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# Formative Assessment and its Influence on Classroom Community in Biocalculus

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## Abstract

Most of the attrition from STEM majors occurs between the first two semesters of calculus, and prospective life science majors are one of the groups with the highest attrition rate. One of the largest factors for students that persist in STEM major beyond the first semester of calculus was a sense of community and a perceived connection with their instructor. Since building a sense of community is one of the stated purposes of formative assessment, we investigated how instructor and student perceptions of the purpose of formative assessment contributed to the formation of classroom community in a calculus for life science course. This qualitative ethnographic case study examined two cases of formative assessment used in difference sections. Although formative assessments have been found to increase a sense of classroom community, students and instructors reported that this was only the case when both the student's and instructors' beliefs about the purposes of formative assessments agreed.

## Keywords

Calculus, Classroom Community, Formative Assessment, Taken-As-Shared



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*Most of the attrition from STEM majors occurs between the first two semesters of calculus, and prospective life science majors are one of the groups with the highest attrition rate. One of the largest factors for students that persist in STEM major beyond the first semester of calculus was a sense of community and a perceived connection with their instructor. Since building a sense of community is one of the stated purposes of formative assessment, we investigated how instructor and student perceptions of the purpose of formative assessment contributed to the formation of classroom community in a calculus for life science course. This qualitative ethnographic case study examined two cases of formative assessment used in difference sections. Although formative assessments have been found to increase a sense of classroom community, students and instructors reported that this was only the case when both the student's and instructors' beliefs about the purposes of formative assessments agreed. Keywords: Calculus, Classroom Community, Formative Assessment, Taken-As-Shared*

Students who have a poor perception of their quality of relationships with their instructors are more anxious, earn lower grades, are less likely to seek assistance, and are more likely to cheat on assignments during their first year (de Guzman, Hodgson, Robert, & Villani, 1998; Kurland & Siegel, 2013; Nadelson et al., 2013). The first year of college is also where the largest number of students switch out of a STEM major, and this switch is most likely to occur after calculus (Ellis, Kelton, & Rasmussen, 2014; Worthley, Gloeckner, & Kennedy, 2016) Biology majors are most likely to switch majors after calculus (Ellis, Kelton, & Rasmussen, 2014; Rasmussen, Marrongelle, & Borba, 2014), but students who passed calculus who perceived a personal connection with their instructor are less likely to switch.

While creating a positive classroom environment where students feel personally connected to their teachers would likely boost individual learning, since students then feel more comfortable asking peers for help where they may be reluctant to ask their instructor (Salomon & Perkins, 1998), it is also very difficult for instructors, even experienced ones with a great deal of pedagogical content knowledge, to establish norms conducive to class participation in group work and discussions (Speer & Wagner, 2009). One possible avenue for establishing participation norms to build such a class environment is formative assessments, which are low stakes assignments that are graded on completion and used for instructor planning purposes. These brief assignments can create a communication loop between instructor and student, even in large classes, and is a non-labor intensive way to address post-calculus STEM attrition (Clark, 2011; Shute, 2008; Wiliam, 2009). Formative assessment has also been identified as a high leverage practice with minimal instructor burden in undergraduate science education, so students in classes geared for science majors are likely to be familiar with these practices (Windschitl, Thompson, Braaten, & Stroupe, 2012).

## Literature Review

### Transition to College

The primary transition course for STEM majors is introductory calculus; most students who enroll in this gateway course are highly motivated and believe they are well prepared for the experience (Bressoud, Carlson, Mesa, & Rasmussen, 2013). One potential challenge in the post-No Child Left Behind era in the United States is that although students believe they are well prepared, the emphasis on standardized testing has placed a great deal of emphasis on surface learning, which leaves students unready to make connections between concepts in their initial undergraduate mathematics courses (Gueudet, 2008; Selden, 2005; Selden & Selden, 2002). Hence, without accounting for the system in which students learned mathematics in during high school, students are more likely than ever to struggle with the transition to college and the advanced mathematical thinking needed to be successful in courses beyond calculus (Kajander & Lovric, 2005; Selden & Selden, 2002; Tall, 2008). Students often have difficulty transitioning to the college environment, particularly if the size of the school makes it difficult to find stable peer learning groups for new students and larger class sizes may create additional barriers for students seeking help from instructors with limited time (de Guzmán, Hodgson, Robert, & Villani, 1998).

