Expectation gaps between high school mathematics courses and college calculus

Lauren Godfrey

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Expectation Gaps Between High School Mathematics Courses and College Calculus

An Honors College Project Presented to

the Faculty of the Undergraduate

College of Education

James Madison University

by Lauren M. Godfrey

May 2020

Accepted by the faculty of the Department of Middle, Secondary and Mathematics Education, James Madison University, in partial fulfillment of the requirements for the Honors College.

FACULTY COMMITTEE:  

Project Advisor: Ann H. Wallace, Ph.D.  
Associate Professor, Department of Middle, Secondary, and Mathematics Education  
College of Education

Reader: Elizabeth G. Arnold, Ph.D.  
Assistant Professor, Department of Mathematics and Statistics  
College of Science and Mathematics

Reader: Zareen Rahman, Ph.D.  
Assistant Professor, Middle, Secondary, and Mathematics Education  
College of Education

HONORS COLLEGE APPROVAL:

Bradley R. Newcomer, Ph.D.  
Dean, Honors College

PUBLIC PRESENTATION

Due to the COVID-19 pandemic, the requirements for a public presentation have been waived.
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Abstract

As a tutor at the Science and Math Learning Center (SMLC) at James Madison University (JMU), I have seen a disconnect between students’ preparation from their high school math classes and their application of particular topics in higher level math classes (i.e. Calculus I). As a future high school math teacher, I wanted to investigate the expectation gap between high school and college math classes. I observed a Calculus I class during the first week of classes to determine the students’ initial struggles. I finally landed on the topic of logarithms and specifically the rules associated with them. I conducted a survey in the same Calculus I class, and collected data on the students’ college and high school math classes and grades, other university math classes and grades, and their current and expected grade in the class. I also presented a problem for them to solve, requiring logarithmic differentiation, to determine their ability to apply a high school math topic in a Calculus I setting. I took the responses from the problem and compared them to the other data collected to see if interesting patterns arose to determine if there was a disconnect between high school math classes and the application of those topics in college math classes. I ultimately focused on the freshmen in the class for my analysis because they are the closest removed from high school. In addition, the majority of the participants from the Calculus I class were freshmen. From my analysis, I observed that many freshmen did well in their Algebra II courses in high school (when logarithms are taught), but most were struggling with applying the rules of logarithms to answer the question on the survey.
Introduction

The purpose of this study is to determine how to better prepare high school mathematics students to take college-level math courses. As a future secondary mathematics teacher, it is imperative to know what is expected by college math professors, in particular those taking college-level Calculus. I am currently a mathematics tutor at the Science and Math Learning Center (SMLC) at James Madison University (JMU), which supports students enrolled in a variety of math classes, ranging from College Algebra to Calculus 3. In my experience working at the SMLC, I observed many calculus students struggle with the algebra topics (from pre-requisite courses) required to solve a problem, rather than the actual calculus concepts.

An example of this disconnect may be related to optimization problems (e.g., given a set perimeter, find the maximum area that can be made from that perimeter). To solve these types of problems, students are required to take a derivative. Most students recognize that, but they may get stumped by which equation to take the derivative of, or how to get there. These problems have two equations, one that we are trying to maximize and one that has the constraint, each with two variables. For example, if you are trying to maximize the area of a rectangle with the perimeter being a fixed number, say 20, the two equations would be $2x + 2y = 20$ and $xy = A$. The students are given the two equations and they know they must take the derivative, but they do not know which equation to take the derivative of. Once the students figure out which equation to take the derivative of, they may get stuck because they do not know how to take derivatives of equations with two different variables. The students struggle to see that there is a constraint on one of the equations, and they can actually solve for one of the variables in terms of the other variable and substitute it into the other equation. Then they have one equation, one unknown, and they generally understand how to take the derivative of that and solve. The
problem students face is recognizing that they can solve one equation for a variable before substituting it into the second equation, generating a solvable equation. This is referred to as ‘solving systems of equations’, something they learned in high school algebra.

