Student Experience in a Student-Centered Peer Instruction Classroom

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ABSTRACT
Although studies have shown Peer Instruction (PI) in computing courses to be beneficial for learning and retention, study of the student experience has been limited to attitudinal survey results. This study provides a preliminary evaluation of student experiences in a PI course – specifically asking them to reflect on their role as a student in a PI lecture compared to a standard university lecture. Student responses to this question are first analyzed using Chi's Interactive-Constructive-Active-Passive framework which categorizes student activities by their value in a constructivist learning framework. This analysis finds that the majority of students reported activity in a PI lecture as "interactive" in contrast with "active" (e.g. taking notes) in a standard lecture. Additionally, a grounded theory open-coding analysis provides an initial examination of student perceptions of the PI lecture experience. Although students positively value learning-related aspects (feedback and increased understanding) a surprising breadth of value was noted around issues of affect and increased sense of community. In particular, these experiences invite discussion about PI and issues of STEM retention in post-secondary education.

Categories and Subject Descriptors
K.3.2 [**Computer Science Education**]

General Terms
Human Factors.

Keywords
Peer Instruction, Flipped Classroom, Student-Centered Learning, Affect.

1. INTRODUCTION
There are numerous reports showing Peer Instruction, as one form of a student-centered learning environment, to be successful. This has been measured at the course level through pre-post concept inventory tests [7, 12] and final exam performance [22]. Even more directly, learning from the attempt to solve a "clicker" question, peer discussion, and instructor explanation and feedback has been measured in-class through the use of isomorphic questions in the classroom [17,23].

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Recent results showing a dramatic 61% average reduction in course fail rate [16] across 16 PI instances of 4 different computing courses taught by 7 instructors leads one to wonder: is there some other effect impacting student persistence? Or is it just the difference in the 3 hours a week spent learning in the PI classroom? Certainly, students in PI courses benefit from having a clear idea of what an instructor wants them to know, and whether or not they know it (assuming clicker questions reflect knowledge and skills measured in course assessments). But, as instructors in similar courses, we have noted something else – a different student attitude towards the course and towards learning.

Existing literature has reported Likert-scale attitudinal surveys showing students both enjoy and value PI classrooms [18,21]. But why? Is it because they are getting better grades? Because they don't fall asleep?

In this study, we provide preliminary documentation of both student experience and student valuation of their experience in a successful PI class [22]. We asked students to self-report their experience in the PI classroom through a post-term open-ended question asking them to describe what they did (in lecture) in this class and compare it to their experiences in other classes. Their answers indicate a deep, thoughtful, and affective experience with our PI learning environment. We believe the character of these responses will help us better understand what contributes to the overall "success" of PI – spanning both cognitive and socio-psychological effects. Moreover, these results may have bearing on other student-centric techniques (i.e., POGIL, PLTL, PBL).

First we use the Interactive-Constructive-Active-Passive (ICAP) framework proposed by Chi for rigorously delineating student activity in learning environments [5]. This framework differentiates overt, observable classroom activities based on their engagement of students in the learning process. Most valuable for student learning are interactive and constructive activities. Less engaged "active" behaviors include taking notes and listening to lecture, compared to "passively" daydreaming or browsing the web. Coding our data, we find students describe activities in the PI course as constructive and interactive, and behavior in other courses as passive and active. These results help document why we expect improved student learning: students, not surprisingly, report engaging in activities associated with better learning.

Additionally, in these rich responses, students shared their views on their experience in the classroom – the grand majority of which were positive. Students describe the PI classroom as providing a better setting, and therefore an increased opportunity, for learning. They cite this improvement based on increased feedback and an opportunity to develop deeper understanding through engagement with, and discussion of, challenging questions.

However, the collective student response ranged far beyond the more measurable "learning" experience. Specifically, prominent in many of the student responses are the very socio-psychological issues often noted in the research on why post-secondary students leave STEM fields [25]. These range from affective experiences of enjoyment and comfort in the classroom to extensive and varied experience with an increased sense of community. We perform an open-coding analysis of student responses to better understand the student experience. By taking a "student-centric" approach to understanding the student experience (i.e. asking them directly), we contribute to a more nuanced understanding of effective student-centered classrooms.

2. RELATED WORK

Peer Instruction (PI) is the pedagogical classroom practice of (1) asking students to answer a question individually (often using clickers), (2) having them discuss the question in groups, (3) having them answer the question again (often using clickers), (4) having the instructor lead a class-wide discussion based on the student responses, and (5) the instructor dynamically adjusting class content based on student performance. Peer instruction was originally developed in physics [7] and has been shown to cause a two-fold improvement in student performance on concept inventories in multi-institutional studies [7].

