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Using Wikis to Support Student Inquiry in Large Math Classes

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Abstract: This article explores the use of wikis to support student inquiry in large classes. The traditional tools of inquiry-based learning, such as group work and in-class presentations, are described and their applicability to large classes is assessed. Online learning management systems, and Wikis in particular, can help to address issues of scale and meet instructor needs. Wikis offer a unique collaborative space for writing, and this article surveys the uses and benefits of wikis. In particular, issues of anonymity, stereotype threat, and inclusivity are addressed. These observations were made while using MediaWiki to support student inquiry in a multivariable calculus course.

1. Introduction: Wikis and IBL

1.1. Inquiry Based Learning

There are a variety of different practices which constitute inquiry based learning. Consider, for example, the following definition given by Maass and Dorier:

> Inquiry-based mathematics education (IBME) refers to a student-centered paradigm of teaching mathematics and science, in which students are invited to work in ways similar to how mathematicians and scientists work. This means they have to observe phenomena, ask questions, look for mathematical and scientific ways of how to answer these questions (...), interpret and evaluate their solutions, and communicate and discuss their solutions effectively. [8, p. 300]

Such a broad definition allows for a range of implementations. IBL is a student-centered pedagogy that emphasizes the importance of students' engagement with mathematical practice and their ability to communicate their findings. The intent is for students to engage in ways which model or simulate the mathematical practices of experts. Education researchers have tried to distill this in to a practicable framework for classroom pedagogy. Laursen and Rasmussen [27] identified four fundamental principles underlying much of the work on inquiry based mathematics education:

1) Student engagement in meaningful mathematics
2) Student collaboration for sensemaking
3) Instructor inquiry into student thinking
4) Equitable instructional practice to include all in rigorous mathematical learning and mathematical identity-building

These fundamental principles overlap and are mutually supportive. The list of properties which characterize IBL has been alternatively narrowed and expanded by different educators. There is a wide range of what instructors feel constitutes inquiry based learning, as shown by a survey of teachers in twelve European countries [9]. For example, three leading practitioners of IBL [12] have identified two core principles:

1) Students work on rich mathematical tasks
2) Students work collaboratively to create their own mathematical understanding

Although this formulation of inquiry based learning is very broad, it has been proven to be effective even at large scales. The effectiveness of IBL has been studied across four universities in the United States, spanning over a hundred course sections, and has been shown to improve student learning outcomes, especially for women and other marginalized in mathematics [26]. We will emphasize the collaborative aspect of inquiry based learning. We view it as a student-centered pedagogy which encourages the growth and development of a learning community, through collaboration and sharing of information.

1.2. Wikis

Wikis are interactive websites which facilitate the process of collaborative writing and knowledge sharing. Users log on to a wiki, access various pages, and perform edits. A database manages the edits, keeps track of a history of revisions and edits, and stores additional data related to the textual content such as images or videos. Ward Cunningham, the creator of the first wiki, noted that a wiki is "the simplest online database that could possibly work" [29, p. 15]. The first wiki, The WikiWikiWeb Project, was put online as a central location for storing information about the Portland Patterns Repository, a project dedicated to collecting high-level patterns used in computer programming. For more information about the early history of wikis, see [7].

As software, wikis are pedagogically neutral. They are not necessarily used for teaching and learning. Despite being pedagogically neutral, wikis have many applications in higher education. For example, a wiki can be used as a collaboratively written textbook [22], as a lab notebook [28] for exploratory mathematics, or as a solution manual to a course text. For an overview of the use of Wikis in higher education, see [45]. Moreover, wikis can be used as tools for supporting student inquiry. When we make the construction of a wiki an integral part of our course structure and embrace what has been called the "wiki way" [29], we naturally develop a sense of active, community oriented, constructive teaching. The wiki way is to build a document piece by piece, collaboratively, with support from a group of active editors.

2. IBL and Largeness

The foundational principles of IBL, that students work on rich tasks and collaborate to create their own understanding, can be interpreted in many different ways. The IBL community is actively experimenting to find the best practices when implementing these ideas. One model of IBL taught by the Academy of Inquiry Based Learning at their influential summer workshops as a format for using IBL in mathematics involves students working through structured hand-outs, solving problems inside and outside of class, and presenting their solutions orally to the class [18, p. 62]. When solutions are presented orally, the instructor moderates a group discussion where the merits, weaknesses, and style of the presentation are discussed. To get a sense of a student's growth throughout the semester, it is advised that every student present multiple times throughout the semester.