The objective for this study is to determine if there are expectation gaps (Achieve, 2010) in the high school mathematics preparation of students in one college Calculus I course. Expectation gap is defined as the gap between what students know leaving high school, and the actual knowledge they need to be successful in college (Achieve, 2010, p. 7). Are the expectation gaps consistent among the students in the course? My experience tutoring at the SMLC indicates that gaps do exist. However, the students I tutor are taking a variety of college-level math classes. My focus will be specific to one college Calculus I class. Determining these gaps will benefit me as a future secondary mathematics teacher to better prepare my students for college-level math courses.
Using an electronic mailing list (Wallace, 2018), I received feedback from both high school and college professors regarding my research question. Several of the high school teachers agreed that students struggle with: 1. rewriting exponential expressions; 2. determining when functions are being multiplied (for product rule) and composite functions (for chain rule); and, 3. factoring complex fractions when doing the product and quotient rule (which is used for taking the derivative). One teacher in particular commented that “students know $y = mx + b$ but they do not know or want to use the point slope form of an equation which is really simpler when finding equations of tangent lines.” Another high school calculus teacher commented that “the student is focused on getting the answer and not fully understanding what the process means. I have asked students to explain what a logarithm means and been met with a blank stare.” In addition, “they struggle with applying the basic rules of adding, subtracting, multiplying, and dividing fractions” which only inhibits students’ ability to do calculus.

A college calculus professor commented that the students “seem to be more daunted” and “they seem to be algorithm followers and not problem solvers.” He stated that he “got an email question for a take home quiz for finding critical numbers of a function and he knew to take the derivative, but he did not know what to do next.” Another college professor stated that she has had “groups of exceptional learners, but for the most part, student understanding is all over the place, disconnected and discombobulated.”

The research literature also supports my premise. Ayebo, Ukkelberg, and Assuah (2017) found that the transition to college life, attending lectures, and quality of high school calculus class have an impact on students’ success in calculus. They concluded that notation “is one thing
that should be taught in high school and pre-calculus college courses because it is like learning a new language which is needed before being required to apply concepts in that new language” (Ayebo et al., 2017, p. 17). The students being interviewed in the study had some suggestions for teachers to help prepare students. They included: 1. reviewing limits; 2. telling the students where specific concepts are used, and 3. how they will help them succeed in their careers.

In *Rethinking College Readiness* (2008), David Conley found that “students with a thorough understanding of basic concepts, principles, and techniques of algebra are more likely to succeed in an entry-level college mathematics course” (p. 25), which suggests that understanding the fundamentals of algebra will increase the mathematical success of students in college. For students who do not have a strong algebra foundation, it will be harder for them to succeed in college-level math courses. He argues that college-ready students should possess more than a formulaic understanding of mathematics. This includes “the ability to apply conceptual understandings in order to extract a problem from a context, to solve the problem and then to interpret the solution back into context” (Conley, 2008, p. 25). In other words, students should be able to apply what they have learned in more than one context.

Several studies found a disconnect between what high school teachers feel is important in preparing their students and the preparations college professors feel their students have (Kocher, 2017; Venezia & Jaeger, 2013; Er, 2018; American College Testing [ACT] National Curriculum Survey, 2009; Corbishley & Truxaw, 2010). In particular, the ACT National Curriculum Survey (2009) found that “71 percent of high school teachers reported that their state’s standards prepare students ‘well’ or ‘very well’ for college, while only 28 percent of college instructors reported this” (p. 5). They also found that 91 percent of high school teachers feel their students are prepared for college level work in general. In contrast, only 26 percent of college instructors
reported that their students arrive prepared (p. 6). Oddly, in contrast to college mathematics
instructors, high school mathematics teachers tend to rank advanced topics as being more
important than fundamentals, while college professors valued fundamental skills such as those
related to simple algebraic expressions, arithmetic operations, elementary number concepts, or
basic facts and formulas (p. 8). The college instructors also feel that high school learning
standards are not sufficiently aligned with postsecondary expectations.

In *Logarithms- a meaningful approach with repeated division* (Ansah, 2016), the authors
state that “many students find logarithms difficult” (p. 30). They say that this is because “the
rules for calculating logarithms are not visually salient” (p. 30) and “they limit themselves to
memorizing, and then the rules remain difficult to remember” because they have no further
meaning of logarithms to work with (p. 30). These are the challenges that students face when
first learning logarithms in a high school math class. To apply the rules of logarithms, they
really need to have an understanding of the concept as a whole.

The literature confirms that there is a disconnect between what high school teachers teach
and what post-secondary instructors expect with regard to students’ college mathematics
preparation. This study will look more critically at one college Calculus I course to determine
where the expectations gap lies.
Methodology

To conduct this study, I used two different data collection methods: 1. Data from my survey (Appendix A) and; 2. Classroom observations. From my data, I wanted to pinpoint any gaps between high school mathematics classes and how those gaps may hinder students’ ability to perform well in college Calculus classes. I wanted to do this by selecting a prerequisite topic to determine how the students in a Calculus I class would perform answering a problem that used that topic in a Calculus application. I would be picking that topic from my classroom observations.