PI is relatively new in computer science classrooms, but a recent wave of computer science education research has shown that students value PI and recommend more instructors use this practice in both large institutions and small colleges [18,21], that instructors value PI [15], that real learning occurs during student discussions [17], that PI students achieve a 6% higher final exam grade than their standard instruction counterparts on identical final exams [22], that PI reduces failure rates by 61% on average across four computer science courses [16], and that PI (along with Media Computation and Pair Programming) contributes to a 31% increase in retention of majors [19].

The courses we are describing here were also developed under very specific learning theories. In [4], Brown et al. describe situated cognition wherein they argue that "knowledge is situated, being in part a product of the activity, context, and culture in which it is developed and used." They posit that learning, or knowledge, is not in the information itself, but in the way in which learners acquire the knowledge and practice it. Since the goal of the course was to have students understand and be able to discuss computing concepts and problems, the instructor wrote PI questions that would engage the students in addressing the problems they would address in the future in a similar context. In this course students acquired knowledge through actual discussions and interaction with peers.

Furthermore, constructivist learning [3] describes learning to occur only when students are able to build on pre-existing knowledge. Encouraging the students to discuss during the PI course allowed each student to evaluate their understanding, compare it to the understanding of their peers, and discuss why an understanding was incorrect. This allowed students to self-identify when their model was incorrect and construct a new model. In [8] we have seen that demos often hides the students misunderstandings from them, and therefore students attempt to force what they are watching or hearing into their incorrect model. We can see that Chi's ICAP framework clearly describes constructivist learning to occur in **constructive** and **interactive** activities whereas in **passive** or **active** activities students are not modifying their existing model [5].

The work most closely related to this investigation is the work by Gaffney et al. [11] on how active learning pedagogies violate students' initial expectations of the classroom. Investigating multiple classes using the Student Centered Active Learning Environment for Undergraduate Programs (SCALE-UP), Gaffney et al. found that the shift in student expectations was generally positive. They also provide advice to instructors on how best to orient students to the changed atmosphere. Their work is complementary to this work, as this work focuses how students feel their role in the classroom changes and their work aims to help us better prepare them for the new classroom environment.

3. METHODOLOGY

The CS0 in this study was taught at a large, research-intensive, public university in Winter 2012 using a PI approach (N=84). Of specific note, as this was a non-majors computing course, the instructor explicitly communicated to students that the goal of the course was not simply to teach them to program, but to help them understand and develop skills in analyzing computer programs in detail and to understand the core concepts underlying all computer program execution (repeated and conditional execution, abstraction, etc.). A core mantra of the course was to learn to think like computer scientists think, so as to be better prepared to go on to learn any new computer program or application needed in one's future career in any discipline. We believe this explicit focus on "learning to learn" is important to this study and should have impacted students' views on their role in the class.

3.1 Course Characteristics

Previous reporting on this course, documents it as a "successful" PI course in that students experienced better learning outcomes than in a comparable standard instructional format (scoring higher on an identical final exam) [22]. In accordance with standard PI methodologies, students were assigned pre-class preparation (reading the textbook and being asked to follow along creating the Alice programs described in the book [10]). This work was incentivized by a short quiz at the beginning of each class. Lecture was comprised, in the main, by a series of "clicker discussion questions" where a challenging issue from the day's material was asked and answered via the following process:

1. Students answered individually with a clicker
2. Students discussed the question in assigned groups of three. The instructor and tutors would walk around listening in and could interact with students.
3. Students voted again. To incentivize groups to engage in step 2, groups were told to come to a consensus and all vote the same way.
4. A class-wide discussion was run, usually started by the instructor asking several groups to share their thinking and discussion. The instructor would wrap up the discussion, varying her explanation depth and detail based on students' success in answering and explaining the question.

Questions were interspersed with mini-lecture and Alice live coding demonstrations to back-up and/or further extend the concepts in the clicker questions.

3.2 Student Survey

Students were surveyed on their experiences in the course as part of a "take home final" at the end of the course. Here we analyze student response to the following open-ended question:

*Compare and contrast your role as a student in *this* course's LECTURE with other "standard" course lectures. That is, what are you here to do in this lecture? In other course's lectures?*

Answer with an essay of 150 words or longer. Any thoughtful answer (positive or negative) is desired.

