Mathematics & Teaching Learning Community

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For our ASSETT Faculty Fellows Project we established a Faculty Learning Community (FLC) to reform our Calculus 2 curriculum. This report outlines our project, challenges we encountered, desired results, actual outcomes, and reflections on the project.

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1 Challenges Addressed

Over the past several years the University of Colorado-Boulder's mathematics department transitioned our Pre-Calculus through Calculus 3 courses from a large lecture format to small sections. The purpose of this shift was to improve undergraduate students' mathematics education by adopting the recommendations of evidenced-based instructional practices (Bressoud, 2014; Freeman, et al., 2014; Smith, et al., 2009; Sonnert, et al., 2015) to incorporate active learning into these courses. To assist instructors and graduate students with this reform and implement active learning strategies in their classes, members of the mathematics faculty developed sets of active learning activities and projects for each course. In addition to these resources, the mathematics department established a course coordinator position to support the constant cycle of instructors and graduate students with the logistics, content, and pedagogical professional development.

These reforms created new sets of challenges for the calculus courses: (1) a need for a sustainable model for reform and improvement, (2) a system to transition between coordinators, and (3) pedagogical professional development for instructors and graduate students.

1.1 Sustainable Calculus Reform and Improvement

Our department's initial reform of the calculus sequence was undertaken by a handful of faculty who were allocated time and resources to set a schedule, create homework, and develop resources for the courses. Apart from a few revisions, these resources largely unchained. Over the semesters various faculty, lecturers, and graduate students put these resources into practice in their classes, finding many of the materials to be highly effective, several to be average, and some to be quite ineffectual in achieving their intended learning goals.

Outside of this initial reform, there have been only a handful of updates to the courses. These updates have come from either faculty that have taken on this task outside of their standard responsibilities as course coordinator or from graduate course assistants with some direction from a course coordinator. With only a few individuals investing time and energy into these course improvements, it demands significant effort for them to share their reasoning for the changes and how to best implement their changes with other instructors and teaching assistants within a course. Furthermore, without input and collaboration from a broader collection of the department, this institutional knowledge the sustainability of these reforms rest with only a few individuals. As these reform stakeholders take on new responsibilities or leave our department, institutional knowledge becomes lost. Because of this, there is a need to develop a model for members of the department to gather to share and receive ideas to sustain and continue reform in our calculus sequence.

1.2 Transitioning Coordinators

The course coordinator role for the calculus sequence involves managing a number of components, including organizing weekly instructor meetings, weekly TA and LA seminars, administering a course website, and assisting with course logistics over a large number of sections. Due to all these aspects, it is challenging for faculty effectively manage these responsibilities during a single semester. Often the coordinator will rely on experienced instructors and teaching assistants to help explain to how the course has worked in the past. While it is beneficial for the coordinator to collaborate with their peers, to reduce redundant work for new coordinators there is a need to establish a set of expectations for each coordinator and logistics and problem documentation that coordinators can reference.

In addition to the challenges the coordinators experience during this transitional period, instructors and teaching assistants can struggle to adjust to the rotation of coordinators. Instructors and teaching assistants may find uncertainty in the shifting of course expectations and content focus from semester to semester, as each coordinator may have their own vision for the learning goals of a course. Because of this uncertainty, there is a need to establish course expectations and a set of learning goals for each calculus course.

1.3 Pedagogical Professional Development

We have instructors and graduate students who have little knowledge or experience incorporating active learning strategies. Even with the active learning resources developed for these novice instructors, research (Auerbach, et al., 2018; Smith, et al., 2009; Sonnert, et al., 2015) suggests that there exist significant differences in the effectiveness between expert and novice active learning instructors. More experienced instructors demonstrate a greater ability to recognize student misconceptions, elicit student thinking, and provide students with opportunities to generate knowledge and contribute to the mathematical discourse in the classroom. Therefore, to improve our undergraduate students' mathematics education, there is a need to provide pedagogical professional development for our novice active learning instructors and graduate students.