During the fall 2019 semester, I observed a Calculus I class during the first week of the semester. The students were reviewing prerequisite material, which gave me the opportunity to see what topics they mostly struggled. The students in the class worked together to complete packets of prerequisite material, such as rules of logarithms, domains of trigonometric functions and their inverses, and graphing exponential functions. As they worked on the packet, I walked around, observing and answering any questions that they had. As I walked around, I noticed that many of the students struggled with remembering and applying the rules of logarithms, especially the product rule for logarithms, quotient rule for logarithms, and the power rule for logarithms. Logarithms are first introduced in a high school Algebra II or Pre-Calculus course. Logarithms are the inverse of exponential functions and they have rules that simplify multiplication to addition and division to subtraction. These rules of logarithms are very important in Calculus I class when using logarithmic differentiation. Taking the derivative of a classic logarithmic differentiation problem without logarithmic differentiation would be a long and tedious process, but to do logarithmic differentiation, they have to know the rules of
logarithms. Thus, for this study I chose to focus on the rules of logarithms as my high school concept and logarithmic differentiation as my college-level calculus concept focus.

Once I decided on rules of logarithms as my high school math topic focus, I developed a survey for students to take after learning logarithmic differentiation. Before conducting this survey, I received IRB approval for the project, with IRB protocol # 19-0769. On the day that the survey was completed, I went to the class and told students that I was doing an honors project about the expectation gap between high school math courses and college math courses and I asked them to complete a survey. I administered the consent form (Appendix B) to sign and told them that it is a voluntary, anonymous survey. If the student signed the consent form, he or she received a survey to complete. Only the data I discuss are from those who consented. The survey asked about the student’s grade level, high school math classes they completed and the grade received, other math classes they have taken at JMU and the grade they received, their current grade in the class and what grade they believe they will earn, and a logarithmic differentiation problem for them to complete. I had them use logarithmic differentiation to take the derivative of \( y = \frac{(x^3 + 2x)^4 e^{2x}}{e^{6x}(\sqrt{x^2 - 3x - 4})} \). I gave the participants about 20 minutes to complete the survey.

I analyzed the data using mixed methods, both qualitative and quantitative methods of analyses. I looked at all of the responses to identify what kinds of errors that the students made and compared those to the other data collected through the survey to see if any relationships arose.

When looking at the responses to the logarithmic differentiation problem, there were eight different rankings, 1-8 based on the accuracy and types of mistakes that students made. In
the analysis section, I will describe what each of these classifications mean as well as provide examples of students’ work for each of them.
Analysis

There were a total of 26 students who participated in the survey. I ranked each of the students’ answers to the logarithmic differentiation problem from 1-8. Of the 26 participants, 18 were freshmen, 6 were sophomores, and 2 were juniors.

A ranking of 1 indicates that the student correctly took the derivative using logarithmic differentiation. Figure 1 represents a student’s solution with a ranking of 1.

\[ y = \frac{(x^{-3}+2x)^4 e^{2x}}{e^{6x}(\sqrt{x^2-3x-4})} \]

\[ \ln y = 4 \ln(x^{-3}+2x) + 2x - 6x - \frac{1}{2} \ln(x^2-3x-4) \]

\[ \frac{y'}{y} = \frac{4(-3x^{-4}+2)}{(x^{-3}+2x)} - 4 - \frac{2x-3}{2(x^2-3x-4)} \]

\[ y' = \frac{(x^{-3}+2x)e^{2x}}{e^{6x}(\sqrt{x^2-3x-4})} \left[ \frac{4(2-3x^{-4})}{(2x+x^{-3})} - \frac{(2x-3)}{(2x-6x-8)} \right] - 4 \]

A ranking of 2 indicates that the student correctly applied all of the rules of logarithms, but made a minor error in taking the derivative of the function, (i.e. forgetting to apply the chain rule). Figure 2 represents a student’s solution with a ranking of 2. In this problem, the student incorrectly applied the chain rule when taking the derivative of the term, \(4 \ln (x^{-3} + 2x)\). The correct derivative of this is \(4(x^{-3}+2x)(-3x^{-4} + 2)\), and the student only included the \(-3x^{-4}\).
A ranking of 3 indicates that the student applied most of the rules of logarithms correctly and did not get the answer correct. An example of this is not simplifying $\ln(e)$ as 1. Figure 3 represents a student’s solution with a ranking of 3. In this problem, the student incorrectly applied the quotient rule for logarithms. They failed to make the fourth term negative, which it should be because it is in the denominator in the original problem.
A ranking of 4 indicates that the student applied one or two rules of logarithms correctly and did not continue solving the problem. From their response, I do not know if those students would have continued applying the appropriate rules of logarithms or not, had they kept going. An example of this would be that the student applied the division rule for logarithms correctly, but stopped there. Below is a figure of a response with a ranking of 4. In this response, all of the work that this student did for the problem is given. They were correct in taking the natural log of both sides, but because they stopped, I do not know what their next steps would have been; and it is unclear whether they understand the rules of logarithms.
A ranking of 5 indicates that the student applied one logarithm rule and started taking the derivative, which indicates that they only knew one rule, which is not enough to simplify the problem all the way. An example of this would be that the student applied the division rule of logarithms correctly, but took the derivative from there, when there was more simplification that the student could do. Below is a figure of a response with a ranking of 5. In this response, the student correctly applied the quotient rule for logarithms, but went straight to taking the derivative (what the arrow represents). There are more rules of logarithms that the student should have applied before taking the derivative to simplify the problem.