To counter concerns that the reported experiences may be purely instructor-driven, we analyze student responses in both this PI section and a standard instruction (SI) class (N=124), led by the same instructor, at the same institution, in the same term, and with the same learning goals. The standard instruction version of the class is described in depth in [22], but included slide-based lecture and live coding demos where the instructor posed questions to both engage students and help them attend to important issues. Notably, the instructor received identical, very high student satisfaction evaluations in both courses.

3.3 Student Classroom Activities

In 2008 Chi recognized that research in cognitive and learning science inconsistently and unclearly used common terms such as passive, active, constructive and interactive [5]. She proposed a framework specifically describing these phrases in terms of observable, overt activities. Her ICAP framework provides evidence from literature to support a hypothesis that increased learning comes at the highest level of interaction. Each student response to the "role" question shown in 3.2 was coded passive, active, constructive or interactive according to overt activities they describe. Since the question asks students to compare their role in this class against a "standard" course, we coded both their response to the computer science course as well as the "standard" course (if they describe behaviors in the "standard" course). Our coding scheme adhered to the following descriptions of each level of student activity:

- **Passive**: Not engaged in lecture by doing something else (daydreaming, facebook, zoning out, etc.) or not attending.
- **Active**: Listening to lecture and/or taking notes.
- **Constructive**: Solving problems on their own. Reflecting on their own understanding. Justifying, explaining, and asking questions of the instructor.
- **Interactive**: Argue/explain concepts with other students. Learn from or teach a partner.

An important note for the reader who is familiar with the term "Active Learning" is that Chi describes **active** activities to be what some might call passive (e.g. taking notes, or listening to lecture). We believe that "Active Learning" would fall into either **constructive** or **interactive** in Chi's Framework.

Student submissions, predominately for the SI course, would often vaguely refer to improved learning, more engagement, or more interaction as a result of the in-class demos. Though students were describing these experiences, we only coded on *actual activities* they described. For example, if a student said they "learned a lot from watching demos and the class was interactive," this would be categorized as **active** because they did not describe any activity aside from watching demos.

Quotes were categorized using the highest Chi category, for example, if a student described attentively listening and then also described interacting with their peers, it would be marked as **interactive**. We categorized the data from both the standard lecture and the peer instruction lecture combined together with no indication of course, and then separated the data. We had two authors categorize 10% of the data at a time until they reached an 85% inter-rater reliability. Then the rest of the data was split evenly between the two authors and categorized.

3.4 Student Reflection and Valuation

To further describe the variation of student experience in the PI lecture, we performed a grounded theory analysis. Due to both the exploratory nature of our work, and the limitations of our dataset, we performed only the first level of analysis in the grounded theory methodology – open coding. Open coding involves "fracturing data and making connections" through a process of noting and labeling categories [6]. Also known as the constant comparative method, the goal of analysis using grounded theory is not to quantify or reduce a data set to what is frequently experienced, but instead to seek to provide a rich description of the scope of variation of experience in a situation – so as to inform future theory development that should be applicable in the setting observed.

Open coding was performed by two authors, each reviewing one-half of the PI section responses and identifying phrases which augmented understanding of student experience beyond strict activity definition. Each author developed an emergent set of category names, which provided an organizational structure to the phrases. After discussing both categorizations and after one author coded the half originally coded by the other author, a structure of categories emerged which communicated the variation observed in the data.

4. THREATS TO VALIDITY

There are threats to the validity of this study, as is common for analysis of qualitative data. Of greatest note, and as mentioned in the methodology, is that students' responses and depths of thought about their role as a learner in this course may have been affected by the explicit goal of the course to prepare students to be confident and more successful in future computer use. Compared to, for example, a foreign language course where the primary learning outcome would be to develop student ability to understand and speak in a foreign language, our course specifically did not emphasize a learning outcome of being able to write code in Alice. Instead, we explicitly and frequently reinforced with students that we were only using Alice to help them understand the basic "language" which underlies all computer applications; and that our goal was that they would be able to use this understanding in whatever technology and computer use they might face in their careers in the future. This greater focus on "learning to learn in future situations" may have impacted students' metacognitive view of their goal as a learner in lecture.

Secondly, three authors were heavily involved in the development of the course, though only one served in an instructional capacity in these specific course offerings. All authors have been involved in the offering of PI-based courses and bring to this study their perception of the changed experience and engagement of students, as they perceive it during lectures. However, the purpose of the post-hoc analysis of students' own responses in this study serves as a different and hopefully more individual and accurate documentation of students' experiences in the classroom than merely a report from the instructor's point of view. Still, a post-hoc, short answer question cannot possibly provide sufficient evidence for the development of a theory of student experience in the PI classroom. This study means to serve as initial data to help inform effective design of a more thorough ethnographic study.