Although it is ultimately the students' responsibility to make the transition to undergraduate mathematics (Kajander & Lovric, 2005), there are several steps that can be taken to help students adjust to undergraduate mathematics more easily, particularly multiple graded assignments prior to exams. Recent qualitative studies that include flexible pedagogy and meeting students where they are can help to build success and begin to overcome low self-efficacy (Wyatt, 2011). This psychological support is the first step to increasing the success and retention of at-risk students (Elliot & Gillen, 2013). Courses should also provide academic and social support for learning, particularly for life science majors, who are most at risk for leaving STEM majors after one semester (Bressoud, Carlson, Mesa, & Rasmussen, 2013).

### Classroom Community

One of the major factors in all students, but especially transfer students, is a sense of classroom community. In fact, social integration into new classroom settings may be even more important for transfer students than adjusting quickly to new academic standards (Bahr, Toth, Thiroff, & Masse, 2013; Jackson, Starobin, & Laanan, 2013) Transfer shock also appears to be reduced if interventions take place within the classroom as opposed to larger, first year experience programs (Townley et al., 2013). Students who experience success in a mathematics classroom report feeling like a part of a classroom community, but students without a strong sense of classroom community withdraw from participation, tend to be overlooked by instructors, and are reluctant to seek help (Ulriksen, Madsen, & Holmegaard, 2015). Students' perceptions of the strength of their classroom community are closely correlated with their perceptions of intellectual growth over the course (Bahr, Toth, Thiroff, & Masse, 2013; McKinney, McKinney, Franiuk, & Schweitzer, 2006).

Pre-service teachers are more likely to improve their self-efficacy for teaching in classes with a strong sense of classroom community (Moody & DuCloux, 2015). The most critical time to engage students is new classroom communities are in transition courses (Bahr, Toth, Thiroff, & Masse, 2013; Fauria & Fuller, 2015; Schmidt & Fulton, 2015), so classes likely to have large numbers of transfer students are high leverage courses for changing students' beliefs about learning and teaching.

O'Flaherty and Phillips (2015) found that high expectations and regular higher order thinking are required to increase student engagement and create a positive classroom environment. Extrinsic measures and praise can also help foster good classroom community, as long as praising intelligence, talent, or speed is avoided (Ulriksen, Madsen, & Holmegaard, 2015).

Students in classes where group work is regularly used and within students' Zone of Proximal Development are more likely to have students self-report on a positive classroom community (Chandler & Redman, 2013). Gradually reducing scaffolding when groups ask for help will also increase student engagement (Ford, 2015). The high leverage practices for improving classroom community are: prompt feedback (within a week), high expectations, and time for peer communication (Fauria & Fuller, 2015). This suggests that a flipped classroom may be an ideal way to build a positive classroom community with high student engagement, but classroom community and flipped classrooms remained understudied in undergraduate mathematics courses (Strayer, Hart, & Bleiler-Baxter, 2016).

**Formative Assessment**

One of the most effective high leverage pedagogies to help beginning students make the transition to undergraduate thinking is formative assessment (Windschitl, Thompson, Braaten, & Stroupe, 2012); these assessments are especially promising given the relative lack of positive results with technology-infused and flipped calculus classes (Sonnert, Sadler, Sadler, & Bressoud, 2015). Formative assessments, which are low stakes assignments given to assess students' current level of understanding, can increase student achievement on summative assessments when used properly (Black & Wiliam, 2009; Clark, 2011). This is because formative assessment encompasses many of the best practices of teaching. For instance, formative assessment allows instructors to teach at the developmental level of students by collecting data on students' current level of proficiency and clearly defining the goal structures for achieving success and avoiding failures in the questions asked in the assessment (Pekrun, 2006). The regular use of formative assessment may help close achievement gaps for students in underrepresented groups (Stiggins & Chappuis, 2005). Regardless of the content area or age of participants, the effect size on most quantitative formative assessment studies is around 0.5, a moderate effect with minimal instructor effort (Pinger, Rakoczy, Besser, & Klieme, 2017Further, formative assessment is a useful tool in making critical decisions about lesson planning and working through discussions with students (Schoenfeld, Thomas, & Barton, 2016). These studies show that classes where formative assessment is used do better on average on common summative assessments than those classes where no formative assessment is used.

Almost all of the research on formative assessment has been quantitative quasi-experimental studies (Black & McCormick, 2010; Black & Wiliam, 2009; Clark, 2011) where a treatment class is compared to classes that do not use any formative assessment on some common summative assessment. However, there are two studies that suggest participation in formative assessment may be of particular benefit to students struggling with difficult material. In the first study, math students who scored low on an aptitude pre-test who were taught using formative assessment outperformed high-ability students who were taught with general lesson plans from the textbook and a common unit test (Chiesa & Robertson, 2000). Other studies have found using formative assessment to inform teaching decisions raises all students' achievement levels, though low-achieving mathematics students show the most gains in a course that uses formative assessment (Gallagher, Bones, & Lombe, 2006).