2 Mathematics & Teaching Learning Community

We sought to establish a sustainable model for calculus reform, develop a system for transitioning between coordinators, and provide pedagogical development for instructors and graduate students. To accomplish this, we established a Mathematics & Teaching Learning Community within the mathematics department. This Faculty Learning Community (FLC) allowed for interested parties, which included tenured faculty, instructors, lecturers, and graduate students to build a collaborative community assess our current Calculus 2 curriculum for areas of improvement, make reforms based upon these assessments, develop active learning projects to support our reforms, and address concepts/topics that have proven to be challenging for students to understand and/or instructors to teach.

2.1 Bi-Weekly Luncheon

Our incentive for department participation and contribution to our FLC, was the establishment of a biweekly luncheon in MATH 350 to hold directed discussions involving calculus resources and pedagogy. We began hosting luncheons in the Fall of 2019, and continued them through the Spring 2020 semesters until campus was closed due to COVID-19. The food provided for each luncheon was paid for through the funds we receive through the ASSETT faculty fellows program. We hope to continue hosting the luncheons, and establish them as a regular professional development opportunity for members of the department.

Before each luncheon, we set an agenda to focus issues needing to be addressed and set desired outcomes for the luncheons. Our agendas began by first identifying areas in the Calculus 2 curriculum that needed reforming, which led to our push to come to a consensus on learning goals for Calculus 2, and then we moved to develop active learning projects to support our reforms and identify concepts that have proven to be difficult to teach and/or learn. Our luncheon discussions ranged from what we valued as mathematicians and wanted students to take away from our Calculus 2 course, to how we might best teach these values.

3 Desired Result

3.1 Improve Teaching Culture

Often, the first course a graduate student teaches for the department is one of the calculus courses. They have expressed concerns about preparing lectures and how to fit the activities into the very full schedule. Another desired outcome of the learning committee will be to develop a set of lecture notes, built around the active learning mentality. These notes will have the stated learning goals for each class meeting, a lecture plan with rough estimates for how long each example should take, and when appropriate, when activities/projects will be incorporated into the class meeting.

By creating these notes throughout the year, we hope to improve the overall teaching culture of the department. Having a focused plan in place will lower the entry barrier for new instructors and coordinators. By creating these plans in the learning community, they will under go scrutiny and raise questions about teaching practices. Furthermore, this will become an excellent source of professional development for graduate students and give them a means to make their growth and accomplishments visible.

3.2 Sustainability

At present, the success of a calculus course is reliant upon quality coordination. The course coordinator is given the materials for the course with little instruction on how to implement them effectively, provided with a prior semester's syllabus to update, and a loose schedule to adhere to with topics of instruction listed. This creates many redundancies of each subsequent coordinator, as they often recreate materials that were "lost" in the transfer.

One outcome of the learning community will be to develop supporting documentation for coordinators to ensure their success. During the course of the learning community, we will develop notes on effective course management, learning goals and outcomes of the course, areas of student misconception, teaching methods and how to use the already developed activities and projects effectively. This document will break down the semester week by week and provide much needed support to new and returning coordinators. It will identify what materials and resources already exist, the rationale behind them, and give suggestions for areas of future improvement.

Full attainment of the desired results of this project may not occur by the end of the 2019-2020 year. If this were the case, a mark of success for this project would be the continuation of these luncheons beyond the funding of the ASSETT grant or participation of us. The continuation of these meetings until all the goals have been met will serve as strong evidence that sustainable change has occurred in the calculus courses.

3.3 Improve Undergraduate Mathematics Education

Naturally, the overall improvement of mathematics education is the desired result of this project. A significant impact on students' attitude towards mathematics is related to their instructors' pedagogy (Sonnert, et al., 2015; Welsh, 2012). Thus, our work to improve the teaching culture will also have positive impacts on our undergraduates' mathematics education. Furthermore, by having our reforms sustained throughout the calculus sequence, it will help undergraduate students persist throughout the calculus sequence and may help attract a greater number of mathematics majors (Bressoud, 2014). Our work to establish a community of practice to help us develop engaging calculus courses, promote the use of active learning, provide pedagogical professional development for graduate students address four of the seven characteristics for a successful calculus program (Bressoud & Rasmussen, 2015).