5. RESULTS

We analyze our data from two perspectives: characterizing type of activity and describing student perception of that activity.

Table 1. Chi categories for CS0 PI course versus another course

	Passive	Active	Constructive	Interactive
CS0 Peer Instruction	0%	2.4%	12.2%	**85.4%**
Other college course	16.4%	**79.1%**	4.5%	0%

5.1 Student Activity Characterization

In Table 1 we find that the activities during the CS0 PI lecture are very different from other courses the students described. The majority (85%) of the students said they did some kind of **interactive** activity: "*I felt I had more of a role as a "student-teacher" than a student. I was extremely happy about this because it helped me reexamine the material in a different way while explaining it to another student*." No student described any **interactive** activity in other courses they took at the university, but instead described activities as **passive** "*In other lectures it is easy to get distracted and not really be paying attention to what the professor is teaching*" or **active** "*In other course's, I feel like a lump on a log that soaks up whatever information I can squeeze onto my notes/slides that the professor has us print off.*"

Students sometimes did not describe the **interactive** activities that might usually occur in a PI course (peer discussions), but still described **constructive** activities where they were constructing their understanding through effortful activities. For example, "*In this class, you must stay active in order to answer the questions, so it keeps you focused on the task at hand*." Though the clicker questions were coupled with group discussions, this student only described the activity of answering the questions throughout lecture, but did not describe the interactions with their peers.

There were still some students who described only an **active** role in the PI course. Though students might have been implying a **constructive** or **interactive** role, we only coded those with specific evidence. For example, this student only describes an **active** role in the course "*The course is really hands on and visual, which helps me learn.*"

A possible concern is that it is merely a characteristic (e.g., the personality) of the instructor that causes students to describe the engagement that they do – regardless of instructional method. To assess this possibility, we coded student responses to the role question given in a standard instruction (SI) version of the course taught by the same professor in the same quarter (reported in detail in [22]). In the SI course, only 4% of the students described **interactive** activities and 24% described **constructive**. 67% of the students described only **active** activities, which indicates that the difference in instructional method is what drove the students to be **interactive** rather than **passive**. However, we urge the reader to interpret these results with care: these students had not experienced peer instruction and their responses are not comparable to those of PI students. Indeed, these SI students respond to the question by comparing a "computer science" course (with live coding) to non-computing courses. But the results indicate student activity in the course is not merely a result of a characteristic of the instructor.

5.2 Analyzing Student Reflection/Valuation

5.2.1 Affect

The course had a strong influence on student affect, both on how comfortable they felt as learners because of a perceived permission to be unsure and to ask questions, and on how much they enjoyed the course.

Comfort. One student wrote that the course design "*made for a very comfortable learning environment. There was no stress or embarrassment; one could speak their mind freely*." A student who had previously failed classes and was on academic probation wrote "*I recognize my responsibility to do pre-reading, but sometimes I struggle with certain topics. The professor made sure to cover every detail and as a student I felt way more confident in this class than in other classes.*" This student earned an A grade in the class. Casting this in the light of Dweck's work on self efficacy, the learning environment clearly promotes a growth mindset, where it is accepted that learning involves struggle and asking for help and feedback is necessary at times [9]. More importantly, it was clear to the students that the instructor knew this: "*It made me comfortable to know I could ask a question and others could too, and receive feedback (that was actually wanted by the instructor).*"

Enjoy. Students noted their enjoyment of the class, with a sense of surprise: *"for once this class was actually quite fun*", *"the transition of my attitude [towards enjoying in-class discussion] is unexpected"*, and *"it made me realize how boring other classes can be when the prof is just rambling on about something half the class might not understand"*. One student alluded to how the negativity associated with getting an answer wrong was turned around through discussion with peers: *"we get to redeem ourselves by talking amongst one another to further our knowledge. I enjoy the discussion part of class because it allows my classmates and I to participate in learning too."*

5.2.2 Social/Community

Many students wrote of the shift from individual learner to being a member of a community of learners.

