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Students' Perceived Utility of Precision Taught Calculus

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Abstract

The last decade of calculus research has showed students learn best when lecture is supplemented with thoughtful use of technology and group work; however, educators are given little direction of how they are to balance the already full first semester calculus class. Precision teaching is an instructional model that employs formative assessment to provide information on what topics are understood by students as well as indicate troublesome concepts. With this information, the instructor can adjust class time accordingly by incorporating supplemental activities most beneficial to students. The purpose of this interview study was to explore the perceived utility of precision teaching by eight students earning to see if further exploration of this topic was warranted. Although precision teaching requires more work for the instructor, students' high perceived utility makes precision teaching a valuable method of undergraduate instruction because they claim to study more, understand material better, and earn higher grades

Keywords

Calculus, Formative Assessment, Perceived Utility, Precision Teaching

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Students' Perceived Utility of Precision Taught Calculus

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The last decade of calculus research has showed students learn best when lecture is supplemented with thoughtful use of technology and group work; however, educators are given little direction of how they are to balance the already full first semester calculus class. Precision teaching is an instructional model that employs formative assessment to provide information on what topics are understood by students as well as indicate troublesome concepts. With this information, the instructor can adjust class time accordingly by incorporating supplemental activities most beneficial to students. The purpose of this interview study was to explore the perceived utility of precision teaching by eight students earning to see if further exploration of this topic was warranted. Although precision teaching requires more work for the instructor, students' high perceived utility makes precision teaching a valuable method of undergraduate instruction because they claim to study more, understand material better, and earn higher grades. Keywords: Calculus, Formative Assessment, Perceived Utility, Precision Teaching

Introduction

The recent research conducted on calculus courses suggested that conceptual exploration and science lab-like group work supports student engagement, understanding, and achievement (Hsu, Murphy, & Treisman, 2008; Oehrtman, 2009). These efforts also increase students' grades, but can leave students with the same misconceptions about the material regardless of pedagogical approach. Furthermore, few studies have investigated how to identify study misconceptions within exploratory calculus courses (Garfield & Ben-Zvi, 2007; Hsu et al., 2008; Nickerson & Bowers, 2008; Rasmussen & Marrongelle, 2008). Calculus instructors remain unclear which instructional methods to pair with these new activities, especially given the broad amount of context they are expected to cover.

In this study we¹ explored a potential solution in order to help calculus instructors identify misconceptions prior to lab activities that occur in class. After noticing that some instruction time was not relevant for most of the class, we began wondering how we could determine what information students had coming into a given lecture day. Rather than large-scale assessments that were lengthy for students to complete and teacher to grade, we began looking at how daily formative assessment that occurs over material yet to be covered could help teachers identify material students struggled with and excelled at prior to the material being covered in the course.

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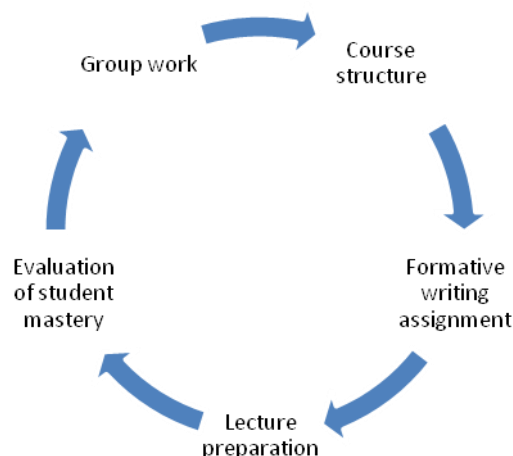
For example, by collecting a formative assessment over multiplying binomials the day prior to the class meeting where multiplying binomials would be used as a step to computing the derivate of a factored polynomial, instructors could make informed decisions about how to spend the class time. If 95% of the students indicated understanding how to multiply binomials, then the instructor could feel justified in jumping straight into the important material students have not covered. Or, if over half of the students had problems with multiplying, the instructor would feel justified in the spending time to do an example, or multiple examples, depending on the severity of the misunderstanding indicated.