3.4 Dissemination of Work

In order to establish a level of commitment from individuals and create a responsive culture for those attending and working within our FLC, we will document our agendas, rationale for changes, ideas generated from discussions, actionable items, and developed course materials. How this documentation will be shared will vary on the purpose and intended audience. Meeting notes, proposed changes, and pedagogical discussions will be posted on a cloud-based collaborative platform, such as Slack or Canvas, to allow for review and comments. New or updated course materials will shared through course folders that coordinators have access to so that they can disseminate the materials just for course instructors, or if they want to include as part of the resources on course website for anyone to access. Both instances will aid in the spread of institutional knowledge inside and outside the mathematics department.

4 Outcomes

The department committed resources to a complete reform of Calculus 3 in the Spring of 2017, and we used the assistance of a graduate course assistant to make modest reforms to Calculus 1 during the 2018-2019 academic year. After reviewing the current curriculum for our Calculus 2 course, we found that it has been a significant number of years since any significant reforms had been undertaken. Because of this we decided to direct our attention to reforming our Calculus 2 course. During our reform process we worked to identify where our efforts were productive and where they were not. We also wanted to note lessons to take away so that we may improve and evolve our future FLC.

4.1 Calculus 2 Reforms Approved

The first two to three meetings focused on assessing the Calculus 2 curriculum for areas of reform. We discussed not only what content in the course we valued as a group, but also what type of learning experiences we valued for our students. This led to a reorganization of the course including creating a new schedule, agreeing upon general learning outcomes, establishing an overarching course narrative, and the development of a set of learning goals. All this provides structure for transitioning course coordinators to help them understand course expectations and build consistency across semesters.

While these course reforms were proposed by an invested group with a diverse set of backgrounds, tenured faculty, instructors, lecturers, and graduate students, we wanted to ensure that we had broad approval from the department. To gain this approval we put together a proposal of our changes, and then submitted them our Undergraduate Committee for review. The Undergraduate Committee approved our proposed reform. We include our proposal below:

Proposed Course Reforms

These proposed reforms to our Calculus 2 course were developed through input of faculty, instructors, lecturers, and graduate students during biweekly meetings of the Mathematics Faculty Learning Community.

4.1.1 General Learning Outcomes

The following describes general learning outcomes we want our students to develop for the act of doing and learning mathematics in our Calculus 2 course.

1. Demonstrate grit and resilience by analyzing mistakes through reflective discussions, revising of thought process, and then attempting problems again.
2. Collaborate in class with peers and their instructors to discuss content and develop their own understanding of mathematical concepts.
3. Demonstrate mathematical reasoning and thinking skills through active learning projects and activities.
4. Communicate mathematical ideas, verbally and written, using appropriate mathematical language, notation, and style relevant to the course.
5. Evaluate arguments, evidence, assumptions, and conclusions about concepts.

4.1.2 Learning Outcomes or Skills

The following describes the specific learning outcomes or skills we expect students to be able to do upon completing our Calculus 2 course.

1. Identify, calculate, and differentiate between various methods of integration and justify that decision at a level that addresses the benefits of that method and/or limitations of potential alternatives.
2. Identify and integrate derivatives of a compositions of functions.
3. Identify and integrate products of functions by parts.
4. Identify and decompose rational functions using partial fractions with first degree linear factors.
5. Identify and apply appropriate methods to integration products of trigonometric functions, involving products of sine and cosine as well as products of secant and tangent.
6. Develop and apply appropriate trigonometric substitutions to integrate functions involving Pythagorean identities.
7. Apply the concept of limits to the bounds of integration to determine convergence of improper integrals with discontinuities in their domain or infinite limits of integration.
8. Select and compare appropriate known improper integrals to unknown integrals to determine convergence.
9. Interpret an area between curves as an infinite sum of infinitesimal rectangles, and represent the area as a definite integral to calculate its value.
10. Interpret a volume of revolution of a function's graph around an axis as an infinite sum of infinitesimal disks or cylindrical shells, and represent the volume as a definite integral to calculate its value.
11. Interpret the length of a curve as an infinite sum of infinitesimal linear segments, and represent the length as a definite integral to calculate its value.
12. Identify the components of calculus that are ubiquitous and where they are present in different applications.
13. Analyze contexts to apply concept of integration by appropriately defining infinitesimal quantities, calculating an infinite sum of these quantities, and then interpreting the sum in context.
14. Apply appropriate methods of integration to real-world physical applications.
15. Compute the length of a parametric curve as an infinite sum of infinitesimal linear segments, and represent the length as a definite integral to calculate its value.
16. Be able to parametrize a line segment and other planar curves.
17. Apply differentiation concepts to determine the instantaneous rate of change and concavity of a parametrized curve.
18. Express and interpret planar curves using both rectangular and polar coordinates.