Responsibility to team. The requirement to work in groups increased the importance of preparing for class: *"having done the homework actually had an effect on what I did in class and could possibly affect my partners' group discussions*." They were no longer doing it only for themselves but also to ensure that their peers fared well. Note that students refer to this responsibility in terms of their peers' *learning* and not to their *grade*, when in fact credit for working effectively together was based only on the members of each discussion group answering the same way. Furthermore, the learning of the whole class emerges as an important feature. For example, *"It wasn't only about your learning but also everyone else in the class learning as well"*, *"in this class, everyone is encouraged to learn and everyone must learn so that no one is left behind"*, and *"I had a wider array of responsibilities in this class because I had to interact and be involved in the group and class-wide discussion ... almost the entire time"*. Students appear almost proud of their contributory role in class: *"I was not only a receiver but a giver in the class"*, *"encouraged to help others to learn while also furthering our understanding"*, *"we [discussion group] made sure that all of us understood what was going on, taught each other along the way."*

Connection to professor. While not explicitly responsible, students also indicated a greater connection to the professor –

even in the large lecture hall. *"I feel more connected with the professor who takes her time to hear our opinions."*

Participation. Students report having permission to speak out in the class, and thereby being an active participant in the lecture: *"Every student has the opportunity to participate"*, *"I was involved in the lecture, not just a sponge trying to absorb everything the instructor is saying*" and *"I can express my opinion to all"*. There is no sense of coercion in these statements, no sense that the students *had* to speak out, further contributing to the inclusive quality of the learning environment. Some found participating hard initially, but worked it: *"I may still be reluctant to speak in front of the whole class, but now I feel really comfortable to express my thoughts and opinions to my partners."*

Social and academic inclusion. Other lectures are reported to be isolating experiences: *"It is easy to feel lost in a lecture hall of hundreds of students"*, *"in other classes I often feel isolated ... since there isn't a value placed on discussion with other students to cement the topics"*. The PI class is significantly different: *"I now enjoy it because I know my partners pretty well and have made new friends from the class"*, *"This has been my favorite class for the simple fact that it was an open environment"*. The isolation of traditional lectures spills over into the students' perception of learning: *"In other classes, I have to learn everything by myself"*. This isolation transfers to study outside lectures as well: *"In other classes, I have to do homework and study alone and hope that my explanation is correct"*. This student may be indicating that in the PI class, he/she works with other students outside lecture, or that homework/study outside lecture is still undertaken on their own, but that the in-lecture experience provides feedback on their learning.

Negative: group consensus. A student admitted to being initially skeptical about the format, but came to the realization that he learned by discussing with others. Nonetheless, he continued to be bothered by the incentives to work in his group saying, *"I did not like how we needed to have a group vote for discussions."*

5.2.3 Learning

The main bulk of student comments that we identified relate, not unsurprisingly, to the students' learning in the class.

Understanding. Students note in general terms that their level of understanding is deeper: *"[the course helps to] solidify the topics so we remember and understand rather than memorize"*, *"discussions helped me to understand ... 'why' I chose an answer"*, *"I can see all sides and get a thorough understanding of what is right or not"*, *"better than ... (reading textbook, just listening, taking notes (frantically)) I come to lecture to solve problems and not just have information thrown at me"*.

Students explicitly refer to critical thinking: *"[being required to] provide input in lectures is what makes us think critically"*, *"in other classes the teacher just lectures instead of promoting critical thinking"*. Students note that they are developing reasoning skills: *"one may be encouraged to actually use reasoning, if one does not know the answer"* and *"by discussing with my classmates, I learn how to defend my choice by backing it up with evidence or by examples."*

Crucial aspects of deeper learning are identified. Examples include: the benefit of working through wrong answers - *"Discussions helped me to understand why I chose the wrong answer along with why the right answer is the correct one"* and *"the professor was really good at picking [distractor] answers because it gave us a chance to think the answers through critically"*; multiple ways of thinking about a problem - *"I had a role as a student-teacher. [This] helped me re-examine the material in a different way while explaining to another student"*, *"having others participate and share ... their thoughts ... definitely helped in opening my eyes to different ways of thinking"* and *"conversations ... with my classmates help me to see their point of view and how they think about questions";* and finally, the opportunity to consolidate learning - *"repeating concepts really helped me understand"* and *"my skills that I had learned in lecture were constantly tested in every lecture and every lab"*.

Feedback. Students wrote both about the feedback they received from, and also about the feedback they provided to, the instructor, underlining the connected nature of the class.

Votes and discussion in class were *"encouraged and desired"* by the instructor, enabling her to *"adjust the class discussion, which was very helpful in building knowledge when my group decided it wanted to talk to make it [the class discussion] focus more on areas people don't truly understand."* This adjustment to the students' needs positively affects the pace of classes: *"This course moved at a reasonable pace, allowing me to take time to make sure I understood each concept, and asking the TA for help when I encountered any confusion."* Other classes are noted as *"impersonal, move too fast, lose my attention"*.