Formative assessment may also help students make the transition to undergraduate mathematics, because two of the major purposes of formative assessments are for instructors

to use class time efficiently and to increase student ownership of their own learning (Black & Wiliam, 2009). This increase in student ownership of learning is intended to provide support for positive changes in students' self-efficacy, calibration, and motivation to learn (Black & Wiliam, 2009). Formative assessments open lines of communication between instructor and student for those students that complete these assignments; such communication can help strengthen the students' perception that their instructor cares about their success since students can see the instructor responding to their specific needs (Ellis, Kelton, & Rasmussen, 2014). Formative assessments may also strengthen student motivation to learn and help students develop some time management and self-monitoring skills (Alkharusi, Aldhafri, Alnabhani, & Alkalbani, 2014; Black & Wiliam, 2009). However, for formative assessments to be successful, these assignments must be implemented in a manner so that the purposes of the assignments are taken-as-shared by the instructor and students (Nolen, 2011). However, these studies have been primarily conducted on K-12 students in areas other than mathematics, and without qualitative investigations, it is not clear how much of these results will translate to a radically different content area. This study was guided by the question: in what ways does the use of formative assessments influence students' and instructors' perceptions of classroom community? We argue that without a shared vision towards the purpose of formative assessment, these assignments have the potential to become a significant negative factor in student and instructor perceptions about the quality of classroom community.

## Methods

We each came to be involved in this project in different ways. Dibbs is currently a faculty member whose primary research interests are formative assessment, equity, and calculus. Christopher is a graduate student with in undergraduate mathematics education and equity. Rios' is an undergraduate research assistant whose published work has been in the development of classroom communities and equitable communication. We were interested in biocalculus in particular because it was a newly-developed course, and the majority of students taking the course were also participating in a first-year experience for pre-medicine majors. Students lived together in the dorms, had a resident advisor who was an upperclassman biology major, and took their mathematics and science classes together. Formative assessment seemed like a natural way to leverage students' existing cohort bonds and include lines of communication with the instructor.

Yackel and Cobb's (1996) sociomathematical norms were used as the theoretical framework for this study; sociomathematical norms are taken-as-shared ideas between students and instructor as to what constitutes appropriate behavior in a mathematics classroom. Sociomathematical norms that are taken-as-shared serve as the basis for classroom communication and community (Yackel & Cobb, 1996). Sociomathematical norms are established in the first few weeks of the course, and are difficult to change once they are established (Yackel & Cobb, 1996). The negotiation of what constitutes good communication in a mathematics classroom provides learning opportunities for students; this is especially true for students in transition years like first-year undergraduates (Yackel & Cobb, 1996). During the critical initial weeks, the teacher's beliefs and goals for the class are the primary drivers in the establishment of sociomathematical norms (Yackel & Cobb, 1996).

We chose a qualitative approach for this study since our main interest was in instructor and student perceptions, and felt that survey work would be too reductive to capture all of the nuances because our setting was so radically different from the prior research. We chose a case study because we wanted to collect detailed information about the experiences of these participants, who were the first group of students to experience this course. The natural bounds of time and space lent itself to the choice of case study as a general method. Since our primary

data collection was observation and we wanted to understand perceptions and the evolution of classroom culture, we used an ethnographic case study design for the two sections of calculus for life sciences taught in the fall semester at a mid-sized doctoral granting institution; the primary data sources were observations and student interviews bounded by a cycle of a phenomenon; in education this is generally considered to be at least one cycle of a course (Patton, 1990; Wolcott, 2005). Neither researcher was an instructor of record for the classes, nor were the researchers involved with the class planning or student assessment during the semester.

Although the two courses were not identical, there were many commonalities between the two sections. Both sections of calculus for life science majors were held at the same time during the Fall 2010 semester. Both of the instructors teaching were teaching the course for the first time and used a common schedule, formative assignments, suggested ungraded homework problems, and had common test questions on every test. The department chair randomly assigned 33 to each instructor after unexpected demand for the course required that the original roster be split in half and a second section be created. All of the students taking the course were biology or biochemistry majors. There is no formal pre-health major at the institution, but the majority of the students enrolled in the course intended to apply for medical schools at the end of their undergraduate careers. Since this course is recommended as a first year course, 75% of the students in each section were freshmen participating in a first year experience; these students took several classes together and lived in the same dorm. The remaining students in each section were upperclassmen.

