Active learning designs for Calculus II: a learning community approach for interconnected smart classrooms

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Abstract: We present a study of active learning in Calculus II, which was conducted across 7 interconnected smart classrooms, with a single professor, 8 teaching assistants, and 317 undergraduate students. Our study explored (1) how to leverage this unique infrastructure so that all 7 classrooms of students were actively engaged as a whole learning community, (2) how to enable students across all seven classrooms to build a community knowledge base that serves as a resource for their subsequent learning activities, and (3) how active learning pedagogies influence students' epistemological beliefs. We will present our theoretical perspective of learning communities, our four active learning patterns, and how they were applied to create curriculum each week, as well as student outcomes. We found that participating in this particular course made a significant impact on students' epistemological beliefs, including stronger beliefs about the value of peers and teaching assistants as sources of knowledge. We close our study with a discussion of the implications of our work.

Keywords: active learning; learning community; smart classroom; calculus; math teaching; group learning.

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Biographical notes: Yanhong Li is a PhD student at Ludwig-Maximilians-Universität München. She is currently interested in the intersection of active learning and human-computer interaction design. Her upcoming research will involve the development of tangible technologies and active learning activities to engage students and form learning community curricula.

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Xinli Wang teaches at the Department of Mathematical and Computational Sciences at University of Toronto Mississauga. Her research interest includes student engagement, active learning in mathematics education, and Open Educational Resources and practices. She's also interested in finding out the best ways to help ESL students to overcome language barrier in their university math classrooms.

Jim Slotta is a Professor and President's Chair of Education and Knowledge Technologies at The University of Toronto. He has more than three decades' experience researching technology-enhanced learning, including the Web-based Inquiry Science Environment (WISE) from 1997–2009, and the Knowledge Community and Inquiry (KCI) model, from 2008 to the present. During that time, he has collaborated with hundreds of middle and high school teachers, and university instructors in developing rich inquiry curriculum that leverages technology environments and materials.

1 Introduction

An active learning approach (e.g., flipped classroom) can promote engagement with mathematics, and help students better understand and better use their mathematical knowledge both inside and outside of math class. However, despite early indications of its efficacy, active learning remains largely ill-specified and difficult to study (Brownell et al., 2013; Ruiz-Primo et al., 2011). For example, while "small group strategies" like cooperative learning, collaborative projects, or jigsaw groups are commonly touted as effective, little is known about the learning processes that occur within such groups, the design of specific activities, materials or assessments, nor the instructor's role during enactment (Henderson and Dancy, 2007; Slotta, 2010): on what tasks should students collaborate, and to what end? When should small groups be used within the curriculum? How should their progress, process or products be assessed? General strategies or approaches fall short of explicating how such approaches should be designed into curriculum materials, activities and assessments. There is a clear need for transparent models and *practicable patterns* that guide the development and evaluation of active learning curriculum.

2 Objective or purpose

To help students learn mathematical concepts and develop deep conceptual understandings, this paper investigates a set of active learning patterns that take advantage of the unique affordances of a Connected, Synchronous Smart Classroom (CSSC) learning environment. It consists seven active learning classrooms that are connected through broadcasting and social media technologies. Guided by the Knowledge Community and Inquiry (KCI) model (Quintana et al., 2017), we sought to leverage the large number of students in the overall CSSC learning environment and allow their sheer numbers to serve as a knowledge resource. We also drew upon the bounded nature of each classroom (with approximately 40 students per classroom) as a feature within our design of curricular activities. This paper will present two related research outcomes:

First, in the context of a Calculus II course for 308 students (i.e., across the 7 classrooms), we designed and tested and sequentially improved *four Active Learning Patterns* that could be used in combination with Peer Instruction (PI), or on their own. These patterns are an important outcome of this study and will be used as a basis for future research. Second, we assessed students' epistemological beliefs and how these change as a result of their engagement in our active learning designs, as well as the relationship between student epistemologies and engagement or performance in active learning.

Our conjecture that collective and community-oriented forms of inquiry will have a deep impact on students' learning suggests that, if we are successful, this should result in shifts in students' epistemological beliefs (i.e., about the nature of learning, the sources of knowledge, and the value of their peers as learning resources). Studies about students' epistemological beliefs transformation are rare but have found some positive effects on students' achievements, attitudes towards learning and their persistence to study mathematics, science and engineering (Springer et al., 1999). This paper addresses those relationships.

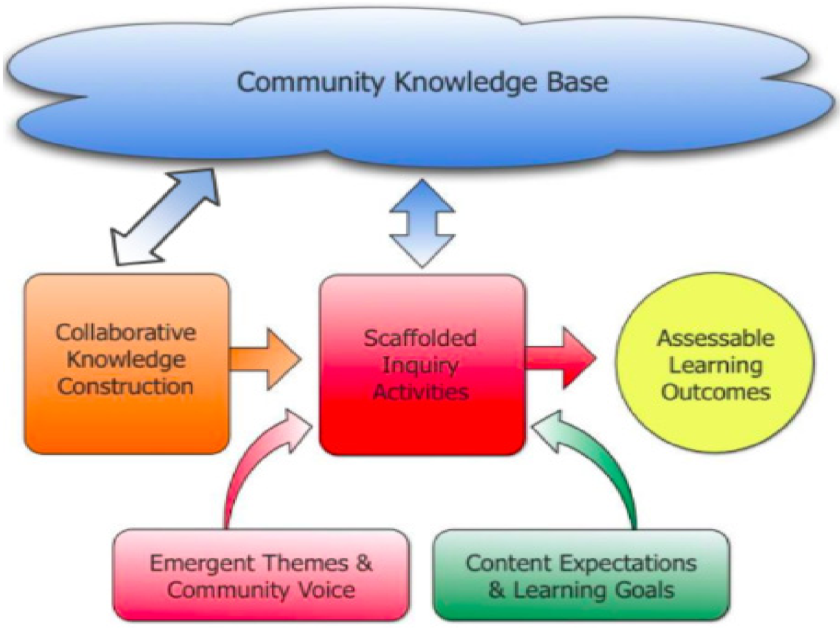
3 Literature review and theoretical framework