19. Compute the arc length of polar curves and compute area bounded between polar curves.
20. Describe the meaning of convergence in words.
21. Analyze series to determine appropriate test for convergence.
22. Apply the concept of the limit at infinity to determine whether a sequence of real numbers is bounded and whether it converges or diverges.
23. Interpret the concept of a series as the sum of a sequence, and use the sequence of partial sums to determine convergence of a series.
24. Identify, calculate, apply, and differentiate between series and justify that decision at a level that addresses the benefits of that method and/or limitations of potential alternatives.
25. Decide if an infinite geometric series converges and to what value.
26. Interpret and represent a geometric series as a numerical sum and geometric figure.
27. Comparing a series to an integral to decide whether an infinite series (including p-series) converges or diverges.
28. Determine the convergence type of an alternating series.
29. Distinguish between absolute and conditional convergence of an alternating series.
30. Rearrange the terms in conditionally converging series to sum to an arbitrary value.
31. Perform the ratio and root test to determine convergence of infinite series.
32. Interpret a converging power series as a function. Be able to compute the radius and interval of convergence of a power series.
33. Determine the Taylor polynomial of the nth order of a function and determine an upper bound its remainder.
34. Establish Eulers Formula by comparing the Taylor series for the complex exponential and the trigonometric functions.
35. Manipulation of Taylor series to obtain Taylor series for other functions.

4.1.3 Overarching Course Narrative

The following describes the overarching course narrative for Calculus 2. There has been some complaints that there is not a current course narrative that makes the course seem disconnected for instructors and students. As part of our revised plan for Calculus 2, we propose the following narrative for the course consisting of themes that provides a connected path of concepts throughout the course.

1. **Theme 1: Adding up infinite amount of small things**
   - Techniques to add up small things
   - Applications of adding up small things
   - Adding infinite number of discrete things
2. **Theme 2: Approximations in infinite sums**
   - Numerical approximations
   - Error in continuous and discrete sums

4.1.4 Mapping of Learning Outcomes within Course Narrative

The following maps our specific learning outcomes for the course to the course themes.

Theme 1: Adding up infinite amount of small things

1. Identify, calculate, and differentiate between various methods of integration and justify that decision at a level that addresses the benefits of that method and/or limitations of potential alternatives.

2. Identify and integrate derivatives of a compositions of functions.

3. Identify and integrate products of functions by parts.

4. Identify and decompose rational functions using partial fractions with first degree linear factors.

5. Identify and apply appropriate methods to integration products of trigonometric functions, involving products of sine and cosine as well as products of secant and tangent.

6. Develop and apply appropriate trigonometric substitutions to integrate functions involving Pythagorean identities.

7. Apply the concept of limits to the bounds of integration to determine convergence of improper integrals with discontinuities in their domain or infinite limits of integration.

8. Select and compare appropriate known improper integrals to unknown integrals to determine convergence.

9. Interpret an area between curves as an infinite sum of infinitesimal rectangles, and represent the area as a definite integral to calculate its value.

10. Interpret a volume of revolution of a function's graph around an axis as an infinite sum of infinitesimal disks or cylindrical shells, and represent the volume as a definite integral to calculate its value.

11. Interpret the length of a curve as an infinite sum of infinitesimal linear segments, and represent the length as a definite integral to calculate its value.

12. Identify the components of calculus that are ubiquitous and where they are present in different applications.

13. Analyze contexts to apply concept of integration by appropriately defining infinitesimal quantities, calculating an infinite sum of these quantities, and then interpreting the sum in context.

14. Apply appropriate methods of integration to real-world physical applications.

15. Compute the length of a parametric curve as an infinite sum of infinitesimal linear segments, and represent the length as a definite integral to calculate its value.