The main goal of this technique, which we term precision teaching, is to inform the instructor what concepts students struggle with in order make instructions activities tailored to this information. We also developed this dynamic instruction practice to create time to add the activities research suggests to the syllabus without sacrificing content.

Given our experience, we acknowledge how precision teaching requires more preparation than traditional classes, but will argue the time is worth the outcomes. This study is a result of our work aimed to document the effects of precision teaching in a calculus course. We feel it is important to formally document the perceived utility of the teaching technique, to provide the justification for other calculus instructors on the merit of precision teaching. Teacher fidelity to the method is an important concern for the outcomes of any new pedagogy, as Kilpatrick (1997) highlights.

Precision teaching was an instructional method based on the weekly decision cycle outlined below (figure 1). The amount of content to be covered each week was designated at the start of the unit. The day before the material will be covered in class, the students completed a pre-lecture writing activity, called a reading sheet. Reading sheets consisted of approximately five short answer writing questions about the principles and concepts in the section. Based on the mistakes on the writing assignments, lecture notes focused on these problematic areas; topics 80% of the class answered correctly were not addressed with formal class time. If a student is part of the 20% who incorrectly answer a question, their pre-lecture sheet was returned with detailed comments on their mistake, and they were encouraged to attend office hours for additional help. After lecture and summative assessments, the concepts that remained troublesome by the class as a whole formed the basis of the weekly group work capstone assignment which incorporated technology for students to further explore and practice. At the end of the class day, the instructor decided if the class has mastered the material well enough to start new material, or one of the four unscheduled class periods normally used for test review to spend additional time on this set of topics.

Figure 1. The precision teaching cycle



An example of the precision teaching process can be seen in a calculus class meeting four days a week (MTWTF), where the Wednesday's lesson involves teaching the chain rule. On Monday, a reading sheet would be given to the students that included basic questions such as "What are the two forms of the Chain Rule?" and "Find the derivative of using the power rule, product rule, and chain rule (the power rule and product rule would at this point be review concepts for the students)." On Tuesday, the instructor would collect the completed reading sheets from the students, and would evaluate them after class to see what patterns emerged. For instance, if almost all students (more than 30 of the 35 who completed the reading sheet) could correctly write down the two versions of the chain rule, the instructor would then alter her Wednesday lecture to not rewrite the formulas for the students. Also, if the instructor notices most students had trouble with the chain rule, she could devote more time on Wednesday to emphasize that the three rules generate the same answer; if students did poorly on the chain rule problem, the instructor could plan a supplemental activity with additional scaffolding to assist students during class on Wednesday.

Our study aimed to address Black and Wiliam's (2009) unanswered call for additional research investigating precision teaching at the post-secondary level. This study addressed the following question: What is students' perceived utility of precision teaching? The driving force behind investigating precision teaching was the thought that formative assessment could (a) be used by instructors to make decisions to productively use class time, and (b) improve study skills for the students, which will lead to higher achievement and possibly better understanding in calculus.

Literature Review

Given the recent research into hot cognition (Kuhn, 2007; Pintritch, Marx, & Boyle, 1993), without students perceiving a technique is worthwhile, it will not succeed. Recent qualitative studies that flexible pedagogy and meeting students where they are at 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), but precision teaching may also provide social and learning support for these students; two other parts of the researcher's suggested framework. Finally, pedagogy that empowers the students and gives their teachers structure in how to help at-risk students succeed in a high failure course like calculus may help to reduce burnout on the young and often inexperience instructors (Santoro, 2012).

Formative assessments are the driving force behind precision teaching, since these assignments provide the data that forms the basis of an instructor's decision for how to approach the next class. After summarizing the prior literature on formative assessment, we argue our study adds to this body because we used a qualitative paradigm and focused on students' affect and perceptions rather than measuring achievement gains. Given that there is little literature on the use of formative assessment with undergraduates it is necessary to examine whether the additional grading time is worth the commitment, and our study aims to address this lack.