Feedback to the students was clearly important also: *"it gave me instant feedback and allowed me to know if I made a mistake ... not something I can normally do in other lectures"*, *"knowing right away whether or not my answer was correct was also really helpful to my learning because I could understand what areas I was lacking in right away"*, and *"in this forum-like, communal class, I had the assurance that my understanding ... was correct and allowed me to further my knowledge more effectively"*. A comparison with knowledge-filled lectures was made: *"in other courses, I usually do not participate because the class is big and everybody just receives knowledge instead of feedback"*. The course structure amplified what the student needed to know or be able to do: *"makes it clear what we have to know and what we need to focus on"*.

Efficiency. Students found the time spent in class to be more beneficial than in other classes: *"I learn the information a lot easier, more efficiently"*, *"I have never had a class like this in which I felt by the end of class that I truly had a grasp of the material"*, compared to *"in most other classes I walk out feeling as if I had learned nothing and have a lot more studying to do on my own"*. This represents a shift in effort from outside lecture to inside, with a consequent overall reduction in time spent on the course: *"as a student in lecture, the course demands much more - but overall, this course demands much less, seeing as demanding participation in lecture facilitates and requires learning"*, also expressed, at its simplest, as: *"better learning with less out of class study time"*. That said, some students wanted greater efficiency saying "*Sometimes it would get repetitive on very simple topics which would cause my group to stop working."*

Authenticity. A few comments referred to a perceived lack of authenticity in the learning environment. *"Still not doing what you are learning... it would have been more helpful if we had done most of the learning in the labs with the tutors showing us how to do it instead of trying to make us figure it out from the reading"* indicates that the instructor had failed to make it clear to this student that a primary aim of the course was to get students doing exactly this kind of 'figuring out'. *"Clickers create a fake learning environment where most of the students are just sitting there clicking buttons and not really caring about the learning but* *just about getting points"* does not seem to be supported by the responses from other students, though was felt by at least one.

5.2.4 *Flipped Structure*

The format of the course, with preparatory work assessed using a quiz at the start of each lecture followed by regular questions and discussion, influenced students' preparation for and attendance at class, as well as the level of their focus on the material covered.

Preparation. Students reported that the PI format requiring them to be prepared for class was a benefit, both as a primer to the class itself: *"mandatory pre-reading really useful because you get the general idea what you gonna learn in class"* and to enable participation in the group discussion: *"practically required that you do the homework and pay attention just so you can contribute in class"*. Quizzes were a driving factor in completing the preparatory work, although this represented a challenge to the workload balance between courses: *"the quizzes ... made it critical that you had done the reading and the exploratory homework and that also helped learn better. The only difficult part was keeping up because of other class engagements and assignments ... The only thing is it is easier in other lectures to slack off and critical you keep up in this class."* It is interesting to speculate how students would fare taking a number of PI courses simultaneously.

Attendance. The course structure affected students' attitudes towards attending lectures. Comments ranged from a coercive influence: *"Clickers made me attend (and pay attention)"*, to a realization of the learning benefits: *"It was exponentially more beneficial to actually attend class"*. Clear changes of practice were noted: *"I never ever usually go to class, ever. At first I was sad that I had to go to class. I usually read the book and follow along on my own rather than attending class. But after taking this course I realize the importance of actually attending class. It made a huge difference in how I learned and remembered the information"*. Not all comments were positive on the perceived requirement to attend: *"People should be able to choose whether or not they're gonna go to lecture without being penalized"*.

Attention. Some students noted that they *had* to pay attention more in the PI class; others stated that it was *easier* to do so. *"it forced me to engage with the material while I was in class"* and *"it was important to pay attention and be engaged because if you did not you would miss the point of discussion and clicker questions"* exemplify the need to pay attention. On the other hand, *"in this course it was hard not to pay attention", "[clicker questions] really helped me keep focus and take a stronger interest in what was being presented in lecture"*, *"interacting with others allows our brain to function again and draws our attention back to the lecture"* and *"helped me focus and learn the material in class, instead of losing focus thinking about other things I have going on in my life right now"* exemplify how the course design aids students to concentrate on the material.