16. Be able to parametrize a line segment and other planar curves.

17. Apply differentiation concepts to determine the instantaneous rate of change and concavity of a parametrized curve.

18. Express and interpret planar curves using both rectangular and polar coordinates.
19. Compute the arc length of polar curves and compute area bounded between polar curves.
20. Describe the meaning of convergence in words.
21. Analyze series to determine appropriate test for convergence.
22. Apply the concept of the limit at infinity to determine whether a sequence of real numbers is bounded and whether it converges or diverges.
23. Interpret the concept of a series as the sum of a sequence, and use the sequence of partial sums to determine convergence of a series.
24. Identify, calculate, apply, and differentiate between series and justify that decision at a level that addresses the benefits of that method and/or limitations of potential alternatives.
25. Decide if an infinite geometric series converges and to what value.
26. Interpret and represent a geometric series as a numerical sum and geometric figure.
27. Comparing a series to an integral to decide whether an infinite series (including p-series) converges or diverges.
28. Determine the convergence type of an alternating series.
29. Distinguish between absolute and conditional convergence of an alternating series.
30. Rearrange the terms in conditionally converging series to sum to an arbitrary value.
31. Perform the ratio and root test to determine convergence of infinite series.

Theme 2: Approximations in infinite sums

1. Interpret a converging power series as a function. Be able to compute the radius and interval of convergence of a power series.
2. Determine the Taylor polynomial of the nth order of a function and determine an upper bound its remainder.
3. Establish Eulers Formula by comparing the Taylor series for the complex exponential and the trigonometric functions.
4. Manipulation of Taylor series to obtain Taylor series for other functions.

4.1.5 Proposed Course Schedule

The following provides a tentative schedule for our proposed reforms to the Calculus 2 course. These proposed reforms seek to address various complaints about the course from over the years, including:

- The course feels like an assorted collection of concepts without an overarching narrative connecting ideas.
- There is too much content in the course, which hinders the practice of active learning in the course.

Note the following changes from the previous schedule:

- Cutting down the amount of differential equations content so that greater time could be spent on series. This decision was based on faculty who teach our upper level differential equations courses perception that students demonstrated little knowledge of this content after leaving Calculus 2, and often had to reteach the material anyway.
- Focusing on a deeper understanding of the basics for partial fraction, trig integral, and trig substitution techniques instead of a surface level understanding variations of examples within these techniques. This decision was based on acknowledging that due to technological advances over the last decades, there is less of a need for students to be able to integrate every integrable function by hand, and that is we should emphasize students' conceptual understanding of integration techniques versus students' procedural understanding.
- Moving the work with parametric equations and polar coordinates to follow integration techniques. This decision was to try to create a more cohesive narrative in the course by grouping the continuous and discrete aspects of the course together.

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Aug 24th A: Review of Anti-Derivatives A: Indef. Int. Dominoes	25th Change of Variables A: Mechanics of u-sub A: Recognizing u-sub	26th Integration by Parts	27th P: Trig Integrals	28th Integration by Parts (cont)
31st Trig. Integrals	Sep 1st Trig. Integrals (cont)	2nd Trig Sub	3rd P: Partial Fractions	4th Trig Sub (cont) Partial Fractions
7th Labor Day	8th Partial Fractions (cont) A: Approx Int	9th Improper Integrals	10th P: Comparison Test	11th Improper Integral Tests
14th Volumes of Solids	15th Volumes of Solids (cont)	16th Volumes of Solids (cont) A: Integration Practice	17th P: Area and Volume Practice	18th Avg Value of a Function
21st Exam 1	22nd Work Integrals	23rd Work Integrals (cont)	24th P: Applications of Integration	25th Work Integrals (cont) Center of Mass
28th Center of Mass (cont)	29th Parametric Equations	30th Calculus with Parametric Eq	Oct 1st Calculus with Parametric Eq (cont)	2nd P: New Project?
5th Arc Length	6th Surface Area	7th Polar Coord	8th Calculus with Polar Coord	9th P: Polar Coord Practice
12th Calculus with Polar Coord (cont)	13th Calculus with Polar Coord (cont)	14th Sequences A: Sorting Rates	15th Sequences (cont) A: Sorting Sequences	16th P: Recursive Sequences