Active learning refers to classroom practices that engage students in activities such as reading, writing, discussion, or problem solving, that promote higher-order thinking. These methods have been shown to strengthen student learning and achievement in mathematics (Ali et al., 2010; Freeman et al., 2014), foster students' confidence in their ability to do mathematics (Dogan, 2012), and increase the diversity of the mathematical community (Koellner-Clark and Borko, 2004; Little, 2012). Active learning pedagogies have been shown to influence students' approaches to study (Prince, 2004), their motivation (Cicuto and Torres, 2016), engagement (Chi and Wylie, 2014), and persistence (Braxton et al., 2008). However, more research is needed to understand the source or mechanism of these effects, particularly the connection of active learning to student epistemological beliefs, which refers to their beliefs about the nature of knowledge and knowing (Hofer and Pintrich, 1997).

The acquisition of epistemological beliefs is similar to a process of enculturation, which means epistemological beliefs are influenced by the surrounding culture and the by-products of specific social contexts, such as the classroom settings. Students' beliefs about learning are shaped by activity, the culture, and the context in which they are developed (Jehng et al., 1993). Personal epistemological development and epistemological beliefs attract the interest of educational researchers since the late 1980s, because they influence students' cognitive processes of thinking and reasoning (Peer and Lourdusamy, 2005) and active involvement in learning (Baxter, 1992). To some extent, a person's epistemological beliefs create a context within which knowledge is utilised and accessed.

Learning communities have been defined as "a culture of learning in which everyone is involved in a collective effort of understanding" (Bielaczyc and Collins, 1999). Students bring diverse interests and expertise to the classroom, and the teacher helps them work collectively to advance knowledge. Over the past decade, we have developed the Knowledge and Community Inquiry (KCI) model to guide the design of science curricula in which the whole class works as an inquiry community (Slotta and Peters, 2008; Slotta, 2019). As shown in Figure 1, KCI provides structural requirements and design principles for (1) an epistemological orientation to help students understand the nature of science and learning communities, (2) a knowledge base that is indexed to the targeted science domain, (3) an inquiry script that specifies collective, collaborative and individual activities in which students construct a knowledge base that serves as a resource for subsequent inquiry, and (4) student outcomes that allow assessment of progress on targeted learning goals.

Figure 1 KCI model



KCI curricula typically span multiple weeks or months and are developed through a sustained process of co-design amongst researchers, teachers and designers (Roschelle et al., 2006). The designed curriculum constitutes a "script" that includes student-contributed content (the knowledge base), inquiry activities such as design, debate, critique, argumentation and reflection (Slotta et al., 2013) as well as a technology environment to support all forms of student and teacher inquiry.

This paper reports on a design-based research study of a Calculus II course, taught in Central China during the winter of 2018. The course was taught in a unique physical and technological configuration, wherein 7 "smart classrooms" are interconnected using advanced audio-visual and information technology systems. There is a single professor, who rotates to a new classroom each day, so that all students have his physical presence once every 7 days. Our goal in this work was to see if we could apply the KCI model to develop active learning patterns where all students (i.e., across all 7 classrooms) contribute to a common knowledge base, and then apply that knowledge in the context of inquiry activities. The design-based research methodology is well suited to the challenging real-world context of classroom-based learning, where controlled comparison studies are usually not possible. In design-based research, the designed products (e.g., the curriculum or assessments) are seen as an important outcome of the research, allowing for qualitative analysis, and leading to subsequent studies in which those products can be applied. Here, we present our initial effort over the course of one semester, to advance several pedagogical patterns, as well as some outcomes relating to students' epistemological beliefs, which may have been impacted by our designs.

4 Methods

In the winter of 2018, we engaged students, instructor and Tas from an undergraduate course at a university in the central part of China participated in this research. They were given a pre-survey of their epistemological beliefs in the second week of the course, and a post-survey at the end of the semester.

4.1 Setting and participants

As shown in Table 1, 308 student participants were seated in seven interconnected smart classrooms with only a single instructor, 8 graduate teaching assistants and 3 technicians. Students' age ranged between 18 and 23, with 64 (29.09%) are 18 years old and 114 (51.82%) are 19 years old. The gender distribution was dominated by female students, with 171 (77.73%) are females and only 49 (22.27%) are males. In addition, two hundred and six (93.64%) of them are freshmen, 12 (5.45%) are sophomores, and 2 (0.91%) are juniors. Most of them will become future chemistry teachers.

In each smart classroom, there is a double interactive whiteboard in the front, which shows the teacher's materials on the left and classroom live video on the right. Additionally, several interactive whiteboards are equipped around the classroom.

This study was situated in a course titled "Calculus 2" and lasted 16 weeks, with each week including two 90 minutes class sessions. We used several technology tools, including Rain Classroom (a Chinese learning management system), GeoGebra, Desmos and Padlet, to facilitate the active learning activities. Each class was described in a detailed lesson plan including instructional design notes about the lesson goals and activities. After each class, the researchers watched the course video (captured in the CSSC) and noted any problems about the implementation of the active learning patterns. To get additional feedback, the researcher held debriefing discussions with the instructor and teaching assistants after each lesson.