The focused instruction of precision teaching in clinical lab settings has been about measuring achievement gains (Hartley & Davis, 1976; Miller, 1992). In the classroom, little has been done with precision teaching except for one intriguing study. Low-ability math students on an aptitude pre-test that were precision taught outperformed high-ability students who were taught with general lesson plans from the textbook (Chiesa & Robertson, 2000). Precision teaching raises all students' achievement levels though low-achieving mathematics students show the most gains in a precision taught course (Gallagher, Bones, & Lombe, 2006).

The use of formative writing assignments in mathematics, an essential part of the precision teaching process, has been studied in secondary and post-secondary levels such as college algebra and calculus. Black and Wiliam (1998) describe formative writing assignments consist of short one or two paragraph assignments due before class; these researchers did not examine how the assignments could be used to alter the courses or how students viewed the assignments. Hoek, ven den Eeden, and Terwel (1999) attempted to describe the effects writing assignments provided; they found the assignments provided a great deal of information about student understanding to the teacher and the researcher since many students struggled with conceptual meanings even after computations were mastered.

Focusing on undergraduate classrooms, Shield and Galbrath (1998) investigated the effects of written formative assessments that asked students to define the vocabulary words and write down the theorems that would be covered in a future lecture. These assignments which are later used by the instructor to create modified lecture notes; for instance, the elimination of writing basic definitions in class (Shield & Galbrath, 1998). Student achievement and conceptual understanding significantly increased, but this increase was likely because the instructors participating in the study had more time for group work and class discussion rather than any inherent value in the writing assignment itself (Rouet, Vidal-Abarca, Erbol, & Millogo, 2001)). This type of formative assessment typically focused on information-retrieval only, relating to the lower level of Bloom's taxonomy (Krauthwohl, 2002).

The abovementioned articles on formative assessment or Hartley's characterization of precision teaching are not sufficient to understand how formative assessment, or our non-behaviorist characterization of precision teaching, would function in an undergraduate mathematics classroom. All of the research summarized above was quantitative, so we have no understanding of how students perceive formative assessment. With the exception of Shield and Galbrath (1998), the participants were not undergraduates, and were often in a clinical rather than a naturalistic setting. This purpose of our study was to investigate if undergraduate mathematics students, who are presumably more sophisticated learners than the participants in these studies, could perceive benefit from adaptive instruction based on formative assessment, a practice we called precision teaching.

Limited research on perceived utility indicated that a lack of perceived utility is detrimental to an endeavor. According to the Game Theory, if a person or organization does not perceive an action as valuable, it will not enter the decision loop on how time spent on tasks can be optimized (Fishburn, 1970). There was evidence that lack of perceived utility may be only on the part of the student or the teacher – if both parties do not see value the instructional technique fails (Kilpatrick, 1997). Hence, it is vital to check that a new instructional technique is perceived to be useful before committing any resources to implementation, as Kuhn (2007) and other hot cognition researchers maintain.

However, when students (and instructors) saw utility in an instructional technique, there were several positive consequences. First, the perception of usefulness may increase both general and mathematical motivation (Ames, 1992; Hannula, 2006). Perceived utility of an instructional technique also may cause students to place more value on a course, the major that includes the course, and the value of an undergraduate degree in that content area (Ginns, Prosser, & Barrie, 2007). The strongest halo effect is in cohorts, like First Year Experience, or within courses taken primarily by majors (Kuhn, 2007; Richardson, 2010).

Overall, precision teaching appeared to have merit, but remains unexamined with undergraduate mathematics education. While there was literature about the benefits of precision teaching, a thorough review of the literature showed students have not been asked about their opinions of the precision taught courses; this is precisely why we intended to

address our question using a qualitative approach. The methodological lens we used was that of basic qualitative research, which we describe in more detail in the following section.

Methods

Theoretical perspective and research design

Given the dearth of literature on our population of interest, we employed a basic qualitative design, as characterized by Merriam (1998). Our primary approach was an interview study, which we triangulated with classroom observations, member, peer and expert checks.