The formative assessments related to the forthcoming content; this assignment was intended to be used as a planning tool for the instructors. Before a section of the textbook was covered in class, students were asked to read the section, define all major terms, write down all formulas, attempt a sample problem, and state what questions they had about the section; these assignments were graded on completion and worth 5% of the course grade.

The primary differences in the courses were the frequency in the formative assessment collection and group work. In Class 1 these formative assessments were collected weekly and not referenced in class by the instructor while in Class 2 the formative assessments were collected before every new section and referenced at the start of every new section by the instructor. Class 1 did group work no more than 25% of the instructional time every week with the remainder of the time dedicated to lecture, while Class 2 completed group work during every class. A typical formative assessment appears in Figure 1.

**Figure 1**. Typical formative assessment

1.6: Analysis of Discrete Time Systems

1. What is cobwebbing?
2. How can cobwebbing help us understand a system?
3. What are the steps for using cobwebbing to find a solution?
4. What are equilibria?
5. Where do equilibria appear on a cobweb diagram?
6. How can equilibria be found algebraically?
7. What questions do you still have about the material in this section?

Before collecting data, we obtained approval to conduct the study by the Intuitional Review Board. After the data for Class 1 was more sensitive than anticipated, we consulted IRB, and agreed to a six year waiting period for all students to graduate, both instructors to change institutions, and for the researchers to change institutions. Participants re-consented to

be in this study after the moratorium on publication. The data collected throughout the semester consisted of daily classroom observations; these observations were intended to document the classroom environment throughout the semester. Each researcher chose a section as their primary observation responsibility. A researcher was present every day in class except for three exam days and three class days from each section where both researchers observed the same class to triangulate the observations. Observations were done by observing for five minutes, then writing brief field notes for five minutes throughout the class meeting. The brief notes were expanded into longer narratives before the next class meeting. During class, the researcher documented what the instructors were doing, when and how many questions were asked, which students participated, any mention of the formative assessments, and student off-task behavior. For the purpose of coding, an instructor question was considered to be any statement where the instructor expected a response from the students, even if the statement was not grammatically a question. Field notes were also taken when students were talking informally about their perceptions of the class before class, after class, during breaks, and during evening pre-test study sessions. The researchers met at least twice a week to discuss the observations and confirm that their observations were consistent. When both researchers observed the same class, these field notes were reconciled after every class.

The classroom observations were supplemented with interviews: a midterm semi-structured interview of the instructors, eleven semi-structured end-of-semester interviews with students (Table 1), semi-structured end-of-semester interviews with both instructors, and at least one unstructured interview throughout the semester with the interview participants in Class 1 and the instructors. Students were selected for interviews using typical case sampling (Patton, 1990). During instructor interviews, each instructor was asked to discuss how they felt the class was going, how they could characterize their interactions with the class, how they used the formative assessments, how useful they found the formative assessments, and what the purposes of assigning the formative assessments were. Students were asked to discuss how they felt the class was going, their interactions with their classmates, their interactions with their instructor, and how they studied for class. During the interviews seven of the students in Class 1 spontaneously brought up the formative assessments. When students brought up the formative assessments, they were asked to discuss their perceptions of the formative assessments and how, if at all, the students used these assignments. Students who did not spontaneously bring up the formative assessments were asked about these assignments at the end of their interviews. These interviews were recorded and then transcribed for later analysis. For informal interviews, students brought up some of the topics discussed in the semi-structured interviews with the researchers. During these interviews, the researchers did not bring up any topics that the students did not disclose. The instructor informal interviews discussed class culture and the use of formative assessments; the students discussed classroom culture, their perceptions of the class, and brought up the formative assessments on two occasions, one of which was a group discussion of the usefulness of the formative assessments. Informal interviews were recorded if the participant gave permission; otherwise the researcher took notes, and expanded the notes into a narrative that day. The participant was then showed the narrative and asked to member check the document. When the participant was satisfied with the narrative, the participant initialed (or signed with their pseudonym) and dated the document and the researcher signed the narrative.

We interviewed eight students in Class 1 and Class 2, three male students and five female students. All were biology or bio-chemistry majors, and all students intended to go to medical school, veterinary school, or graduate school after graduation. Half of the interview participants had prior experience with calculus topics, which is typical for undergraduate calculus class. At the time of the interviews, three participants were earning A's, two were earning B's, one was earning a C, and one was failing the course.

