data. The purpose of this work-in-progress paper, however, is to report the results of phase one.

III. Results

To answer our research question "How do students perceive the various features of PSS, and how do these perceptions affect their motivation and approach to learning?", we conducted a two-phase mixed-methods study. The first, quantitative phase, identified participants for the second, qualitative phase of the study. The second phase used a phenomenological interview approach to capture the wide range of ways students experience PSS. Here we describe the results of phase one whose purpose is to identify participants with a maximum variation in their experiences.

To gain insight into the extent to which students' experiences varied, four times during the 16-week semester, during weeks 5, 9, 13 and 15, students were given a few minutes at the end of class to answer a set of open-ended questions. The questions prompted students to reflect on the course, their level and types of motivation for the course work, and on their approaches to learning. The questions were based on items in two instruments: the Approaches and Study Skill Inventory for Students (ASSIST) [29], which is used to identify deep, strategic, and surface approaches to learning, and the MUSIC Model of Academic Motivation [23].

We coded the students' responses for statements that indicated their approach to learning and their perceptions of their types and levels of motivation. We identified a subset of the codes that varied the most among the students' responses. These were the codes *Deep Early* and *Deep Late*, which identified responses that indicated whether or not students had adopted a deep approach to learning early or late in the semester, and the code *Useful*, *Success*, and *Interest*, which identified responses that provided evidence for a student's level of usefulness, success, or interest motivation with respect to the course.

Next, we created a profile for each student that consisted of a numerical score for each of these five codes. A score of -1 indicated there was evidence the student did not take a deep approach to learning or had a negative form of that type of motivation. A score of 0 indicated there was no evidence or the evidence was mixed, and a +1 indicated there was evidence the student had taken a deep approach to learning or had a positive form of that type of motivation. Finally, we assigned three more codes to indicate which motivation was most prevalent in each student's responses: The code for the most prevalent motivation was assigned a value of +1, and the codes for the less prevalent forms were assigned a value of -1.

To help us identify groups of students with similar profiles, we used k-means clustering analysis. We chose to represent the data in four clusters, after analyzing a range of cluster numbers, because the four-cluster model minimized the within-group sum of squares while keeping the number of groups relatively small [30]. Five students were assigned to cluster I, ten to cluster II, thirteen to cluster III, and eight to cluster IV. The demographics of each cluster, and the entire study group, is shown in Table I. We used the Freeman-Halton extension of the Fisher test for gender and under-represented minority status, and one-way analysis of variance for the other demographic variables to determine if there were any significant differences among the clusters [31]. No significant differences were found.

The primary difference among the clusters was the frequency with which students exhibited one type of motivation versus another (see Table II). The dominant motivation types were interest motivation for students in clusters I and IV, usefulness motivation for students in cluster II, and success motivation for students in cluster III. We used the Kruskal–Wallis test by ranks to determine if there were any other

TABLE I. PHASE ONE PARTICIPANT DEMOGRAPHICS

Cluster	Gender (M | F)		URM? (N | Y)		Age (years) (mean | s.d.)	Grade (GPA) (mean | s.d.)
I	4	1	5	0	20.2 ± 1.3	2.6 ± 0.9
II	3	7	8	2	21.2 ± 3.6	2.9 ± 0.9
III	3	10	11	2	20.7 ± 1.4	3.5 ± 0.7
IV	2	6	7	1	20.0 ± 1.2	2.9 ± 0.6
ALL	12	24	31	5	20.6 ± 2.2	3.1 ± 0.8

TABLE II. **FREQUENCY OF PROFILE CODES***

Cluster	*N*	Deep early (DE)			Deep late (DL)			Usefulness (U)			Success (S)			Interest (I)			Most prevalent
I	5	5	0	0	4	0	1	1	0	4	0	2	3	0	0	5	Interest
II	10	5	1	4	1	1	8	0	0	10	0	3	7	0	0	10	Usefulness
III	13	13	0	0	11	1	1	2	3	8	4	4	5	2	1	10	Success
IV	8	0	1	7	0	1	7	0	1	7	1	1	6	0	0	8	Interest
ALL	36	22	2	11	16	3	17	3	4	29	5	10	21	2	1	33	

*Each code has 3 columns. From left to right, these values indicate the number of students with a profile code score of -1, 0 or +1 in that cluster.

significant differences among the clusters [32]. No significant differences were found among the clusters in students' usefulness, success, or interest motivations. Students in clusters II and IV, however, were more likely to adopt a deep approach than students in clusters I and III (see Figure 1). Interestingly, there was a significant shift towards deep approaches to learning in cluster II students over the course of the semester. Four of the five students in cluster II who started the semester not taking a deep approach, shifted to a deep approach by the end of the semester, although this shift was not statistically significant ($p = 0.1031$; via a Mann–Whitney U test) [33].