We used symbolic interactionism as my theoretical perspective in this research, since it allowed us to infer affective beliefs students held through their actions and conversations. There are three main components to symbolic interactionism (Bruner, 1986). The first premise is humans act towards things on the basis of the definitions they have for that thing. For instance, someone behaves in a mathematics class based on what their definition of a student is; from observation we may infer parts of the student definition of a particular person. Symbolic interaction also claims all of these definitions are socially constructed (Bruner, 1996), so how upsetting failure is to a particular student will be constructed by interacting with peers and their environment through a socio-cultural lens. Finally, these constructed definitions are acquired and changed by the learner through an interpretive process by interacting with their environment; this process is an iterative one where meanings are refined whenever they are used (Bruner, 1986).

Setting

The participants of this study consisted of students who enrolled in introductory calculus at a mid-sized public Rocky Mountain region university that was being precision taught. The course section we observed consisted of approximately 40 students, a typical class size for the institution. Two thirds of the students in these calculus classes had prior exposure to calculus topics; half of those students had previous exposure to calculus; this is slightly higher than the estimated national average of calculus exposure before undergraduate calculus of 40% (Ganter, 2006). Students sat at five person tables in class, which helped to facilitate the group work. The precision taught course was an early morning class, and the instructor had five years of undergraduate teaching experience and taught introductory calculus multiple times. The students were aware that their class completed extra pre-lecture writing activities, which were called reading sheets, but they were not aware that the course was precision taught. We chose not to inform the students about the nature of the instruction in an attempt to avoid biasing their perceptions of experiencing precision teaching.

Participants

After securing institutional IRB approval from the institution our participants attended to conduct our research, we invited the entire section of the precision taught class to participate in our study. We used stratified random sampling to select the eight participants who appear below (Table 1). We chose to employ this sampling method since the literature suggested that high and low achievers have different gains from precision teaching, and so we wanted to ensure that we talked with students in every grade band; our sample coincidentally included students of a variety of ages and most of the typical majors that enroll in introductory calculus, in that sense our sample could be considered maximum variation;

we have included students' ages and majors to illustrate how these students are typical students in a first semester calculus course. The participants' pseudonyms were chosen during the interview and were used throughout the research. We described the details of these interviews further in the next section. The reason no D students were selected to participate in the study was that no students had a D at the time of data collection.

Table 1. Description of the participants

A Students	B Students	C Students	F Students
Sam, 21 Molecular biology/Biochemistry	Andrew, 28 Mathematics Education	Edward, 25 Geology	Tim, 19 Meteorology
	Jennifer, 19 Special Education	Betty, 19	Tiffany, 21 Music
Madison, 18 Pre-Health	Mathematics Minor	Chemistry	Mathematics Minor

Data collection

After we collected consent forms, we spent some time observing participants before scheduling interviews. Author 1 taught the course and wrote in a journal about her observations of the class after each session throughout the semester. Author 2 and Author 3 observed the precision taught class twice and observed a traditionally taught class twice to establish an observational baseline. After the discussing the observations and decided on a sampling technique, we drew a sample of participants from the precision taught class and scheduled interviews. The original male B student sampled could not participate due to his work schedule, but the second male student earning a B agreed to an interview. The other seven people in the original sample participated in the study.

Each participant was interviewed once using a recording device; the interviews lasted 20 to 30 minutes and occurred during the sixth week of the 15-week fall semester. The interview questions we asked all students were:

1. How is the class going for you this semester? What is and is not working for you?
2. What could be changed to make things work better for you?
3. What are your thoughts on the (lecture/reading sheets/group work? (3 questions)
4. What do you think the purpose of reading sheets is?
5. How do you study for this class?
6. What will you remember about this class?

Based on the student's responses, we asked slightly different probing questions in each interview. We chose to begin with these main question since our review of the literature suggested the use of formative assessment, such as precision teaching, would be most likely to impact the students in the abovementioned areas.

Since Author 1 was both the researcher and the instructor, we chose to use deception in the interview setting in an attempt to reduce bias, a precaution approved in our IRB application. Author 3 was presented to the students as the lead researcher, and Author 1 was

assisting. During interviews, Author 3 was the lead interviewer, and students understood from the interview script that they could ask Author 1 to leave at any point throughout the interview. We felt that since the interviews happened late in the semester, the participants were more comfortable with Author 1, and thus more likely to feel free to share negative information about their experiences.