After the semester was completed, the standards of evidence were developed by the researchers before coding began (Table 1). After developing the coding scheme, the observations were coded by the researcher, with each researcher coding their primary class. After this initial coding, the interviews were coded in the same manner. The data was then axial coded (Corbin & Strauss, 2007) to develop the emerging themes within the data.

Table 1: *Coding Scheme*

| Code | Definition | Example |
|---|---|---|
| Purpose of formative assessment | Any purpose a participant ascribes to formative assessment, either for themselves or as a motivation for their instructor | • "I use the formative assessments to decide how much instruction I need on the section."<br>• "The formative assessments are to get us familiar with the material for tomorrow:" |
| Use of formative assessment | Anything a participant uses the formative assessment for | • "I use the formative assessments so I know what words to use when I search YouTube for extra help" |
| Questions; Participation | Any question or statement from an instructor where a student response is expected. A student is considered to participate if he/she responds to a question | • "Find the equilibrium of this cobweb diagram"<br>• "What derivative rule is appropriate in this context?" |
| Off task behavior | Behavior during class that indicates students are not actively engaged in the material | • Setting down writing implement, staring into space, off task talk during group work, texting |

After each case was coded separately by the primary researcher, we each coded the other class. Once the codes were reconciled, we used our axial coding to conduct the cross-case analysis.

## Findings

The instructors of the two classes began the semester with no experience in using formative assessments in a classroom. As the semester progressed, both instructors developed different views on the purpose of formative assessment; Jordan saw the formative assessment as not being worth the time spent grading, while Jason saw the formative assessments as an integral part of preparing for class. For each of the two classes, the instructor's view of formative assessment throughout the semester is presented, followed by descriptions of how the instructor used the formative assessments; the students' views and uses of formative

assessments in each class follow that of their instructor. Jordan and the students in Class 1 never had a taken-as-shared meaning for the purpose of the formative assessments, which had several negative consequences for the students and classroom environment. In Class 2, where the purpose of formative assessment was taken-as-shared by the instructor and the students, the students saw the formative assessments to be slightly less useful than the students in Class 1, but the formative assessments did not appear to create misunderstandings between the students and their instructor.

**Class 1**

Throughout the semester, Jordan's view of formative assessment became increasingly negative. Before the semester, Jordan was the instructor of the two sections of bio-calculus who was most willing to try formative assessment and believed that such assignments could help students master the material:

> I haven't done anything like this before, but if it gets students reading the book before the lecture, that ought to help. Maybe I can skip some review if they are good at the review parts of the reading sheet [the formative assessment].
> - Jordan, one week before classes

However, as the semester wore on, Jordan did not find that the time spent grading was worth the benefits of collecting formative assessments:

> Look, maybe something like the reading sheets would be good for TAs [teaching assistants] to do in their classes, since they are new to teaching, but I've been teaching for some time. I already know what students don't know, so these assignments don't have any new information. The students like them for some reason, so I can't seem to get rid of them. – Jordan, midterm interview

Three different times throughout the semester Jordan asked the class if the formative assessments could be eliminated from the course, so the workload could be reduced for the students, but the students never agreed to the proposition. By the end of the semester Jordan was convinced that formative assessments never produced useful information for preparing future classes in bio-calculus, and such assignments would be equally useless in any undergraduate mathematics course.

> No, looking back, I can't say that the reading sheet [formative assessment] made a positive contribution to the class. It was just something else to grade… I don't think it was a course specific problem. There is no class that I teach where I would ever find value in grading extraneous things. I already know what students are bad at; I don't need extra grading to tell me that. – Jordan, final interview

Jordan quickly stopped using the formative assessments as anything other than a thing to grade:

> To be completely honest, I looked at them the first few weeks, but after that it was clear that students didn't know what I thought that they didn't know, so that is when I stopped reading them [the formative assessments] and made the assignments weekly. Since I am not getting new information, it makes sense to minimize the grading time. – Jordan, midterm interview

During the first three weeks of the semester, Jordan mentioned the formative assessments three times: once the second, six, and ninth day of classes. These were the days where logarithms, cobweb diagrams, and the definition of the derivative were introduced. The formative assessments on those days were used as a jumping off point to begin class:

> Everyone is here and on time. The three students sitting to my left are talking about cobwebs. They said cobwebbing was confusing-admittedly the book was pretty poorly written in this section. After passing papers back, Jordan began class by saying, "From reading the reading sheets before class, it was clear that everyone had a hard time with the cobwebbing part of this section, so today we are going to spend most of the class on cobwebbing: what it is, why we do it, how we do it, and how to interpret a cobweb diagram..." Several students, including the ones who were complaining about the section before class, sighed in relief. –Field notes, Day 6 (Monday, Week 3)