Taken together, our results suggest that student perceptions and experiences in PSS varied with respect to their motivation and their approaches to learning. We used these results to purposefully sample for maximum variation for phase two of our study. We successfully recruited thirteen participants with representation from each cluster in numbers roughly proportional to the size of the clusters. The demographics of these phase two participants are summarized in Table III. Phase two of the study is currently in progress.

IV. Discussion

We are interested in understanding how students perceive the highly interactive, student-centered problem-solving studio (PSS) learning environment. For our overall project, we are using a phenomenological approach to interview students who have taken PSS, because phenomenological approaches are well-suited for capturing participant experiences and the meanings they make of them [34]. An important decision to make when using such an approach is who to recruit for the study. That is, what purposive sampling strategy should be used? We wanted to document a wide range of ways students experience PSS, which called for a maximum variation sampling strategy [35].

The challenge was that we did not know, *a priori*, the extent to which students' experiences varied in PSS. To address this challenge, we examined, in the first phase of our study, the range of student experiences in PSS with respect to their motivation and approaches to learning. We used the results from this phase to guide our procedure for recruiting students to participate in the second, phenomenological interview, phase of the project. We asked students taking an entry-level biomedical engineering class, taught using the PSS approach, a series of questions throughout the semester that prompted them to think about the course, in what ways it motivated them (or not), and how they approached learning for the course. We analyzed the students' responses and identified four groups of students who experienced PSS in markedly different ways [23, 29].

The primary difference among the groups was the type of motivation that seemed to dominate the students' discourse: some students seemed primarily motivated by how useful the course was to their future; others were primarily motivated by their interest in the material or in the PSS environment itself; while still others were concerned with whether or not they felt they could succeed in the course. Another significant difference among the groups were their approaches to learning. Groups II and IV primarily adopted a deep approach to learning, whereas