We journaled immediately after each interview to maintain an audit trail. Both Author 3 and Author 1 would spend the fifteen minutes immediately following each interview by free writing in a word document in order to expand their field notes while they were still fresh and to record our initial impressions of the interview and make note of statements the participant made that seemed particularly pertinent.

Role of researchers

Our interest in is based on a shared interest in applying formative assessment in the classroom to support learning. Since one of the challenges of formative assessment is implementation, we hoped that precision teaching's more structured approach to formative assessment will lead to more widespread adoption of formative assessment in undergraduate mathematics courses. We acknowledge the following potential biases in the study: Author 1's dual role as a researcher and the course instructor may have made students reluctant to share negative feelings about the course in the interviews; we acknowledge this affects the edibility of our results. On the other hand, Author 3 has no preconceived notions about precision teaching or calculus instruction, because she has little teaching experience in calculus. Author 2 had no direct contact with participants; his role was primarily researcher triangulation and in data analysis. Our biases were ameliorated with collaboration, and with the use of some deception in the data collection, which we have described above.

Data analysis

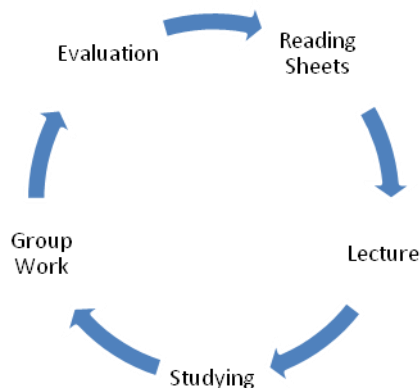
Once transcription was complete, all data was separately coded by each researcher (Corbin & Strauss, 2008). After we discussed our individual coding and arrived at a consensus, a person familiar with our literature peer-checked our initial analysis. Next, we condensed our original twenty code words down to ten themes. We defined a theme to be something that at least 7 of the eight participants mentioned. Later, when it became that our participants fell into two distinct subgroups, we considered a subgroup specific theme to be one that all members of the subgroup mentioned. Then we wrote up our findings for each participant and asked each participant to give us feedback on the accuracy of his or her write up; four participants agreed and offered feedback, the other four were provided their transcripts and analysis but declined to communicate any changes. We then revised the findings for each participant and finalized our categories. Based on the previous literature and the participants data, themes emerged that were member checked by four participants (Sam, Jennifer, Andrew, and Tiffany), peer checked, and expert checked by a qualitative research methodologist and a mathematics educator whose own research employed qualitative methods (Merriam, 1998). While students perceived precision teaching differently than the cycle described in the introduction, they believed that the way the class was taught benefitted both their grade and their learning.

Findings

Students saw the way the class was taught as a cycle, but they focused entirely on their actions during a week of class, rather than cycle presented in Fig. 1, so their cycle varied

slightly (Fig. 2). The students were informed on the first day of class that they would complete pre-lecture activities in this course but there was no mention of precision teaching in the classroom. Students thought the week began with the reading sheets, the pre-lecture writing activity, that preceded lecture, and saw their own studying as the activity between lecture and group work.

Figure 2. Students' precision teaching cycle



All students talked about the usefulness of precision teaching in terms of these five categories, but as earlier literature suggests, the student responses in each subcategory were split into two classes based on the current grade of the student. In general, the students who earned A's or F's were somewhat indifferent to precision teaching, while the students who earned B's or C's thought precision teaching was valuable, which aligned with earlier literature (Gallagher et al., 2006).

The remainder of the findings examines the differences in perceived utility these groups of students had along their precision teaching cycle, starting with the reading sheets at the beginning of the week.

Perceived Utility of Precision Teaching

Reading Sheets. Reading sheets, the name of the formative writing assignments in the precision taught course, were the first exposure students had each week to new content. The students who earned A's or F's disliked reading sheets, but had different reasons for their feelings; while the students who earned B's or C's felt the assignment benefited them, they did not care for reading sheets.

The students who earned an A thought that reading sheets were pointless busywork, as evidenced by Sam's comment,

To be perfectly honest, I am not a big fan of them. They do not deserve much time. I don't really see too much of positive benefits there. For some people, it helps for a certain degree with some problems.