However, after the third week of classes, the only times Jordan mentioned the formative assessment was to ask students if the assignments could be eliminated, and Jordan's belief about the lack of utility of the assignments was readily apparent. After the Test 2 grades were lower than expected, Jordan asked the class if they would like to eliminate the reading sheets so that students would have more time to do the ungraded homework:

> Moving forward from these test grades, some changes need to be made. On your part, something needs to change about what you do to prepare for class. You should be doing the ungraded homework problems all the time. For my part, I want to give you time to focus on what matters. What do you think about getting rid of the reading sheets so you have more time to work on the book problems? – Jordan, Week 8 Day 2

Although the implementation of the same formative assessments (called reading sheets in the class) was different in the two classes, all of the interviewed students in Class 1 identified these assignments were a helpful tool for learning the material. Students found the reading sheets helpful because they made the learning objectives for each section clear and helped identify which parts of the content students found most difficult before instruction; this is one of the five purposes of formative assessment identified in Black and William's (2009) theoretical framework; this was one of the two major purposes students ideally identify as a use for formative assessment. Robert in Class 1 explained, "They [the reading sheets] give a warning for what's coming up next. I know ahead of time which parts of class I have to listen closely ahead of time. This makes a big difference, especially on Monday." All of the interview participants in Class 1 agreed that the main purpose of the formative assessments was to let students know what the most important content would be in the upcoming class.

The behaviors of students in Class 1 and explicit statements made during class indicated that the students considered the formative assessments an important part of their learning for the class. On three different occasions (weeks 4, 8, and 12), the instructor of Class 1 asked students to vote on whether or not the formative assessments should be eliminated from the course. The first two votes, students spoke up in defense of the formative assessments:

> Darcy, who is one of the only students that participates in class, was the first one to respond when Jordan asked to eliminate the reading sheets. "I don't think that would be a good idea," she said, "I think the reading sheets are really helpful

> for getting ready for class. The reason I don't have time to do the bookwork is because [the online homework software platform] is so hard to use. Maybe we could keep the reading sheets and do graded bookwork instead?" Jordan immediately shot down the idea of eliminating the online homework and reiterated that college students should do things without them being worth points, then reiterated that the option was to keep reading sheets or eliminate them. Two other students spoke up in defense of reading sheets, and then the class voted. The only hand raised for the elimination of reading sheets was Jordan's. – Week 8 Day 2

After the discussion, no one voted to eliminate the formative assessments. On the third vote, students were asked to vote on paper ballots; the instructor indicated that the class was still strongly in favor of formative assessments but did not reveal the vote totals. All but one of the interview participants felt strongly at the midterm interviews, which were conducted shortly after the second vote to eliminate formative assessments, that the formative assessments could not be eliminated from the course since they were a very helpful resource outside of class:

> I was glad Darcy said something in class yesterday. This book, it isn't like a regular math book, you know? There are like no examples, and they skip steps. Without the reading sheet, I wouldn't know which parts were the main ones, you know? Once I know the main points, I can go look up on the Internet what I am supposed to be learning, and then the book isn't such a problem. – Dalton, midterm interview

At the end of the semester, all of the students in Class 1 that participated in interviews agreed that the formative assessments were useful for preparation in upcoming classes. However, when the six interview participants who were passing the course were asked at the end of the semester to talk about how they were successful in leaning the content, all five of the students attributed at least part of their success to how they were able to use the formative assessments to organize their own studying:

> The only reason I got a B+ in this class was YouTube; I'd watch videos from lots of different people until I found one that made sense. But the only way I even knew what to look for was the reading sheets. The things [Jordan] cared about had to be on those, and I could use the vocab in the questions as search terms. – Snookie, final interview

In Class 1, students used the identified objectives to seek outside sources of supplemental instruction; half of the students interviewed from this class regularly watched YouTube videos based on keyword searches gleaned from the formative reading sheets. The other four students from Class 1 used the reading sheets to identify when they needed to pay attention in class like Robert mentioned in his interview. The students in Class 1 also used the reading sheet to form a study guide when preparing for the exams to supplement the study guide provided by the instructor. For most of the students in Class 1, the reading sheets became a way to obtain feedback and customized instruction that they were not receiving in class:

> The reason I kept voting to keep the reading sheets was because I didn't feel like I could talk in class. I wasn't smart enough to get it instantly, and [Jordan] only cared about the ones that did. But when I did the reading sheet, I knew what parts I had to pay most attention to before class even started, and if it didn't