The emphasis on oral presentations as a method of practicing IBL has unintended consequences: it limits the scale where IBL is practicable. First, consider the issue of scale. Suppose that a class has sixty students. If each student gave three presentations, each about ten minutes, then the class must spend thirty hours engaged in presentations, which represents the overwhelming portion of many a course's in-person meeting time. At many universities, it is typical to have 150 students per class. At such a scale, it is infeasible to do a completely presentation-based IBL course.

Another aspect of scale is the size and number of groups a single instructor can manage. In an IBL class, it is fairly typical for students to work together in small groups [12]. In my experience, a single instructor cannot handle more than a dozen small groups of three to four students. Research has shown that group sizes of three to five attain similar learning outcomes, but there is a sharp drop-off in learning outcomes when groups get much larger than five people [11]. However, in my experience, it is hard for students to interact meaningfully in bigger groups. Usually, one or two students take the lead, and the remainder of the group is left behind. This puts the cap on a group-work based IBL class somewhere around thirty to fifty students. To handle bigger classes, one can bring in TA support or other co-instructors. Both of these options are resource intensive.

3. Learning Management Systems and Wikis as Aids in Meeting Instructor Needs

Scale is a major constraint in higher education. As the scale of a class increases, the demands on faculty and teaching assistants increases proportionally. To ease the pressures of scale, we must use mechanisms that scale well to large classes. More and more, institutions are using learning management systems (LMS) to handle the ever-increasing volume of students [33] [43].

There are many learning management systems that instructors use to administer their courses such as Canvas, Moodle, and Blackboard. These sophisticated online software suites are capable of handling a large volume of student work, and recording students input. The most common use of an LMS is for content delivery. Learning management systems such as Moodle and Canvas provide mechanisms whereby students may discuss and collaborate, but these are not generally the central use of the LMS. Generally, learning management systems are structured hierarchically, with instructors having a greater amount of power to create and distribute content. For example, only instructors and teaching assistants are able to create class-wide announcements in Canvas [19].

In contrast, wikis are non-hierarchical, user-generated, and promote user interaction. The interconnected structure of a wiki emphasizes topics and meaning over chronology and content-creators. In this sense, wikis put knowledge first and users second [35]. Some users may have administrative powers, such as the ability to create new users or block users from using the wiki. These abilities allow administrators to maintain the wiki and protect articles from vandalism. However, almost all users have the same privilege on a wiki. Thus, the hierarchy is much flatter than a traditional LMS. For example, MediaWiki allows users to freely create or edit pages, with no visible distinction between content created by administrators and editors. This is in sharp contrast to an LMS where students may only create content in limited environments, such as discussion forums, quizzes, or assignments.

On a wiki, people create and manage content that is broadly distributed among the community, and they interact directly through this process of co-creation. The collaborative and community focused nature of wikis supports the notion that meaning-making is a communal practice [10]. The learning community is central to the notion of using wikis in the classroom. Scardamalia and Bereiter [40] were among the first authors to point out the importance of computer supported learning in relation to learning communities.

If a wiki is going to be successful and not make unreasonable demands on the instructor or teaching assistants, then students must develop a sense of autonomy in editing the wiki [21]. They must be authors and creators of knowledge who are free to make their own choices about the direction that the wiki is taking and what needs moderating. If students feel the need to ask for permission, then the high-level task of moderating the wiki will quickly become untenable for the course instructors.

4. Uses of Wikis and their Applicability

4.1. Collaborative problem-solving spaces

As outlined above, wikis allow for collaborative work to an extent not possible with other learning management systems. In particular, a wiki can be used as a framework for collaborative problem solving and meaning-making. In many classrooms, mathematics is enacted as a question-and-answer game between the expert instructor and the novice student. The instructor poses problems, and the students work individually or collaborate in small groups to solve the problems. The task of meaning creation is left to the student. On a wiki, students can collaborate to create their own sense of meaning and structure. The process of meaning creation is distributed among the whole class, and the instructor is able to act as a supervisor or guide for this process.