Sam conceded later in the interview he could tell they were helping others, but they wasted his time. Since he is exhibited high motivation and mathematical achievement in class, it is unlikely Sam would be challenged in any general classroom setting, a fact he also acknowledged. Tiffany, a female student who was failing at the time of her interview, didn't care for the reading sheets for other reasons:

The work sheets frustrate me because I don't really understand the book very much. I can't follow it very well, so it would be more beneficial to me if I do them after I learn from you. [The worksheets help] Not so much I think that all the information is good but I have hard time finding the answers.

Sam and Tiffany both reported that they spend ten minutes or less on a typical worksheet; three of the four students we interviewed who earned an A or an F completed fewer than 75% of their reading sheets. Since the reading sheet questions are either above or below the students' Zone of Proximal Development (Vygotsky, 1978), this is a rational choice from their perspective.

The students who earned a B or a C also spent about ten minutes on a reading sheet. None of these students expressed positive feelings about reading sheets, but thought reading sheets had some value, as illustrated in Edward's statement, "I hate reading sheets. They make me study every day." All eight participants felt reading sheets, which only contained conceptual knowledge questions, could be improved with the addition of a problem: "I think if you had the vocabulary and then at the end of the work sheet you have one problem to work it out, not only the vocabulary, then you see the vocabulary working for you for the class," a sentiment best articulated by Betty that all of the other students earning a B or a C agreed with.

Lecture. When starting each lecture, the instructor would state the goals for the day and make an explicit connection to the questions raised on the formative reading sheets. We asked students in their interviews if they perceived the lectures tailored to pre-lecture student questions were more helpful than usual; student responses were again split by grades. The students who earned A's or F's felt lecture was not noticeably different from any other college math class: "Lecture is the same as any other math class. You come in and take notes," Madison said. Betty, agreed when she said that lecture did not make as much difference as the class size did-with a smaller class she felt safe to ask questions. Of all of the seven participants, Betty is the only one who participates in class – in fact she was one of the few students that asked questions in class.

As a foil to the students in the paragraph above, the students who earned B's and C's actually found lecture more helpful than their prior mathematics courses, though none of them participated during class. Jennifer stated, "[The lectures] are more helpful, my teachers taught differently in high school." Most participants felt lecture already answered their questions, but Andrew suggested the early class meeting time had more effect than anything else; he believed that the early class meeting time tended to make the class more passive and less likely to ask questions during class

Studying and group work. The biggest difference between how students saw precision teaching was in the way they approached group work and studying. Students who earned either B's or C's studied throughout the week, in the same groups as in-class activities, whereas students who earned either an A or an F studied on the weekends in large blocks of time by themselves. This was the only place where the two groups of participants' description of their weekly calculus activities differed.

Madison used her two weekend study sessions to work on old material and prepare for the next week:

I try and read in advance. So I kind of know what she talks about next otherwise I will feel lost and I write down everything she puts on the board, everything, so I have notes to do the homework with over the weekend.

On the other hand, Tim also studied in large blocks, but used his time differently, “When I study I usually just do all my homework and quizzes. I just redo them over and over again and again until I get it.” The biggest difference between how A and F students studied was how and when they studied, all students reported spending about two hours on calculus during the week and eight hours on the weekend.

The students who earned either a B or a C did most of their studying during the week, felt group work was very effective for them, and used the weekend for homework. As Edward stated in his interview:

I find studying with that smart kid [at my table] is helping me. Probably I spend one and a half hours a week, spread out over the week on calculus. I spend one hour a week on my biology and the same on geology.

Edward studied for only a few hours each week, but it was comparable to the time spent on science courses and courses in his major; he felt this was effective for him. While Jennifer and Betty had similar habits to Edward, Andrew reported studying 5-8 hours each week because, “Calculus II has not gone well for me [pause] twice. I must have missed something the first time because we were allowed to have a notecard on the tests. I can’t afford to do that again.” The other three students who earned B’s or C’s studied more than Edward did, but had similar studying habits, all participants formed study groups that met at least weekly without any encouragement on the instructor’s part. Jennifer’s group, which consisted of two A and one B student, met twice a week for an hour, once to talk about the material taught that week, and once to work on homework or projects together.