Table 1 Demographic information about participants

Classroom No.	*# groups*	*# students*	*# participants (%)*	*Gender*	
				Male (%)	*Female (%)*
# 8402	5	40	34 (85.00%)	6 (17.65%)	28 (82.35%)
# 8403	5	44	34 (77.27%)	3 (8.82%)	31 (91.18%)
# 8404	6	43	28 (65.12%)	12 (42.86%)	16 (57.14%)
# 8407	5	41	23 (56.10%)	3 (13.04%)	20 (86.96%)
# 8408	7	55	30 (54.55%)	9 (30.00%)	21 (70.00%)
# 8409	6	46	40 (86.96%)	7 (17.50%)	33 (82.50%)
# 8412	5	39	31 (79.49%)	9 (29.03%)	22 (70.97%)
Total	39	308	220 (71.42%)	49 (22.27%)	171 (77.73%)

4.2 Data sources, evidence, objects, or materials

An important source of data for this paper is designed curriculum, comprising lesson plans and teacher notes. This is used as a source of evaluating the applicability and extensibility of the patterns and delineating any important constraints. Another is the videotaped class sessions, which allow a qualitative measure of student engagement, and adherence to the plans. Finally, we collected student pre-post assessments of the Calculus Concept Inventory (Epstein, 2007), as well as students' epistemological beliefs.

There were two questionnaires used within this study: (1) a demographic inventory that captured participants' age, gender, grade, class and major; and (2) the Student Epistemological Beliefs (SEB) instrument (Acosta et al., 2014; Madhok et al., 2010). The Cronbach's alphas of SEB instrument in this study is 0.80. It contains five main categories to measure students' perceptions of personal relevance and learning preferences (7 items), beliefs about learning from peers (5 items), beliefs about sources of knowledge (6 items), and beliefs about classroom engagement (5 items). All the items in the SEB were scored with a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Table 2 shows the specific items used in the SEB instrument. This instrument was modified from an original version which has been created by one of the authors. It is guided by KCI model and has been used in three doctoral theses.

First, the questionnaires were translated into Chinese by the researchers and verified by two experts, as the questionnaires were originally designed in English and all the participants in this study speak Mandarin as their first language. One of the two experts got PhD in Education in Canada and had been teaching educational technology at a university in China for two years, while the other one was a PhD candidate of education in Canada. At the beginning and end of the term, the lead instructor was contacted for permission to administer the questionnaires. Students were informed that their participation was voluntary, and anonymity was guaranteed. After that, the translated questionnaires were distributed through an online learning platform to the students during a mid-class break.

Table 2 Items in the four sections of the SEB

	Personal relevance and learning preferences
1.	Is what you learn in class relevant to your life outside of school? (Likert 1-5)
2.	Do you have any influence over the topics you learn about in this class? (Likert 1-5)
3.	Do you have any control over how you learn about them? (Likert 1-5)
4.	How do you prefer to learn? (Likert 1-5, sub-items: *Lectures, Reading, Instructional videos, Individual study, Small group work, Whole class discussions, Working on projects*)
	Who is more responsible for your learning in the class? (Likert 1-5, sub-items: *The teacher, Yourself, Your peers*)
	When you have questions, do you prefer to talk to people face-to-face or search and ask questions online? (Likert 1-5, sub-items: *Prefer to ask teachers face-to-face, Prefer to ask my peers face-to-face, Prefer to search the answer by myself online*)
	I know I have really learned something when I - (Likert 1-5, sub-items: *Get a high score on an exam, Can apply the learning to a new problem or topic, Can explain it to a friend, to help them learn, Can solve problems using this knowledge*)
	Learning from peers
1.	Working collaboratively with my peers helps me learn topics more deeply (Likert 1-5)
2.	Sharing information with my peers can help me in class (Likert 1-5)
3.	When peers share information with each other, the total group knowledge is greater than the knowledge of any one individual (Likert 1-5)
4.	Peers who pool their knowledge together are more innovative than individuals working independently (Likert 1-5)
5.	The classroom community (all the students in class, considered together) is an important resource for my learning (Likert 1-5)
	Teaching and sources of knowledge
1.	How do you prefer to interact with the teacher? (Likert 1-5, sub-items: Presenting problem solving to whole class, Meeting one-on-on, Meeting the teacher with small group peers)
2.	Are students' ideas (your own and those of your peers) important for learning in class? (Likert 1-5)
3.	The teacher in this class helps me feel better about myself as a mathematics learner (Likert 1-5)
4.	Our homework should be important to help determine what happens during class time (Likert 1-5)
5.	What are the important sources of knowledge in this class? (Likert 1-5, sub-items: *Textbook, Internet materials, Lecture, Tas, My peers, Figuring things out myself)*
	I like the teacher to teach my mathematics class through (Likert 1-5, sub-items: Giving lectures of mathematical concepts and ideas, Showing how an equation is solved, Helping me work with a small group in problem solving, Showing how a real-world problem is converted to mathematical model, Engaging me in activities that solving a mathematical problem)
	Student engagement
1.	Participating actively in small group discussions (Likert 1-5)
2.	Asking questions when I don't understand the instructor (Likert 1-5)
3.	Having fun in class (Likert 1-5)
4.	Helping fellow students (Likert 1-5)
5.	Finding ways to make the course material relevant to my life (Likert 1-5)

All data were analysed with SPSS v25. First, descriptive analyses were computed, to obtain the average and standard deviation scores of each item. Second, paired-Samples *t*-tests were conducted to examine any changes in students' epistemological beliefs. Finally, a sequential regression was conducted to explore which features might influence student engagement and performance.

Owing the some incomplete data, 220 (71.42%) participants provided both pre- and post-responses, which served as the data source for our analyses.