When teaching with wikis, instructors need to be mindful to teach students collaborative work habits. The process of collaboratively editing a document is so antithetical to their usual experience of mathematics, that students need to be eased into the process. Many students are averse to editing other students' work because they feel that their edits will be seen as aggressive or overly assertive [21]. Other students are concerned that collaboration is too similar to academic misconduct or cheating. When designing a wiki-based course, allow time to ease students into a mindset which encourages collaborative problem solving. Make students aware of the limits of academic misconduct, and how their efforts at collaboration are viewed.

On a wiki, students can edit the mathematical content put forward by their peers. If a problem is put on the wiki by the instructor, several students can make attempts at it, and the community can decide which solution is best or more appropriate. In a proofs-based course, students are able to work on a single proof collaboratively, annotating and expanding upon it until it meets the level of rigor or clarity expected by the learning community. In a calculation intensive course, students might work to explain or embellish a calculation to describe what is happening during each algebraic manipulation. If someone does not think that the proof or calculation is sufficiently clear as written, then they are free to create their own version of the same page and modify the proof or calculation. The mechanisms for copying and pasting material between various parts of a wiki are straightforward and well documented. A student can create their own version of a proof, and link to it from the original proof. Community norms or rules of editing etiquette must be established to determine when this would count as academic misconduct, or plagiarism.

4.2. Sandbox zone for open-ended self-expression

Wikis are blank canvases for content creation. They have the bare minimum of structure needed to operate and allow for content to be stored and accessed. They do not have a pre-specified final end goal in the way that many writing assignments do. Ruth and Houghton [39] point out that this lack of a definite goal can be both exciting and challenging for students. Students can create any kind of structure that they like within a wiki and create their own web of meaning from the material that they have. In this way, they are both constructing knowledge and constructing their own digital learning environment.

Consider the following example from MAT 232, Calculus of Several Variables, one of my courses in which I used wikis. During the middle of the semester, some students asked if they could make an addition to the navigation bar of the class wiki. They wanted a visually central link that would point to a page for storing "Notes." This page would allow them central access to all the students' notes from the class. During a class break, we added the "Notes" page, and it quickly filled up with material contributed by students who had been making PDF notes on tablets and other electronic devices. This was a useful addition to the wiki, curated by the students themselves, in a way that would not have been possible in a traditional learning management system. Whatever structure students want to create inside the wiki, they are free to create.

However, this freedom of expression comes with a cost as it can be difficult to engage students in tasks which are amorphous and unstructured. Page and Reynolds [35] noted that students engage more with digital learning contexts when there is an authentic and motivated reason to use the online resource. If a digital learning environment is seen as a gimmick, or a novelty, then it will not be engaging. To make full use of a wiki, it needs to be framed in such a way that students will engage with it. To take a popular example, Wikipedia has a clear purpose. It is an online encyclopedia which accepts articles, edits, and revisions from the public at large. Editors who contribute to Wikipedia do so for a variety of reasons, but their work is seen by the public as a part of an encyclopedia. In this way, Wikipedia's clear goal of providing a free online encyclopedia provides sufficient pull for people to volunteer their time to contribute to it.

If a wiki is used to support student inquiry, then it must have a clear purpose. Students engage much more strongly when there is a perceived social cause which is motivated both by peers and instructors [23]. It should serve some understood and easily defined purpose with which the students can connect. Each of these use cases would determine a particular course structure and style of interacting with the wiki. Once those course-level parameters are determined, students are able to assess the degree to which the wiki allows for their self-expression.

4.3. Space for commentary and discussion

It is commonly expected in higher education that if students have a fluent grasp of the course material, they will be able to dialogue about it and answer questions in real time. However, posing and answering questions aloud is quite difficult. This is especially true in mathematics where there is a sizable amount of notation that is difficult to transmit orally. For students whose native language is not the language of instruction, it can be quite intimidating to verbalize their thinking in a large group [15].

Wikis can provide a partial remedy to this problem. By allowing students to write and comment asynchronously, wikis can move in-class discussion to a digital platform where students can dialogue, pose, and answer questions, without the usual anxiety surrounding speaking in class [17]. In addition to providing a means of producing and editing content, many wiki platforms allow space for discussion of the content. On Wikipedia, which uses the MediaWiki engine, these are called "talk pages" and they are automatically created with every new article. These pages are used to discuss the content of a page, suggest edits, or clarify ambiguities. A large scale analysis of the talk pages on Wikipedia found that discussions on talk pages have a particular goal: to reach consensus and improve the article under discussion [24]. Talk pages are a mechanism for separating the content from the discussion of that content. This functionality can be used as a means of helping students communicate without disrupting each other's work.