5.2.5 *Transfer of Behavior to Other Courses*

Quite unexpected were reports of how experiences in this course were impacting behavior in other courses. Realizing the value of repeated review one student noted "*clicker questions constantly forced me to review the material over and over.... if I reviewed a clicker question I remembered it... I got a perfect score on the midterm. I realized that I should be doing [this] for other classes*." Another changed his/her approach to lectures, "*I am currently a senior and in my 4 years of college I have probably attended 30% of my lectures. They never hold my attention, I sit on my laptop all class. I am proud to say that I started attending all my lectures and actually tried to pay attention.*"

5.2.6 *Research-Related or Evidence-Based Practices*

Whether or not we, as instructors, find these reported experiences compelling, a number of student reflections very directly connect with findings or recommendations in educational research.

For example, in work on reasons students leave STEM in university, Tobias [25] reports that in STEM classrooms students feel like their contribution is not valued – that they should merely take in the knowledge of the professors. Our students felt differently: "*I felt like my feedback was encouraged and desired*" and "*this has been my favorite class here ... for the simple fact that it was an open environment*." In Talking about Leaving [20], a study of STEM leavers, women who leave STEM are reported to have higher grades than men who stay – perhaps indicating that women incorrectly understand their relative abilities compared to their peers. Our students told us the following: "*the best part [of clickers] was seeing the results of the whole class. This kind of gave me an idea as to where the whole class was and if we were on the same page or not.*" Additionally, metrics like the US's NSSE (National Survey of Student Engagement) are highly scrutinized because of research showing improved outcomes for more highly engaged undergraduates. One area of engagement recognized by NSSE is the positive effect of engaging with the professor and also having a professor express high expectations for student learning. Our students experienced both: "*because of the frequent clicker questions I feel like am forced to be on top of my game as these points are vital for my grade*" and "*students get opportunities to have discussion with the professor during the lecture.*"

In the US National Research Council's report *How People Learn*, educators are implored to employ learning environments that are grounded in the research of how people learn [3]. In our students' responses we see reference indicating experiences with the following:

- **Constructivist learning**: "*Because I was asked to apply myself often, I think it helped form stronger connections to the material in lecture.*"
- **Situated cognition**: "*Here in this class I was a student of computer programming while in others they [profs] are there to present us information and we have to spit it back on pointless exams.*"
- **Metacognition**: "*This lecture focused on the learning aspect of programming rather than the programming itself. In other classes the focus was on the material rather that the learning of the material. I think this is inappropriate for certain subjects where the material is challenging.*"

Students also reported impacts on their studying. Numerous studies have demonstrated the importance of spaced learning (versus massed learning, i.e., cramming) for long-term retention, e.g. [1] and the value of repeated *testing* compared to repeated studying for delayed recall [14]. One student specifically recognized this benefit: "*I actually studied less for the midterm, because I has already mastered a lot of the materials required before I started reviewing contrasting to many other courses where I had to cram because I did not really understand the materials taught in class.*"

One challenge with instructor lecture is that an expert experiences lecture differently, by virtue of their expertise [13]. Students concurred: "*Hearing a different type of explanation from a fellow student who uses terms I may understand better, makes learning* *new concept easier" and "It was nice to hear other class members' opinions about a certain solution because their way because their way of breaking down an answer was at times easier to understand than the tutor's or instructor's*".

Finally, in our goal to develop critical thinkers rather than merely repeaters of information, this quote related to the scientific process is pleasing "*In this lecture, I felt it was OK to be wrong and to work through what caused us to think that way.*"

6. DISCUSSION

We believe the Chi framework for differentiating student activity as passive, active, constructive, and interactive is valuable in examining the fidelity of faculty's adoption of the PI process in classrooms. As Turpen and Finkelstein report, many faculty who describe themselves as implementing PI may in fact evidence a significant lack of fidelity of implementation to PI [26]. For example, faculty who believe they are implementing PI but are perhaps only encouraging their students in an **active** or **constructive** role, not an **interactive** role. This is also studied in 11 research-based instructional strategies in engineering [2]. We believe the Chi framework could be valuable in training faculty in use of student-centric practices – giving them a clearer distinction in the kinds of activity to foster in the classroom.

Along similar lines, the extensive range of student valuation comments was pleasantly surprising to us. In spite of our years of engagement in our own PI classrooms, and given our intense scrutiny of them through our other research in the PI process and student performance and retention, we learned far more than we expected from students' descriptions of their role. While PI has a notable core of research regarding its impact on learning gains, the categories of student report make it clear to us how unique the PI classroom experience is in contrast to students' daily lecture routine. Most notable to us is how much more motivated students must be in this class – whether that motivation comes from having to be prepared each lecture, to looking forward to working with their team and feeling "part of something", to actually learning something, to the pleasure at getting effective feedback on their learning, to simple enjoyment of the experience. Though this data doesn't provide an answer to our initial query of whether "other effects" (beyond increased understanding and feedback) contribute to the successes of PI classes, it helps provide traction to our feelings that our PI classes seem much more motivated.