5 Results

5.1 Active learning patterns

Guided by KCI model, we designed four active learning patterns to engage student learning in our CSSC Calculus 2 course. *Modified Peer Instruction* (MPI), *Community Supported Worksheet* (CSW), *Community Problem Creation* (CPC) and *Participatory Problems or Patterns* (PPP). We have 27 lessons in total, which include 5 implementations of MPI, 9 of CSW, 3 of CPC and 3 of PPP. Each time we implemented a pattern; we evaluated its success and revised the pattern for the next implementation. Table 3 presents short summaries of our evaluations for each version. Note that some versions were run more than once. This approach of successively improving our patterns constitutes a design-based research method and resulted in a set of well-rehearsed and well-defined instructional patterns, presented below.

Table 3 Iterative refinements of each pattern – table shows feedback from the video observation, instructor and TA comments about each iteration, to inform revisions of patterns and materials

	Modified peer instruction (MPI)	*Community supported worksheet (CSW)*	*Community problem creation (CPC)*	*Participatory problems or patterns (PPP)*
Version 1	Instructor didn't give students enough time for peer discussion (week 2)	Need to make more difficult worksheets (week 1)	The activity matched our intended design and expectations, but lasted nearly one hour (week 7)	Students felt novel and excited about the interaction with other classrooms (with real time comments, week 5)
Version 2	Good clicker questions could facilitate the activity naturally (week 3)	Need to improve group discussion (week 4); students did the worksheet but just by themselves (week 6)	To save some time, we made the activity shorter and combined it with the class preview in the previous week (week 12)	Instructor was not familiar with Padlet platform and the internet access has some problems (with Padlet, week 11)
Version 3	Instructor forgot to invite students to share their answers (week 7)	Instructor had different opinions about original activity design (week 8)	It was close to our design (week 15)	With the help of one of the teaching assistants, this activity worked much better (with Padlet, week 15)

Table 3 Iterative refinements of each pattern – table shows feedback from the video observation, instructor and TA comments about each iteration, to inform revisions of patterns and materials (continued)

	Modified peer instruction (MPI)	*Community supported worksheet (CSW)*	*Community problem creation (CPC)*	*Participatory problems or patterns (PPP)*
Version 4	Students were glad to hear their peers' spoken explanation about answer choice (week 12)	Students didn't have enough time to finish the activity (week 9)	*No further versions were run*	*No further versions were run*
Version 5	It didn't need to follow all the steps strictly every time (week 14)	Instructor didn't control the time effectively (week 9) and didn't give a clear instruction about how to do the activities (week 11)	*No further versions were run*	*No further versions were run*
Version 6	*No further versions were run*	Instructor made a clear instruction about how to do this activity and gave students timely feedback (week 13)	*No further versions were run*	*No further versions were run*
Version 7	*No further versions were run*	Had hint cards and time management (week 14)	*No further versions were run*	*No further versions were run*

The iterative improvements described in Table 3 serve as a design-based progression and culminated in "final forms" that are currently being applied in the instructor's classroom. The final active learning patterns are outlined as follows:

Pattern 1: modified peer instruction (MPI): Traditional Peer Instruction (Mazur, 1997), which follows seven steps (1) Question posed, (2) Students given time to think, (3) Students record individual answers, (4) Students convince their neighbours (peer discussion), (5) Students record revised answers, (6) Feedback to teacher: tally of answers, and (7) Instructor's explanation of correct answer. The modification in this case, involves adding one new step after step 3, and before step 4, in which the instructor asks students to share their reflections about the different responses with the rest of the class. As shown in Table 4 (i.e., the Week 12.2 example), the instructor first provided a clicker question to the community and invited students to share their answers and reasons before showing the response distributions. It then includes an extra level of peer or group discussion. The instructor employed standard PI techniques for twelve lessons, out of which grew the modified approach, called "MPI" which was used five times.

Table 4 MPI pattern example

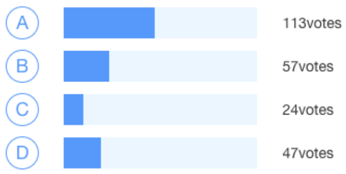
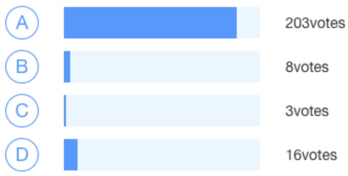
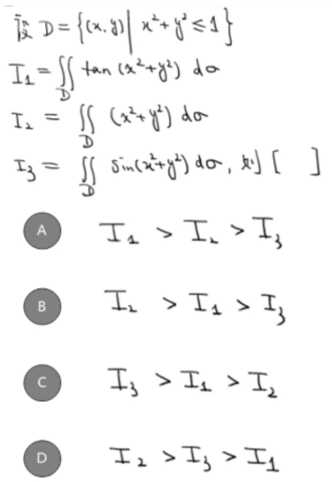
Topic	*Example*	*Procedure*
Background of double integral concept nature calculation method (I)	1. Clicker question: see Figure 2	1. Instructor gives a clicker question to all the classes.
	2. First answer chart	2. Student answers this question individually.
		3. Instructor invites several students to share their answers and the reasons.
	Student argumentation: "Since we know $\tan x > x > \sin x$ when x is between 0 to π, the functions in this question should also satisfy the inequality. So $I_1 > I_2 > I_3$"	4. Instructor shows the answer distribution chart and asks the students to discuss with their peers
	3. Second answer chart	5. Students answer this question again.
		6. Instructor invites those students who changed their answers to share the reasons.
	Student argumentation: "I didn't realize we can actually compare the functions in the integrand without computing what the integral actually is; or compare the functions wrongly"	7. Instructor compares these two answer distribution charts and explains some possible reasons.