The ability to interact asynchronously is especially important in a mathematics class. Often, mathematical ideas come slowly and require a great deal of reflection. It might take hours to fully and completely answer even the simplest mathematical question. On a wiki, students and instructors can dialogue and discuss ideas at this much more thoughtful and intentional pace. Wikis create a space for longer, more detailed, conversation. In a live classroom setting, there is only so much that can be said before the issue of coverage begins to stifle the discussion; there is a limit to how much can be said given the time constraints of a course. This issue has been noted and addressed by the inquiry-based learning community [44]. Wikis can act like moderated discussion forums where a conversation continues for days or weeks, and grows in richness as more students join in the conversation. Making course related discussion asynchronous, can open up a more expansive and inclusive space for dialogue and discussion. Andresen noted that student-to-student interaction and dialogue is especially valuable for learning in online discussions [2, p. 250].

4.4. Wikis promote equity and diversity

The structural inequalities which exist in education can be reproduced in any medium. The power dynamics which privilege expert knowledge over student knowledge can occur wherever there are experts and novices. There are many different ways that this power dynamic can play out in a classroom [32]. However, by making intentional course design choices, these forces can be minimized and create a more equitable and fair learning environment for teaching and learning in collaboration with students [38]. The hierarchical power dynamics of the student-teacher relationship can be partially mitigated by wikis. Oftentimes, when students and teachers interact in a classroom, these dynamics play out in such a way as to render impossible the meaningful co-creation of knowledge. By partially anonymizing the interaction, these forces can be controlled and minimized.

Partially anonymizing student interaction can help to minimize stereotype threat to students' identities. In a full class discussion, students might be hesitant to interact with their peers for fear of reinforcing or conforming to the negative stereotypes held by others. Research on stereotype threat began with studies of women's performance on math exams, and has grown into a robust field of study with findings related to a wide array of identities [36]. Interventions such as seminars and group-discussions centered on the theme of race and academic performance, which can help mediate stereotype threat, are now well documented [41, p. 388]. When students interact online, they create a space where they are able to partially step out of their roles determined by socio-cultural traits [6].

The nature of a wiki is such that the site is maintained by all users equally. The structural integrity of a wiki, the amount of coherence it has between its various parts, and the integration of various resources, is a community-controlled process [20]. It is a communal collection of documents which are co-created and maintained by the learning community. This maintenance requires vigilance and awareness of the evolving document from all the parties involved in its creation. The uniformity of style, or the tone of the wiki, becomes an issue of collective responsibility. By giving over the authorship of the course text to its users, students become empowered. This gives them responsibility and a stake in the co-creation of a useful resource. This work is more active than the usual didactic reading of a text for comprehension. Instead of passively engaging with a text through reading, students are placed in an active and participatory role of author/user.

In a passive learning context, students wrestle with a static text and try to make sense of what is presented to them. They may work alone, or in groups, to understand material from texts or lectures. By positioning the student as a reader of pre-formed texts, there is a higher chance of failure. They perceive their struggle with the text as evidence of their inability to do mathematics. The process of co-creating knowledge on a wiki is more active. When faced with the task of conveying something to someone else through writing, they are already positioned for a more meaningful interaction with the material. They are no longer facing their own failure to understand. Instead, they are trying to convey their successful understanding to the community. If the course is structured in such a way that there is enough time for the process to happen iteratively, with lots of feedback from other students, then the sense of student empowerment over mathematics can be rather profound.

5. Implementing a Wiki-Based IBL Vector Calculus Course

The comments and reflections put forward in this article were developed during the summer of 2019, when I taught a wiki-based version of MAT 232: Calculus of Several Variables. A total of 83 students were enrolled in the course. The course met twice weekly for a total of three hours. Half the course time was dedicated to wiki development work and the other half was dedicated to in-class problem solving, with a short mini-lecture beginning each class meeting.