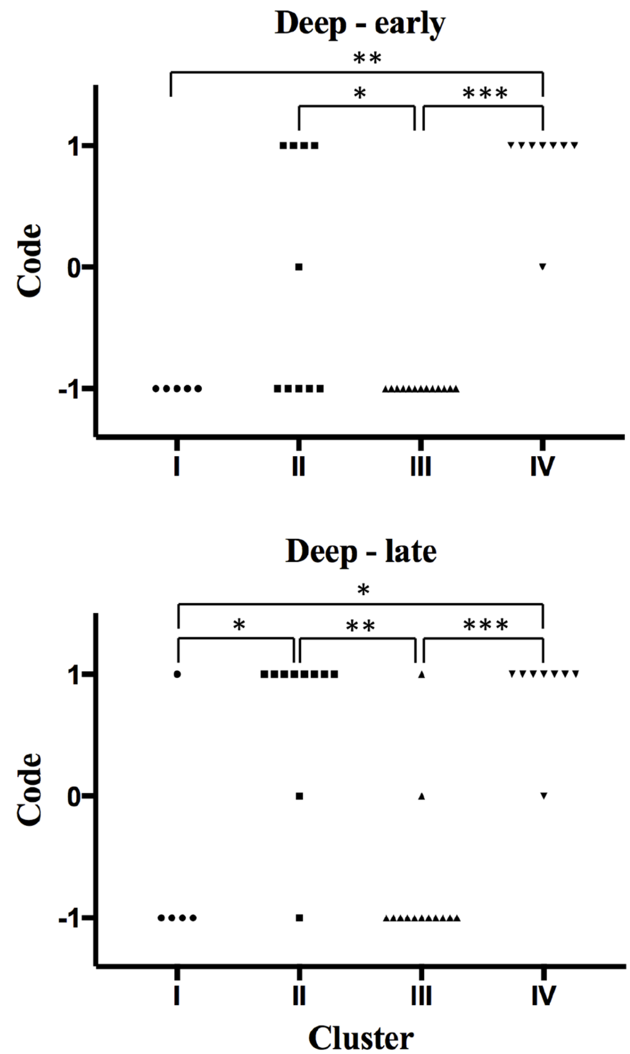

FIGURE 1: The four participant groups, identified by cluster analysis, differ in their approach to learning. Scatter plots of deep-early (top plot) and deep-late (bottom plot) code values (-1,0, +1) for each cluster. Statistically significant groups (Kruskal-Wallis test) are indicated with asterisks (*, **, *** indicates $p < 0.05$, < 0.01, and < 0.001, respectively).

TABLE III: PHASE TWO PARTICIPANT DEMOGRAPHICS

Age	***Years***
range	18-31
mean	21.3
s.d.	3.2
Grades (GPA)	***GPA***
mean	2.92
s.d.	0.86
Grades (Letter)	***N***
A (4)	4
B (3)	4
C (2)	5
Gender	
female	10
male	3
Identifies as an URM	
Yes	1
No	12
Cluster	
I	2
II	4
III	4
IV	3

groups I and III did not. Not all group II students began the course using a deep approach to learning, but most shifted to a deep approach by the end of the semester. Group IV students used a deep approach throughout the entire semester. Taken together, our phase one data confirmed that students experience PSS in significantly different ways. We used these data to recruit thirteen students, from two to four from each cluster, for phase two of our study, which we expect will provide us with a much more in-depth understanding of how students perceive and experience PSS.

We found two aspects of the phase one data particularly intriguing and worth commenting on. We recognize that the phase one data is not sufficiently rich to support any substantive conclusions, but they do raise interesting questions to consider in future work. First, we found it interesting that four of the five students in Cluster II who started the semester not taking a deep approach to learning, shifted to a deep approach by the end of the semester. Is this shift significant? If so, what prompted this shift? For these students, the perceived usefulness of the course seemed most important to them. Did their perception of the usefulness of the course prompt them to adopt a deeper approach to learning? What features of PSS, if any, enhanced their perception of the usefulness of what they were learning, or otherwise motivated them to adopt a deeper approach to learning? We are interviewing four students from this cluster in phase two of our study, one of which never adopted a deep approach, another who shifted to a deep approach, and two who took a deep approach throughout the semester. It will be interesting to see if these phase two data help us to better understand the role the PSS learning environment played, if any, in affecting their approaches to learning.

Second, we were intrigued by the Cluster III phase one data. These students were primarily concerned with whether or not PSS set them up for success with the coursework. Five felt it did, four felt it did not, and four were uncertain. Despite their focus on success, only one of the thirteen students adopted a deep approach to learning. Nevertheless, this group achieved more success, as measured by final course grades, than the other three groups, although these differences were not statistically significant (see Table II). Why did some students feel PSS prepared them for success while others do not? Why did students who were most concerned with success not adopt a deep approach to learning? We are interviewing four students from this cluster in phase two of our study, two who felt PSS did not adequately set them up for success in the course, one who felt PSS did set them up for success, and one who had mixed feelings. Perhaps most interesting, the two students who felt PSS did not support their success earned A's in the course, while the other two students earned B's. We are very interested to see what we learn, from our phase two interviews, about these students' perceptions of PSS.

V. CONCLUSIONS AND FUTURE WORK

Student-centered approaches, including flipped classrooms, are increasingly being used in engineering courses [36, 37]. Numerous advantages have been ascribed to these approaches, including that they increase student engagement and achievement [38, 39]. A concern is that some students may not perceive these approaches favorably, which could adversely impact their learning. This paper described an approach to examine the extent to which students' motivation and approaches to learning varied within a single learning environment called the problem-solving studio (PSS). We used these data to identify students, whose perceptions of PSS varied widely, to interview in the next phase of our study. Each student will be interviewed three times each, using a phenomenologically-based approach that will significantly improve our understanding of how they perceive and experience PSS [34]. Further studies like these are needed in engineering education, given the recent proliferation of new kinds of student-centered approaches to teaching. We see our work as a pilot for one approach for studying students' perceptions of these approaches and how their perceptions affect their motivation, engagement and learning.

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