Figure 2 Clicker question example



Pattern 2: Community supported worksheet (CSW): As shown in Table 5 (Week 13.1 example), this pattern includes two worksheets (e.g., about how to solve a definite integral problem). The first worksheet is an easy one, but the other one is harder such that most students will not complete the second sheet. Students who complete the first part are required to add "hints" for others and encouraged to solve the second part. Students who have not completed the second part are allowed to use the hints, and then "up vote" the most helpful hints… which provides helpful pointers to other students. The instructor used CSW for nine different lessons.

Table 5 CSW pattern example

Content	*Example*	*Procedure*
Calculation method of double integral (II) and application of double integral	Easier worksheet: see Figure 3 Hard worksheet: see Figure 4	1. Students work in groups to solve the first worksheet. 2. The groups who figure out how to solve it are required to fill the answer card, then ask the TA to check its correction and sign his or her name. 3. Those groups start to create solutional hints and upload it the learning platform. 4. The other groups who have difficulty to solve the problem are encouraged to look at above hints. 5. The groups who have already finished the first worksheet will be given the second worksheet.

Figure 3 Easier worksheet example

Figure 4 Hard worksheet example

Pattern 3: community problem creation (CPC): Students create "clicker problems" at home and refine "best ones" in class. As shown in Table 6 (Week 12.1 example), the instructor provided three different topics related to tangent planes and normal planes: (1) problems of surfaces, (2) problems of space, and (3) questions about extreme and maximum values. These topics were distributed to the various classrooms, and students work to create "compelling, helpful study questions", which are uploaded and voted on by peers. The instructor can then easily find the best ones to use with class. The instructor used CPC for three lessons.

Table 6 CPC pattern example

Content	*Example*	*Procedure*
Conditional extremes, maximum values, directional derivatives and gradients.	Preparation before class: see Figure 5	1. Before the class, each student reads the preview materials and prepares a clicker question for the class.
	Clicker question creation processes: see Figure 6	2. In the class, students work in groups to make a good clicker question and upload it to the learning platform. 3. Students vote the best clicker question in their class.
	Clicker question solving results: see Figure 7	4. The instructor chooses a best clicker question from these seven classes and gives it with the whole community. 5. Followed the PI procedure, students work on this clicker question.