The students who earned either an A or an F were not opposed to the idea of group work when they did not perceive themselves to be the best or worst student in the group; self-perception as an outlier in a group tends to lower mathematical motivation (Hannula, 2006). Potential evidence for this was Sam’s statement, “I do not like collaborating with people but it is nice that I can check with Laurel when I am questioning my steps.” Tiffany felt that the usefulness of group work depended on the activity: “Sometimes I think it’s [group work] is good and I get a lot out of it, but other times I think I’m just slowing everyone down”.

Betty worked in a group this semester with Sam, an A student, Laurel a B student, and Preston, who was failing. Betty felt the only reason she eventually passed with a high C was she had the chance to, “Double check with Sam and Laurel before I had to do it for real on the homework.” Andrew, the education major who started his education coursework, was very passionate about group work, and thought it was very effective for his group, which extended beyond the classroom:

Eventually, when we are in team mode and you're helping each other out it is very effective. From where I sit in secondary ed., I can see how that is affecting us, and it's very effective. This is a good thing because maybe sometimes it spreads to the other tables after class and in the dorms when we talk at night, not me I don't live in the dorms, but I know that Scott, Justin, and Kelly talk with other classmates outside of class.

Evaluation. All of the participants except Sam, who believed precision teaching did not help him at all, felt doing the reading sheets and engaging in precision teaching would help them in the class and increase their grade. However, Sam turned in far fewer reading sheets and other assignments as the semester wore on. In a follow up discussion, he admitted that he “got lazy.”

Overall, students saw pieces of precision teaching as valuable, but they were not enamored with the reading sheets. Since all participants were planning to take Calculus II, we asked them if they could choose between a precision taught section or a traditional section, all other aspects being equal, what section would they choose.

Of the students who earned an A or an F, Sam was the least enthused with the idea of taking another precision taught class; he expressed no preference between the two teaching styles. Tiffany, on the other hand, was the most positive about the prospect of another course in precision teaching:

I would probably choose the precision teaching and put up with the reading sheets because the group work is pretty helpful and still learn from the lecture as long as the text is good and I have a group. I compensated this way just like when [my previous instructor] lectured a lot and I was able to get by with my group.

The students who earned a B or a C exhibited a strong preference for precision teaching. All four participants stated they would choose the precision taught Calculus II, and would even rearrange their schedule around the time of the precision taught class. Jennifer said, "I would feel more comfortable in a precision taught class. I know what is expected, and I would not have done this good without my group to work with and do [assignments] with." Andrew, a nontraditional student who failed Calculus II at three other institutions, felt a precision taught course would finally get him over the hump:

I would probably say from previous experience, um, calc II is much more difficult so...probably I need to be reading more and working with others and with my personality, I have to sign up for precision teaching because I don't seek out groups naturally.

Overall, though some parts of precision teaching like reading sheets were less popular than others, no one disliked precision teaching enough to avoid the instructional method in the next class. A comparison of the two categories of students appears below in Table 2.

Table 2. Comparing perceived utility of precision teaching by grade

Theme	Earning an A or F	Earning a B or a C
Reading Sheets	Busywork; Not a reason to attend class	Helpful; Will attend to turn in
Lecture	Typical of a math class	More helpful than usual
Studying	Solitary, only on weekends, large blocks	In groups during weekdays, assignments on weekends
Group Work	Good if not best or worst	Vital to Success in course
Evaluation	Wouldn't avoid precision taught Calculus II	Would seek precision taught Calculus II