![Figure 5: A student’s solution with a ranking of 5.](image)

A ranking of 6 indicates that the student started logarithmic differentiation correctly, but did not know any of the rules of logarithms. An example of this would be a student who takes the natural logarithm of both sides, but did not apply any rules of logarithms correctly. Next is a figure of a response with a ranking of 6. In this response, the student took the natural logarithm of both sides, but then went straight to taking the derivative, not applying any rules of logarithms to help simplify the problem.
A ranking of 7 indicates that the student did not do logarithmic differentiation. Instead, they immediately applied the quotient to take the derivative. Below is a figure of a response with a ranking of 7. In this response, the student did not take the natural logarithm of both sides (an important first step when applying logarithmic differentiation) but went straight to applying the quotient rule to take the derivative.
A ranking of 8 indicates that the student did not respond to the problem at all. Below is a figure of a response with a ranking of 8.

![Figure 8: A student’s solution with a ranking of 8.](image)

After ranking each student’s solution to the logarithmic differentiation problem, I compiled all of the data. For each student, I recorded the ranking they earned on the logarithmic differentiation problem along with their academic year, high school math courses and grades, any other math classes completed at JMU and corresponding grades, and their current and expected grade in their college-level Calculus I course. Next, I wanted to explore the relationship between freshmen rankings and the grades the freshmen received in a high school Algebra II class. I chose to focus on the freshmen because they are the closest removed from being in high school. I decided to focus on Algebra II because that is the course where students learn about logarithms and the rules associated with them. To explore these relationships, I created bar graphs to search for interesting patterns that emerged from the data.
Results

Figure 9 displays the number of survey responses for each ranking.

![Number of Surveys with Each Rank](image)

Figure 9: The number of survey responses at each ranking.

Looking at the bar graph in Figure 9, most of the students received rankings 6-7 and fewer students received ranks of 1-2, with a mode at a rank of 7. The mode at the rank of 7 means that most of the students did not apply logarithmic differentiation to take the derivative of the function. Most of the students who received a rank of 7 started applying the quotient rule and writing out all of the subsequent derivatives that would be needed to apply the quotient rule. Since this takes into consideration all of the survey responses, I thought that I would compare this to the ranks of freshmen responses and the freshmen grades in Algebra II.
Looking at Figures 9 and 10, the one student who received the ranking of 1 was a freshman. All of the students who received a rank of 4, 5, and 8 were freshmen and four out of six students who received a ranking of 7 were freshmen. This means that although these students were closely removed from high school, they had a lot of the lower rankings, indicating they had difficulty with the logarithmic differentiation problem. Seeing this, I was interested in looking at the grades of the freshmen in Algebra II. Some of the students did not report grades on the survey, so I am only including the grades that were provided.
Figure 11 indicates that most of the students who reported their Algebra II grades received an A or A-. This is very interesting since most of the freshmen received the lower ranks in the logarithmic differentiation problem. The ranks that they got indicated that they either applied a few rules of logarithms but did not apply all of them to simplify the expression, all the way to not doing anything on the problem. Since overall the students did well in Algebra II in high school, they should be able to apply the rules of logarithms to simplify expressions. This confirms that there are gaps between what is taught in high school math classes and what is expected in college-level math classes. One other interesting piece of information I found was that the one student who received a ranking of 1 on the problem went to high school in India, so he or she did not take high school math classes in the United States.
Summary of Results

Based on the analysis above, there are some gaps between what high school teachers teach and what college professors expect students to know, particularly freshmen. Especially since all of the participants ranked 4 and 5 were freshmen (participants who either applied one or two rules of logarithms correctly) means that they understood some of the rules, but not necessarily all of them. The ones ranked 4 may have known more rules if they had more time to complete the problem, but the ones ranked 5 only knew one rule. Also, freshmen participants made up half of the students who did not complete any rules of logarithms correctly. This means that although those students were the closest removed from high school, they still have some misunderstandings or gaps in knowledge when it comes to the rules of logarithms that are taught in high school.
Discussion

Looking at the results, it seems that there is a gap between what students remember from high school math courses and what college professors expect in higher level math classes, such as Calculus I. This gap can hinder students’ abilities in higher level math classes in the future. Having a strong mathematical background in high school and remembering the foundational algebraic concepts taught can help prepare students for the rigor of college-level math classes, especially for students who want to pursue STEM related careers. If students have a strong mathematical background and remember the foundational algebraic concepts they are taught, it will make applying those concepts to higher level math classes easier, which may help students develop a deeper understanding of the material.