Figure 5 Tasks before the class

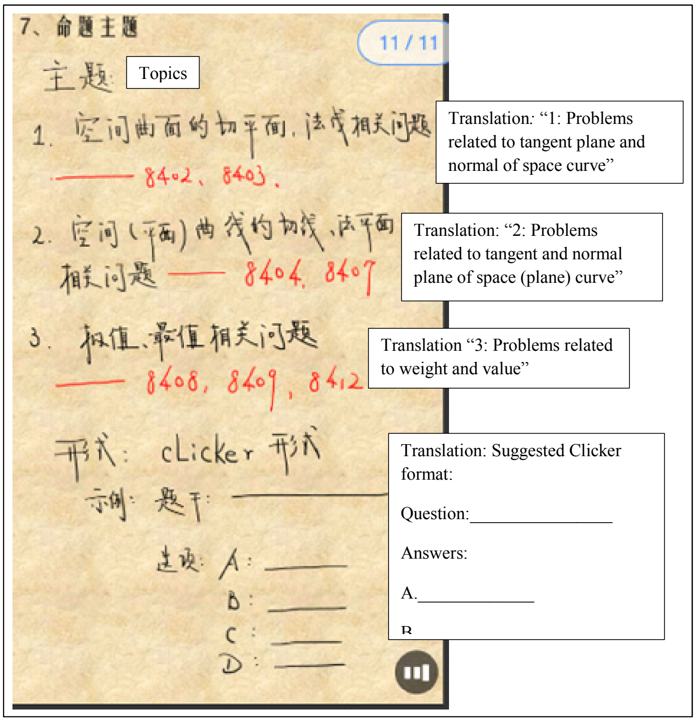


Figure 6 Clicker problem upload

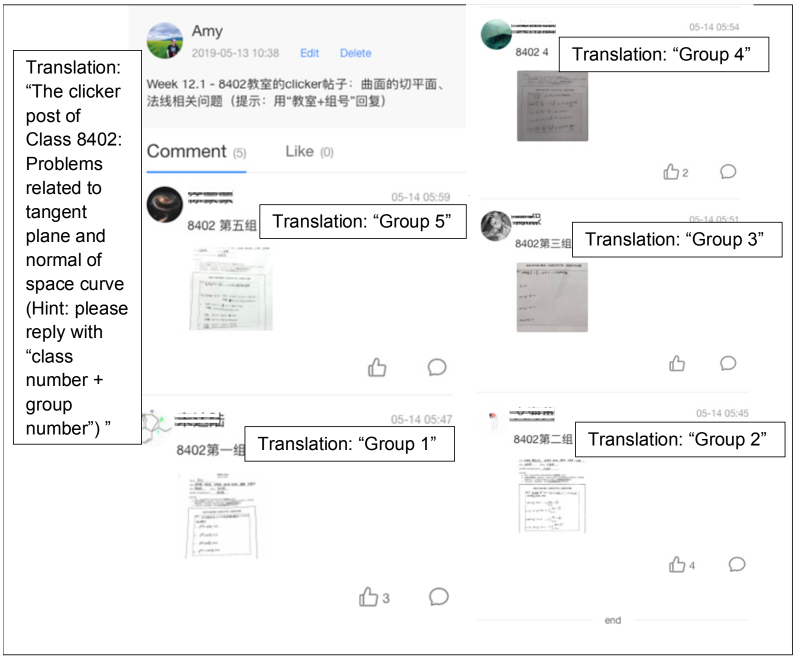
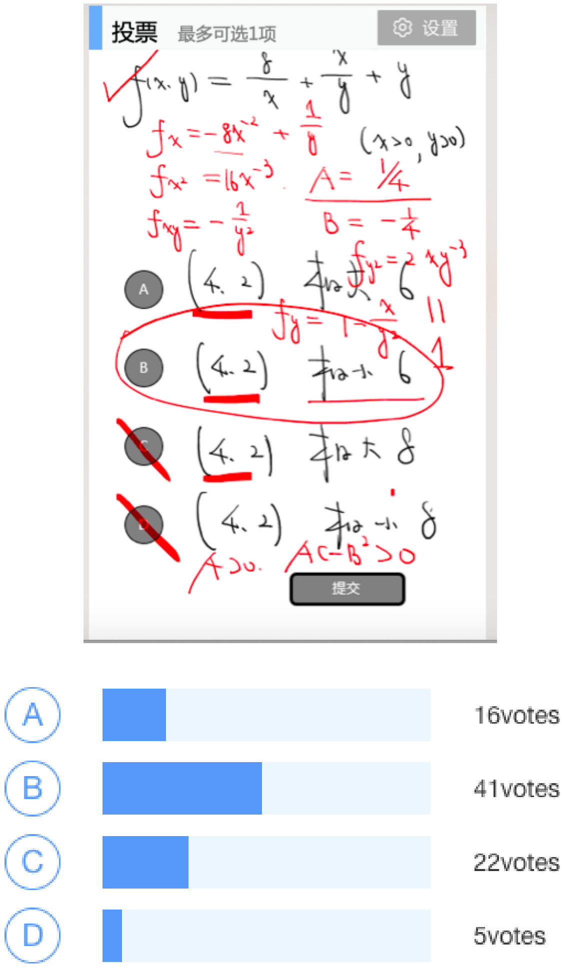


Figure 7 Clicker question solving



Pattern 4: Participatory Problems or Patterns (PPP): Seven classes work in concert to embody a mathematical concept. This was the most sophisticated or involved pattern, requiring that the 7 classrooms actually embody or illustrate the concept while working through a problem. As shown in Table 7, (Week 5.1 and Week 14.2 examples) PPP has tried to use real-time comments and Padlet platform to make each class build on previous class's solution, which means seven classes solve seven parts of the problem one by one. For example, Euler's proof of an alternating series limit was captured by having each class compute the successive term of the series, and work to prove the series limit geometrically. The instructor used PPP for three lessons.

Table 7 PPP pattern examples

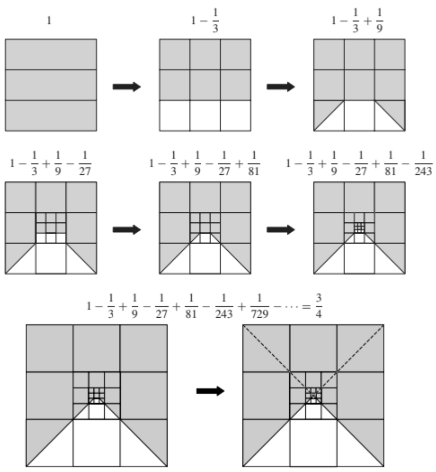
Content	*Example*	*Procedure*
Positive and alternating series	The problem: see Figure 8 The real-time comments: see Figure 9 Proof without words: 	1. The instructor gives an alternating series problem to all the classes and explains the "gaming rules": each class sequentially solves only one part of the problem, which has seven components. 2. Class 8402 posts the sum of first two series, which means 1 (k = 1) plus $-\frac{1}{3}$ (k = 2), using real-time comments. 3. Instructor puts the answer from Class 8402 into the table. 4. Followed the steps 2 and 3, and so on for all other classes. 5. Finally, instructor shows the graph of proof without words to explain proof process.
Green formula and power series	The problem: see Figure 10 The Padlet platform:	1. All the students are given a web link to access the designed activity in the Padlet platform. 2. Before the class, we designed a diagram template to show the sequence of the activity. 3. Followed the activity diagram, students in class 8402 solve the first part of the problem. At the same time, all other students are required to use the function of like or unlike to evaluate the answers. 4. Instructor makes a comment about this answer. 5. Followed the steps 3 and 4, and so on for all other classes. 6. Finally, instructor shows finished diagram with all the students and explains the related concepts.

Figure 8 PPP with real-time comments example

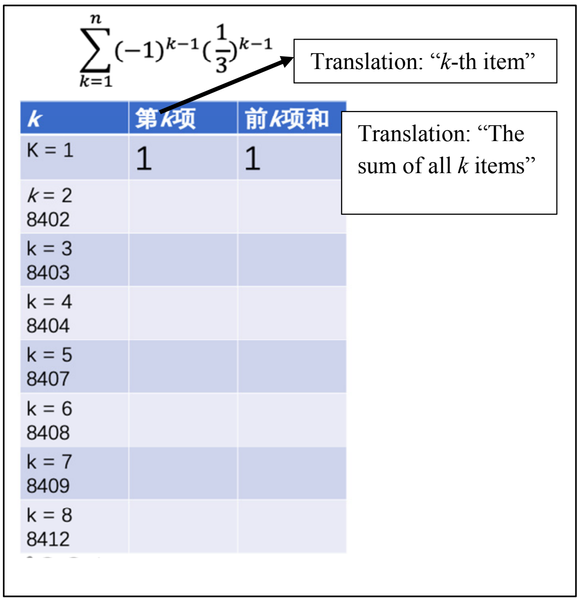


Figure 9 Video screenshot of real-time comment process

Figure 10 Example of PPP, showing which classroom is assigned to each part of the pattern