6.1 Instructor Experience

A few things not mentioned by students stand out from our instructor experience that we would like to report in support of future research on the student experience in the PI classroom. From going around and listening in on student conversations in the group discussion phase we see the need to explore both the process and the value of having students put together arguments in more "novice" terms. In particular, we can see that a scaffold for supporting students in experimenting with the use of new vocabulary to deepen their understanding might be useful. Additionally, further support and instruction in helping students have productive discussions, perhaps by leveraging transactive discourse methods, should be explored [24].

Additionally, we have wondered about the experience of discussions for students who are not native speakers of the language of instruction. Although in our case, we've noticed some likely benefits (e.g., conversations in Spanish) and can imagine scenarios where students can use this time to clarify language issues, one could also imagine these students feeling disadvantaged or isolated in discussions.

Finally, in the PI section a number of undergraduate tutors were used as additional support in circulating during group discussions. This was partly to support training of tutors for a future course and partly from experience in much larger instances of this course. However, we would be interested in seeing in more detail how additional, near-peer tutors impact the student learning attitude and experience.

6.2 Negative Experience

Of particular interest for future ethnographic studies are any negative comments made by students, including those where a student says they were first unhappy about something, but later came to see its value. This was the third time the instructor had taught this course and she had made conscious and significant effort to communicate to students the rationale behind the classroom method including discussion of specific components and their value (especially the discussion). It would be helpful to explore in greater depth (and over the course of the term, not just at the end) the viewpoints of students about the specific issues that were, even at one point, viewed negatively. Greater depth of information and situation of those concerns would be very helpful in developing resources and activities for faculty using PI to be able to use to help their students "come around" to seeing past their (possible) initial negative views. We believe a theory of student experience in PI classrooms would be helpful to faculty wanting to best support their students in learning in this new environment.

6.3 Import for STEM Retention/Education

After repeated readings and analysis, we were quite struck by how our students have become so resigned to the standard university lecture model. They feel isolated: from each other, as having no "part" in class, and as being on their own to learn the material. Worst, they are clearly failing to see the subject matter as something with which they can, and should, engage: they are sponges, they listen to professors "ramble", and they try to copy as much into their notes as possible. We highly recommend the chapter "Introductory Physics: The Eric Experiment" in [25] and to compare the findings there with what our students report in their "other classes". In 20 years, it appears we have failed to make much progress. On the positive side, our students do *want* to be engaged (mostly). They are willing to prepare for class on their own, they are willing to work hard with their peers, and they are willing to engage as a scientist: to get things wrong and to work to puzzle things out. They recognize the unusually proscriptive structure of PI, but they also (again, mostly) recognize how they benefit by having an excuse to not space out, to come to class, and to stay caught up.

But perhaps the most exciting is students' recognition and value of themselves as a community of learners – along with the professor. Both in Tobias' work and in *Talking About Leaving*, the negative impact of lack of supportive community is clear. Why should we care about community? There are many arguments, but as a community of scholars, we understand the value in and the motivation of working with colleagues and having your work critically analyzed for the purpose of improvement. As educators in the 21st century, perhaps looking to define our value beyond that of a dispenser of information via video, our ability to engage students in the process of learning in community is exciting. Certainly, it makes teaching class much more fun – and increases our motivation to teach. And, perhaps, if students are having more fun, and feel more ability to learn, maybe they are spending more time trying to learn -- maybe they are more motivated to persist. Whether and how this motivation may affect out-of-class learning and activity is something we believe should be explored.

7. CONCLUSIONS

This work evaluates students' perceptions of their "role" in a PI computing course. Analysis of students' self-reported activities demonstrated that the majority of students report "interactive" activities (arguing, discussing, explaining to peers) in PI classes whereas the majority report "active" activities (listening, taking notes) in their standard courses. This substantial shift in classroom activities unsurprisingly causes students to also change their perception of their role in a classroom. A grounded theory open-coding investigation of student perceptions finds students positively affected by the shift in terms of class enjoyment, improved attendance and better attentiveness. They also report on improved meta-cognition skills facilitated by more frequent feedback and class discussions. Lastly, a few even report on trying to apply their self-reported improved learning behaviors from PI classes to other classes. This work has potential implications in identifying common desirable characteristics in student-centered learning environments and speaks to the issues raised in the STEM retention literature.

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