When I learned logarithms in high school, we were assigned a lot of practice problems involving expanding and condensing logarithms by applying the rules of logarithms. This practice is okay, but I do not remember going deeper into understanding why those rules exist. I think that when learning math, understanding the reasoning behind a concept is more important than simply memorizing the rules. As a future high school math teacher and given this gap, when teaching logarithms, I would create activities for the students to dive deeper into the understanding of logarithms. I would go over why those rules exist and create more applicable projects to solidify the concept instead of having the students simply complete more practice problems.
Conclusion

In the discussion, the research concluded an expectation gap between what students retain from high school math courses and what college professors expect in college-level (Calculus I) math classes. This informs my knowledge as a future high school teacher to better teach my students the concepts that I know will be integral to higher level math courses. To teach these concepts, I will need to provide activities to give students a deeper understanding of the rules of logarithms as opposed to having my students merely practice computational procedures.
Appendices

Appendix A

Honors Project Survey

1. What is your current year at JMU? _______________________

2. List your high school math classes and the grades you received in each.
   a. 
   b. 
   c. 
   d. 
   e. 

3. List all math classes you have completed at JMU and the grade(s) you received.

4. What is your current grade in this class? What grade do you believe you will earn at the end of the semester?

5. Take the derivative using logarithmic differentiation.

\[ y = \frac{(x^{-3} + 2x)^4 e^{2x}}{e^{6x}(\sqrt{x^2 - 3x - 4})} \]
Appendix B

Cover Letter (Used in Anonymous Research)

Identification of Investigators & Purpose of Study
You are being asked to participate in a research study conducted by Lauren Godfrey from James Madison University. The purpose of this study is to determine how to better prepare secondary mathematics students to take college math courses. The objective of this study is to determine if there are expectation gaps in the high school mathematics preparation of students in one college Calculus I course. This study will contribute to the researcher’s completion of her Honors Capstone Project.

Research Procedures
This study consists of a survey that will be administered to individual participants in Roop Hall. You will be asked to provide answers to a series of questions related to your previous math experiences.

Time Required
Participation in this study will require 5 to 10 minutes of your time.

Risks
The investigator does not perceive more than minimal risks from your involvement in this study (that is, no risks beyond the risks associated with everyday life).

Benefits
Potential benefits from participation in this study include increasing the knowledge in the field of secondary mathematics education.

Confidentiality
The results of this research will be presented at the Honors Symposium in the spring of 2020. While individual responses are obtained and recorded anonymously and kept in the strictest confidence, aggregate data will be presented representing averages or generalizations about the responses as a whole. No identifiable information will be collected from the participant and no identifiable responses will be presented in the final form of this study. All data will be stored in a secure location accessible only to the researcher. The researcher retains the right to use and publish non-identifiable data. At the end of the study, all records will be destroyed.
Participation & Withdrawal

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind. However, once your responses have been submitted and anonymously recorded you will not be able to withdraw from the study.

Questions about the Study

If you have questions or concerns during the time of your participation in this study, or after its completion or you would like to receive a copy of the final aggregate results of this study, please contact:

Lauren Godfrey
Honors College
James Madison University
xxxxxx@dukes.jmu.edu

Ann Wallace
Department of Middle, Secondary, and Mathematics Education
James Madison University
Telephone: (xxx)-xxx-xxxx
xxxxxx@jmu.edu

Questions about Your Rights as a Research Subject

Dr. Taimi Castle
Chair, Institutional Review Board
James Madison University
(xxx) xxx-xxxx
xxxxxx@jmu.edu

Giving of Consent

I have read this cover letter and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. I certify that I am at least 18 years of age.

____________________________________
Name of Researcher (Printed)
This study has been approved by the IRB, protocol # 19-0769.


Proceedings of the 39th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education (pp. 1115-1118).

Indianapolis, IN: Hoosier Association of Mathematics Teacher Educators.


Wallace, A. (2018, November 1). RE: Transitioning from High Schools Math to College Calculus. [seeking input from current high school and college calculus teachers].

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