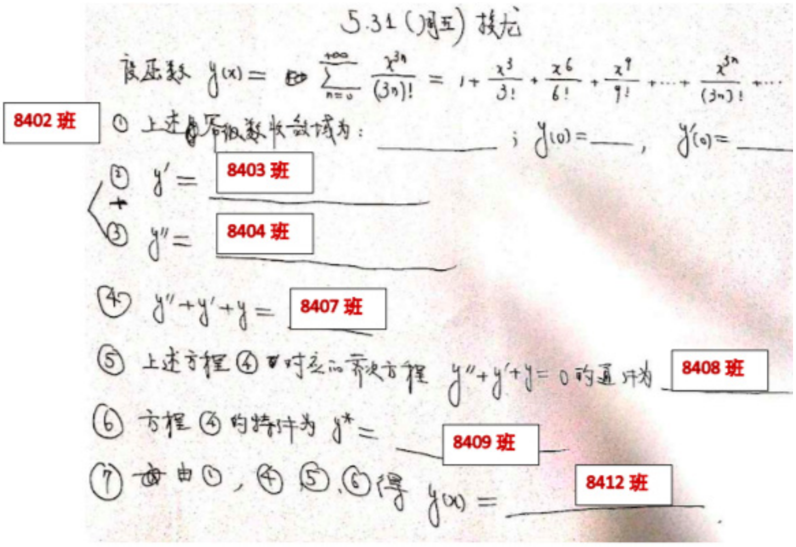
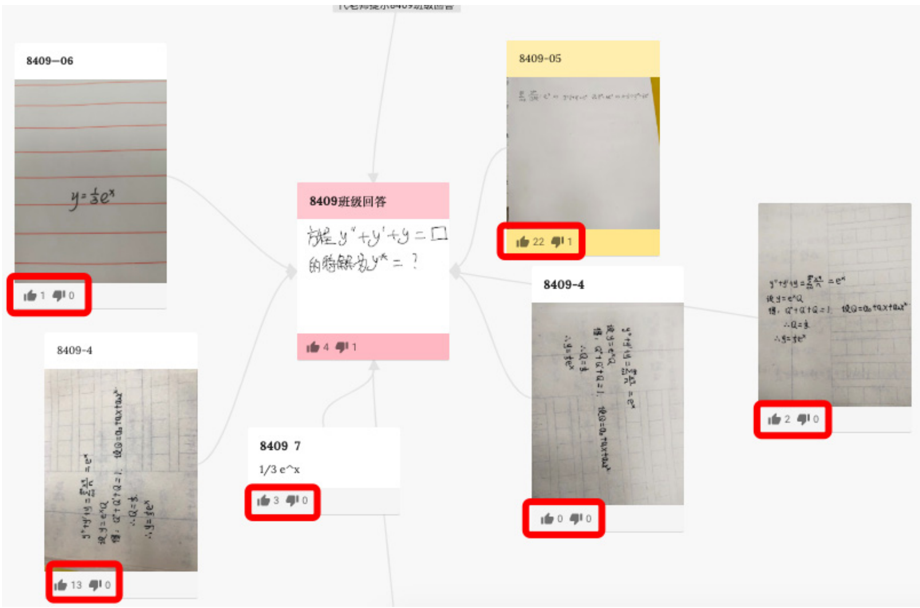


Figure 11 Example of PPP using the Padlet app



5.2 *Changes in student epistemology beliefs*

As shown in the Table 8, students improved in their SEB (Student Epistemological Beliefs) scores from pre- to post, with significant gains ($p < 0.001$, with all Cohen's $d > .50$) on all four major categories: Personal relevance and learning preferences

(M = 3.24, SD = 0.26, *t* (218) = –6.82, Cohen's *d* = .56), learning from peers (M = 3.09, SD = 0.41, *t* (219) = –5.48, Cohen's *d* = .60), teaching and sources of knowledge (M = 3.38, SD = 0.28, *t* (219) = –6.95, Cohen's *d* = .52) and engagement (M = 3.32, SD = 0.48, *t* (219) = –6.03, Cohen's *d* = .50). Some details from each of these test categories is provided in sections below.

Table 8 Descriptive statistics and paired-samples *t*-test results for student epistemology beliefs

Outcome	*Pretest*		*Posttest*		*N*	*Estimate*	*95% CI for mean difference*	*r*	*df*
	M	*SD*	*M*	*SD*					
Personal relevance and learning preferences	3.24	.26	3.38	.29	219	0.56	[–.19, –.10]	.35***	218
Learning from peers	3.09	.41	3.31	.44	220	0.60	[–.22. –.12]	.36***	219
Teaching and sources of knowledge	3.38	.28	3.55	.35	220	0.52	[–.29, –.14]	.07	219
Student engagement	3.32	.48	3.54	.52	220	0.50	[–.29, –.15]	.42***	219

Note: ***$p < 0.001$.

5.3 *Effects on student engagement and performance*

In order to explore the relationship between improved belief scores and student engagement, regression analysis was conducted. As shown in Table 9, pre-test of student engagement ($\beta = 0.359$, $p < 0.001$), post-test of student perception of teaching and source of knowledge ($\beta = 0.166$, $p < 0.01$), and student perception of learning from peers have a significant contribution to students' final engagement. In other words, when student engagement was already high at the outset, this contributed to sustained engagement. Otherwise, when post-test beliefs about the sources of knowledge (i.e., one's peers or the internet) improved, this led to engagement, as did an improved perception of peers as valuable to learning.