> make sense after that, I knew what to tell my tutor what I needed more help on. – Ben, final interview

There were several consequences to the classroom community traceable to the purpose of formative assessment not being taken-as-shared by the students and the instructor. Since the students saw the formative assessments as a vital component of their learning, the repeated attempts by the instructor to eliminate the formative assessments from the course were seen as a breach of trust by the students:

> The thing that I liked least about this class was how Jordan kept trying to take the reading sheets away. We said that they really helped us, and after every test, they almost got taken away. It was like [Jordan] just wanted to save time on grading and didn't care about us. – Robert, final interview

Further, the Class 1 students' behavior showed low confidence, and a reluctance to participate in class. Of the 189 times during the semester when the instructor asked a question, three students accounted for 133 of the answers. When asked about her low participation in the class, Gloria, a student who spoke twice in class all semester, explained, "The class is hard for me, and I'm not going to talk unless I'm sure that I'm right." Darcy, who responded to 68/189 questions throughout the semester, had performance orientated reasons for her participation:

> I'm a junior, and med school isn't that far off anymore. I only have a 3.69 right now. I need to pull my GPA up over a 3.7 or I lose my scholarship, and to do that I need A's in all of my classes this semester. I don't care if I look dumb in front of freshmen I don't know as long as [my instructor] gives me my A.

Five of the eight (62.5%) of the Class 1 interviewees stated that the main reason that they wanted an A was because they had medical school aspirations, and these students showed beliefs and behavior patterns indicative of low confidence and an entity theory of intelligence. 75% (6/8) of the interviewees said that the most important part of the class was to memorize procedures, and that being asked to solve story problems or applications where they had not seen a prior example exactly like it was unfair. All eight participants felt that the instructor did not do enough examples. When students encountered what they considered a novel problem on an exam, 62.5% of the interviewees left the answer blank. During group work, if a group did not succeed on their first attempt, 58% of all groups observed during the semester would wait and wait for the instructor to come by and ask if they needed help. Only the students that regularly participated in class would call the instructor to their group when they had questions.

When the purpose of formative assessments was not taken-as-shared, the disconnection between students and instructors contributed to the class' perception that they could not trust their instructor. Students used the formative assessments as a way to teach themselves, and resisted any attempts to remove their primary learning tools. As a result, the class environment became more adversarial as the semester wore on, and students became ever more grade focused and less willing to speak in class. However, in Class 2, where the purpose of formative assessments was taken-as-shared and used in a consistent manner throughout the semester, the formative assessments appeared to make a positive contribution to the classroom community.

### Class 2

Jason, the instructor of Class 2, shared Jennifer's skepticism of the utility of formative assessments, but he found the formative assessments increasingly useful throughout the

semester. By the third week of class Jason had noticed that the formative assessments were more helpful than he had anticipated when he was prepping class:

> The reading sheets are more helpful than I thought they were. I was not excited about the time it would take to collect and grade them every day before school starts, but it makes planning easier. I think I can start on a higher level of Bloom's [taxonomy] because the prep sheets help get the basic facts across. Now I can start at comprehension instead. – Jason, Week 3 (office hours)

In addition, Jason found that what students struggled with on the formative assessments was a good way to begin class:

> The main way I use the reading sheets is to get ready for class and how I plan to budget time. In class, the main time I use them is at the beginning of class; I tell students what as a class everyone was strongest on, where the biggest struggles were, and what we will be doing that day. Then I remind them that their goal should be to understand the material, and then we start. – Jason, final interview

By the end of the semester, Jason believed that he would be likely to use formative assessment similar to the ones used in this course in future semesters and in other courses; he believed that the formative assessments were an effective way to introduce new material and focus on the content students actually needed help on during the semester:

> I think I would do something like the reading sheets again in other classes-it made planning easier and my students seemed to like them. I think it helped all of us to know what students were weakest on before wasting time in class by starting over everyone's heads. – Jason, final interview

**Cross Class Comparison**

Although the formative assessments were mentioned during every class by their instructor, students in Class 2 didn't believe that the formative assignments were as central to their learning as the students in Class 1 did. However, the students in Class 2 did stipulate that the formative assessments were somewhat helpful because they made the learning objectives for each section clear. Pat in Class 2 concurred: "I think that they're a good tool to using cause it's a little bit of an overview of what you'll be going over that day usually…"

While students from both classes found that the formative assessments clarified the objectives of the upcoming content, students in each class used the information differently. The Class 2 students did not watch YouTube videos outside of class; they considered the reading sheets as a preview of the upcoming material and a chance to ask for help. Since the formative feedback was incorporated into class, in some sense the students in Class 2 did not need to seek the same sort of outside resources the students in Class 1 felt were necessary.