In order to run a wiki based course, we needed to seek departmental support. The systems administrator for the Department of Mathematical and Computational Sciences created an implementation of MediaWiki three months before the course began. The wiki was on a private server hosted by the department, and students logged in using their university assigned login information. This provided a sense of privacy, and students felt comfortable uploading their personal information to the wiki. Once the server was running and secured, I started to build a syllabus for the course and input problems.

The major tasks of the MAT 232 Wiki was to tackle a list of problems from our textbook [42]. The list of problems, which students called "The Big List", was distributed in advance with the syllabus, and contained approximately ten problems per section of our textbook. A typical problem from the list would be: "S10.3Q37: Sketch the polar curve $r = 3cos\ (4\theta)$ by first sketching the graph of r asa function of θin Cartesian coordinates." In addition to solving problems from the Big List, students were asked to verify each other's work and to compile additional resources which students felt benefitted their experience of the course, such as online study guides, videos, and lecture notes.

A typical class would begin with class announcements and a short mini-lecture on a topic such as polar coordinates. This would take at most ten minutes. After a short lesson, we transitioned to in-class problem solving where students worked together in small groups. Worksheets guided students through the process of inquiry and acted as a point of reference for discussion. Worksheets were distributed through the wiki. They featured the learning objectives for that class, as well as topical problems. See Figure 1. Students were given edit access to modify or annotate the worksheets. As an example of a typical worksheet problem, one task asked students to relate the features of graphs $r(\theta)$ drawn in polar coordinates, to the corresponding graphs drawn in (r, θ) cartesian coordinates. During these in-class problem sessions, I would walk amongst the students working on the tasks and check-in. Half-way through class, we would transition to working on the wiki. Groups that had been particularly successful at in-class problem solving were encouraged to write-up their results on the wiki. A small to-do list was added to the wiki page corresponding to the worksheet, and students were assigned to write-up their solutions to the problems.