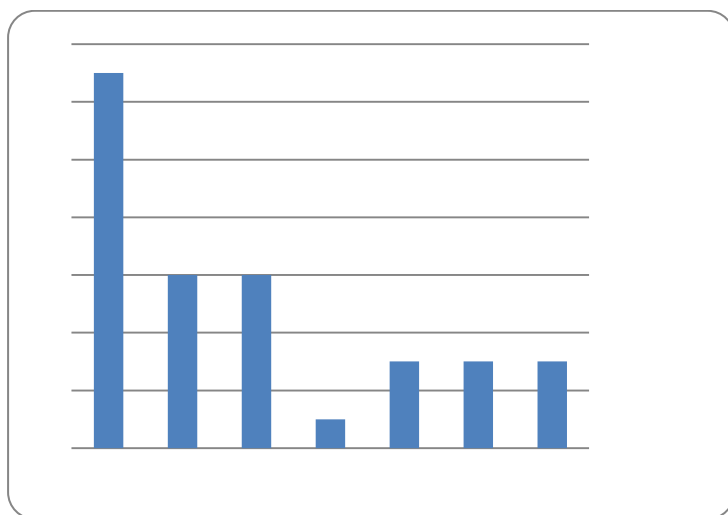
Discussion

Although the students that earned an A did not see the use in precision teaching for themselves, most were willing to concede that it appeared to help their group members. It is unlikely that these students would have felt any more challenged in a traditionally taught course. The other students that passed the course felt that precision teaching made a huge difference in their ability to learn the material and gain understanding at the pace the course ran at. The three students that withdrew did so because they failed the Gateway exam, a high stakes exam that was not part of precision teaching. The students that stayed in the course and still failed did not see utility in precision teaching, but they also completed the reading sheets less than their more successful peers. Given that the failure rate was lower than usual and the group of students the literature suggests saw the merit in precision teaching, this pedagogical technique is worth further investigation at the undergraduate level.

Implications

There were several consequences that resulted from the students' perceived utility of precision taught calculus. The participants all reported the act of completing reading sheets encouraged them to work in a more focused way on calculus, and they speculated it would help them improve their study skills in future mathematics classes. Students felt their grades were higher and they understood the material better than they had in previous mathematics classes; the grade distribution of the course aligns with these statements (Figure 3). At the research institution, a grade of W indicated that the student formally withdrew from the class, while a UW indicates the student ceased attending with more than 2/3 of the semester remaining but never formally dropped the class.

Figure 3. Final grade distribution



Andrew also mentioned being precision taught influenced his teaching philosophy for his future mathematics classes, so this instructional technique may be especially valuable for prospective teachers. When he was interviewed a year later, after he had pre-student taught lessons in the classroom he stated:

I thought how Calc I was taught really helped me learn, but I didn't really appreciate what happened until I started teaching. It was like you used those

reading sheets to know what to focus on. It made a big difference when I taught my students-I wasn't flying blind.

For instructors and administrators, this indicates that precision teaching has the potential to change how pre-service teachers think about pedagogy. Further, 86% of the precision taught students passed calculus, which is significantly higher passing rate than the 60% average passing rate at the institution studied. The students that earned a B or a C in the class increased their self-efficacy and felt that precision teaching supported their learning; which the literature suggests increases student retention (Elliot & Gillen, 2013; Wyatt, 2011).

Limitations

There were several limitations to consider with the results. Half of the students did not member check their analysis, and the small sample size limits what conclusions may be drawn from this study; further quantitative research is needed to follow up on these results. While students were informed at the beginning of their interview they could ask Author 1 to leave at any time, no student did so and hence there was a possibility for a halo effect in the data. Though the participants in this study were all of different majors and ages, all participants were Caucasian; other cultures may feel differently about precision teaching. There were also several potential confounding variables that may have had an effect on the final grade distribution including the instructor, the course time (8 am), the students, and frequency of assessment.

Directions for future research

The first follow up study to is to repeat this design with additional instructors, to see if precision teaching translates to other instructors. Next, since the preparation time for a precision taught lecture is currently longer than many instructors are willing to contemplate, research on exploring technology mediated formative assessment needs to be conducted, since this might streamline precision teaching enough to make the technique acceptable to a wider range of instructors.

Andrew's comments about precision teaching indicated this course changed his teaching philosophy, begs the question, can precision teaching content and methods courses for educators have a similar effect? Can precision teaching work as an instructional method in early graduate courses, where there is generally variation in previous mathematics exposure? Further qualitative and quantitative work on precision teaching is needed to begin to answer some of these questions.

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