Unlike Class 1, the use of formative assessment was taken-as-shared. Both Jason and his students believed that the purpose of the formative reading sheets was to prepare students to start new material in the next class. Students also took Jason's opening spiel about the results as evidence that the primary goals of the class were to understand the material.

> One of Jason's students came to office hours today. She was having trouble recognizing when to use the chain rule and when to use the product rule. Jason

> did a quick example and had her do some. She was not kidding about her confusion; after her answers bore little resemblance to the correct answer, it was clear that her main difficulty was with the transforming radicals into power form. After about 30 minutes, the student finally had practiced enough with the power rule to complete the two sample chain rule and power rule problems on the board. As she was packing up, she said to Jason, "I really appreciate the time you took today. You tell us at the start of class every day that the most important thing is to understand what we are doing, and I really wanted to be sure I got this before the test." – Jason's office hours, 10/26

Since students shared a common vision for the purpose of the class, students in Class 2 had a different participation pattern than the students in Class 1. Most students would participate in Class 2 by talking with peers or instructor about confusing topics which was made easy by the instructor's use of group work in most classes excluding review and test days. If group work is too hard, all of the interview participants would try multiple strategies and then ask for help when out of ideas. This behavior was also observed in 11 of 16 group work situations during class. Also, the instructor would have students approach him right after class or during office hours to better understand the material that the class went over, and had at least four students working in groups during office hours after the first test.

## Discussion

Students in all classes found the formative assessments to be a valuable learning tool, albeit in different ways, which suggests there were benefits to the formative assessments regardless of implementation. The more frequent mention of formative assessment as well as explicit mentions of the formative assessments by the instructor appeared to support more incremental attribution behaviors and increase students' sense of connection with their instructor. However, the class with the less frequent collection of formative assessment appeared to exhibit more performance goals and was reluctant to seek help from their instructor. Although the literature on best practices in formative assessment does not indicate that weekly collection of formative assessments is necessarily problematic (Shute, 2008), the lack of feedback from instructor to students did appear to contribute to students' feelings of disconnection with their instructor in Class 1. Since students that display performance oriented goals are likely to have a fixed mindset and fixed mindset students are more likely to quit when confronted with challenging content, the disconnect between the instructors and students about the purpose of the formative assessments appears to exacerbate the beliefs that cause otherwise talented students to leave STEM majors. These findings support the findings of other studies that suggest that in order for formative assessment to have a positive effect on students' achievement, instructors must view formative assessment as something an instructor does for students rather than something done to students (Alkharusi, Aldhafri, Alnabhani, & Alkalbani, 2014; Stiggins & Chappipus, 2005). Nolen (2011) claims that formative assessment has no benefits when the purpose of formative assessment is not taken-as-shared, but while the students in Class 1 did not share their instructor's views of the purpose of the formative assessments, these students did use the assignments as a central part of their studying and believed they benefited from the addition of the assignments in their classroom. However, since the two classes used different exams throughout the semester, there was no way to measure how, if at all, the lack of a taken-as-shared definition for formative assessment affected the achievement of the students in Class 1.

The situation in Class 2 seems to suggest that formative assessment can be implemented as part of a strategy to help students transition to college level mathematics, but these two case

studies offer two major implications for other entry-level undergraduate mathematics instructors for teaching. Formative assessment, like any other potential pedagogical tool, requires instructor buy-in before the communication cycle created by the formative assessment has a positive influence on the classroom environment. If formative assessments are to be used in the classroom, these assignments should be used sparingly. Students should be told why they are completing the assignment, and explicit verbal statements that the instructor read the formative assessments and took the feedback into account during lesson planning appear to be critical aspects of successful implementation of the formative assessments.

Although the case studies presented here suggest formative assessments may help to ameliorate the aspects of mathematics classes that cause students to leave STEM majors, more research is needed on what the benefits of formative assessment in undergraduate mathematics classes could be when the purpose of formative assessments are taken-as-shared. In this case study, we were limited by the relative lack of ethnic and linguistic diversity in our participants, as only two students were non-Caucasian and all students spoke English as a native language. Also, since Class 1had atypical outcomes, it is difficult to determine what a typical student response would be when the purposes of formative assessment are not taken-as-shared. One such direction is to investigate how formative assessment may be used to help STEM majors transition to college and be successful in introductory calculus. Do completing formative assessments in such an environment increase students' perception of a positive relationship with their instructor? Are students more likely to seek help in such a classroom?

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