Monday	Tuesday	Wednesday	Thursday	Friday
19th Exam 2	20th Series	21st Series (cont)	22nd Geometric Series	23rd *p*-series integral test
26th P: Geometric Series	27th A: Integral Test	28th Comparison Tests A: Comparison Discovery	29th Limit Comparison Test A: Comparison Practice	30th Alternating Series
Nov 2nd P: Comparison Test Big Picture	3rd Ratio Test	4th Root Test and Misc Tests	5th Series Approx	6th P: Series Big Picture
9th Series Approx (cont)	10th Taylor Polynomials A: Taylor Poly	11th Taylor Poly (cont)	12th Power Series	13th P: New Project?
16th Exam 3	17th Power Series (cont)	18th Rep Functions as Power Series	19th Functions as Power Series (cont) Taylor Series	20th Taylor Series (cont)
23rd Fall Break	24th Fall Break	25th Fall Break	26th Thanksgiving	27th Thanksgiving
30th P: Building New Taylor Series from Old	Dec 1st Taylor Series (cont) A: Taylor Series Matching	2nd Error in Taylor Series	3rd Error in Taylor Series (cont)	4th Error in Taylor Series (cont)
7th P: Taylor Series Approx	8th P: New Project?	9th Seperable Diff Eq	10th Seperable Diff Eq (cont) A: Mixing Problems	11th Fall Reading Day

4.2 Development of Active Learning Projects to Support Reform

With our course reforms approved, we recognized that our changes would require new and revised active learning projects to support our reforms. We moved on to discuss how we could develop active learning projects to support the course reform.

- Integration by Parts Project developed by Sarah Salmon
- Geometric u-Substitution Project developed by Lee Roberson
- Improper Integrals Project developed by Lee Roberson
- Integration Techniques developed by Corey Lyons
- Tactile Integration Techniques Project developed by Rebecca Machen and Sarah Salmon

4.3 What Worked Well

Much like free t-shirts, free (quality) food provided a nice incentive to get people to contribute toward our goal. Our decision to make the focus of the FLC to be on reforming Calculus 2 proved to useful and kept us making progress. While we've encountered heated discussions in Calculus 2 coordination meetings in the past, especially when it came to the content of the course, we were able to maintain a cordial and collaborative group. This positivity may stem from the feeling that we were making changes to a source of past frustrations, and just the sense of change kept our group focused.

4.4 What Didn't Work

During the fall semester we staggered our biweekly meetings to accommodate those who could not attend one set time. Our intention was to provide the opportunity as many voices to our reforms as we could gather to make the changes feel as organic as possible. This decision proved to create a couple problems: (1) inclusion of redundancies in our meetings as we brought the separate meeting groups up to speed and (2) a lack of a directive voice to move on non-productive discussions and keep the groups focused on specific tasks.

4.5 Lessons Learned

Providing pizza was the most cost effective way to feed those attending our meetings. However, our attendance was typically greater, and our attendees were happier and more productive when we provided food that was more than just pizza. We found the two favorite choices for our FLC to be empanadas and Indian, and we attempted to provide these options whenever possible.

After the multiple meeting times in the fall semester, we learned to make a single meeting time for the spring semester. We worked to give specific tasks for the meetings, such as reviewing proposed active learning materials or being prepared to talk about a certain teaching issue that was voted online before our meeting.

While we wanted to develop active learning materials to support our reform work, we spent three to four meetings reviewing activities that individuals created outside of the meeting times. Unfortunately, this proved to not be a productive use of time. Often the projects were not in a polished enough state for peer review, we did not provide adequate direction, and the projects became overly criticized. From this we learned that a better use of time was to solicit input from our participants about specific teaching issues they encountered, and to focus our time talking through ideas to come up with ways to improve our teaching.

We found the FLC discussions useful and comforting to talk in the open about long held concerns, there is still a considerable amount of work to be done to prepare our reforms for the fall semester. From this realization, we've learned that there is a need to identify and designate specific tasks that need completing such as creation of new written homework and supportive active learning activities.

5 Overall Reflections

Reflecting back upon on our experience as members of the 2019-2020 ASSETT Faculty Fellows Program one of the most lasting impressions that has stuck with us are the connections we developed. The relationships with the other members of our ASSETT cohort expanded our sense of community within the university. Out of this community we took away not only new ideas for improving our teaching, but also returned to our department with a new focus and energy. This energy allowed for us to strengthen bonds within our own department, and then set a precedence for members of our department to continue their pedagogical evolution.

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