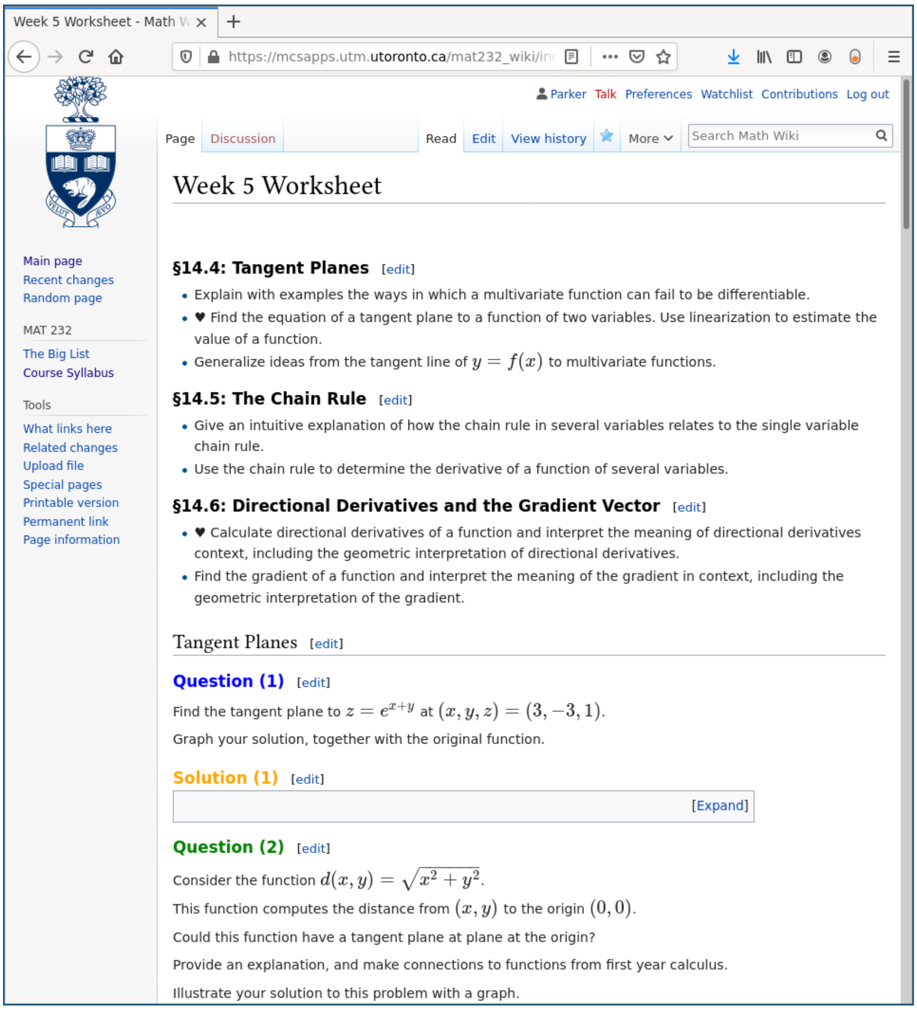

Figure 1: Week 5 Worksheet from MAT 232

The mark distribution for MAT 232 is listed in Table 1. In total, 30% of the course grade was allotted to tasks directly related to the wiki. The assessment for the wiki had both formative and summative components.

Quizzes	5×4% = 20%
Wiki Portfolio	2×5% = 10%
Wiki Participation	10x1% = 10%
Term Test	25%
Exam	35%

Table 1: The MAT 232 Assessment Scheme

Throughout the course, students worked on the wiki, submitted their weekly contributions, and generated two portfolios of their contributions to the course wiki. The weekly contributions were formative assessments, and the portfolios were summative assessments with a reflective component. The grading of the formative assessments was based on contributions to the wiki community. MediaWiki maintains a record of each edit made to the wiki. Once a week, students would self-select their most useful contribution to the wiki and provide a link to that edit with comments describing what their edit did to improve the wiki. This was graded as pass/fail based on whether the contribution positively contributed to the experience of others using the wiki. With only a handful of exceptions for articles, most of which were articles not linked to the main body of the wiki, these contributions were given full marks. In the sixth and twelfth weeks of the course, students were asked to compile portfolios based on their contributions to the wiki. Using portfolios in undergraduate mathematics education encourages holistic thinking and reflection on learning [16].

The mid-course and final portfolios were graded using a rubric based on the following categories. The questions accompanying the categories were distributed to students along with the portfolio assignment.

- *Evidence of growth*: Does your portfolio demonstrate that you have grown in your mathematical understanding?
- *Use of technology*: Do you use the mathematical typesetting and MediaWiki formatting?
- *Contributions to community*: Have you helped other students learn mathematical content through the Wiki?
- *Reflection on learning*: Are you aware of your own learning and significance of your contributions?
- *Presentation of portfolio:* Does your portfolio look organized and neat?

It is notable that mathematical correctness is not a category that was used to assess the portfolios. By the time that students put a wiki page in their portfolio, it would have been checked by many other students, and some students might have edited it or amended it for correctness. One action on the wiki that students often used as their weekly contribution was checking or correcting other students' work. Other actions which were commonly used as wiki contributions include: writing notes for the mini-lectures, finding content online relevant to the course such as study guides or video lectures, and typing up hand-written solutions in LaTeX.

6. Conclusions and Further Studies

This article explored the applicability of wiki technology for supporting the student inquiry in large mathematics classes. Traditional learning management systems are useful in addressing issues of scale, but wikis are able to do more. Fundamentally, the strength of wikis comes from the fact that students can co-create the learning environment. The ability to create and modify content collaboratively opened up new avenues for student engagement.

One formulation of IBL [12] posits that students: 1) work on rich mathematical tasks, and 2) work collaboratively to create their own mathematical understanding. These two goals are evident in the structure of the class outlined above. Students worked on tasks related to multivariable calculus, and they used the wiki to create representations of their own mathematical understanding. The assessments for the course were structured so as to promote community engagement, interaction with other students' work, and reflection on mathematics. Allowing students to check and validate each other's work created a robust system of self-assessment that facilitated students' creation of mathematical understanding.

In addition to facilitating an inquiry based pedagogy, there were several emergent features of using a wiki in class. For example, the wiki helped students to engage in the course in a partially anonymized way, without the pressure of speaking in class. It also helped introduce students to coding and online collaboration.

Finally, the research on wikis in the mathematics classroom is growing, and much more is needed to be learned. For example, it would be worthwhile to determine the effects of a wiki-based course on student achievement, as well as how that translates to future courses. Additionally, research may examine further students' attitudes, beliefs, and perceptions of their mathematical identity and perceptions of learning in mathematics, as well as how partially anonymization may assist different student populations in their perceptions of learning and actively contributing to the learning community.

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