Table 9 Regression analysis with student post-test engagement scores as the outcome

Independent variables	R^2	R^2 *change*	*F change*	β	*p-value**
	0.555	0.132	62.643		0.085
Pre_lfp				–0.069	0.233
Pre_tsk				–0.031	0.544
Pre_prlp				–0.014	0.825
Pre_engagement				0.289	**0.000**
Post_prlp				0.092	0.119
Post_tsk				0.166	**0.002**
Post_lfp				0.495	**0.000**

Note: *lfp* means learning from peers, *prlp* means students' personal relevance and learning preference, *tsk* means teaching and sources of knowledge.

To investigate the relationship between improved belief scores and students' academic performance, regression analysis was conducted. As shown in Table 10, only students' beliefs about their level of engagement at pre-test had a significant contribution to student performance.

Table 10 Regression with post-test student performance scores as the outcome

Independent variables	R^2	R^2 *change*	*F change*	β	*p-value**
	0.058	0.004	0.863		**0.001**
Pre_lfp				–0.024	0.777
Pre_tsk				–0.110	0.138
Pre_prlp				–0.049	0.584
Pre_engagement				0.201	**0.019**
Post_prlp				–0.043	0.615
Post_tsk				–0.122	0.128
Post_lfp				0.077	0.460
Post_engagement				0.093	0.354

Note: *lfp* means learning from peers, *prlp* means students' personal relevance and learning preference, *tsk* means teaching and sources of knowledge.

6 Discussion

This paper reported on our development of a Calculus II curriculum that took full advantage of the unique configuration represented by the CSSC, which consists of seven active learning classrooms that are connected through broadcasting and social media technologies. Our initial designs had resulted in a limited level of active learning, as the instructor attempted a "flipped classroom" approach. But his classroom time was given mainly to additional lectures. This was due in part to the challenge of designing active learning patterns that could engage all 7 connected classrooms in which only one professor being physically present only in one classroom. The research presented here applied a learning community approach to guide the design of active learning patterns that engage students in all 7 classrooms, such that all students feel valued and their opinions and knowledge are perceived as contributions to be built upon.

There are at least three advantages of active learning designs that embrace the learning community pedagogy. First, they facilitate new forms of discourse in the classroom. For example, the instructor invited students to share their problem solving and reasoning process with the wider community in the MPI activities, which helped to reveal student thinking and provide a wealth of opportunities for the teacher to make connections. Second, they provide an instructional scaffold to engage all students. In the CSW pattern, students work on worksheets and create hints to inspire others. Thus, students can either contribute to or benefit from this activity. Third, they motivate students to understand and apply mathematics concepts with higher-order thinking. In the CPC activities, students are inclusively engaged from problem creation to problem solving. Finally, such pedagogical patterns connect students across the distributed classrooms and improve their sense of engagement. For instance, through observation classroom videos, TA and instructor's feedback, students show good interests to know and build on previous class's answers in the PPP activities.

One of the most important findings of this research is that students' epistemological beliefs can be significantly impacted by an active learning approach. In particular, active learning appears to improve student perceptions of group collaborations, and the importance of learning from peers and teaching assistants in the class. This is a step forward from the teacher-cantered pedagogies of traditional lecture delivery method. Collaborative work in groups helps students to better understand and retain their understanding of concepts, while also serving the broader purpose of developing communication skills and increasing an awareness of their peers as learning resources. Moreover, the learning community pedagogy serves to strengthen students' commitment to mathematics learning, help them develop and improve the skills needed for mathematical reasoning and argumentation, and emphasise the interdisciplinary nature of mathematics.

Another finding is that students increase their estimates of the knowledge sources from meeting with teaching assistants and peers after the active learning classes. The patterns of results in our SEB measures suggest that active learning classes helped students understand the complexity of knowledge, the need to consider multiple knowledge sources, the need to construct knowledge within a learning community and that – importantly – lecture are not the only source of knowledge. This is a positive outcome, particularly in the Chinese system where lecture is even more firmly established as the primary approach, and students are generally unfamiliar with other sources of knowledge (and pedagogical approaches).

Finally, we found that students' feeling of engagement at the end of the semester is significantly influenced by their engagement at beginning, post-test of teaching and sources of knowledge and post-test of learning from peers. This suggests that multiple sources of knowledge can improve student engagement. Therefore, when designing active learning activities, instructors should consider providing more choices of materials or sources. Also, learning from peers was an important factor for student engagement, which instructors should also consider as they design cooperative or collaborative learning activities.

7 Limitations

Despite any novel approach to learning, students continue in the believe that getting a high score is the only "true sign" of learning, as opposed the ability to apply the learning to a new problem or topic, explain it to a friend to help them learn, and solve problems using this knowledge. This is likely because of the exam-oriented culture of education in China (and other countries!), where most students consider test scores as the only method to evaluate their learning performance. Another concern is the notion of learning community – a definition that we may only be partly fulfilling with this particular course and patterns. That is, while students enjoy the collective aspects, and really do feel the value of their peers, our designs may still be a good way from a true learning community, or even a KCI design. There is room for deeper levels of inquiry, applying mathematics concepts and approaches to problems, and building a classroom knowledge base. We must remember that structured active learning patterns do not quite constitute a learning community.

8 Conclusion

This research explores the effect of active learning pedagogies on student epistemological beliefs. In this active calculus class context, findings indicate that student epistemological beliefs could be significantly changed, revealing the positive impact of a learning community pedagogy. Overall, the course was a success, and students, instructor and TAs all found the activities to be engaging and effective. We measured improved performance on the Calculus Concept Inventory, as well as on measures of students' epistemological beliefs concerning: Personal relevance and learning preferences, learning from peers, teaching and sources of knowledge and engagement. We are presently analysing student data from the individual lessons and will include all findings in our presentation. We are also examining the instructor's application of the patterns, which improved greatly over the duration of the course.

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