A New Mathematics Course Sequence for Life Sciences Majors: A progress report*

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Abstract

In response to the BIO 2010 report on transforming undergraduate education for biologists [9], a group of faculty applied for and received an NIH T36 grant to support curricular changes. We used a three-pronged approach: 1) modifications in the introductory biology, physics, and mathematics sequences for life science majors; 2) an interdisciplinary research seminar connecting the disciplines; and 3) creation of a new bioinformatics minor. We report here on changes in the mathematics curriculum, assessment of the changes, and related aspects of curricular change. Three new courses were created: Math 105, Introduction to Mathematical Models in Biology (replacing the trigonometry course), and Math 204/205 Applied Calculus I/II. In all new courses, the mathematical concepts are introduced and explained in the context of biological applications. The new sequence started in Fall 2011, and all three courses have been taught at least six times. Assessments of student attitudes towards mathematics and its importance show positive change, and students are taking the courses earlier in their careers. The positive trend in terms of pass rates from the first year of the implementation continues, even as the number of faculty teaching the courses has increased. Ongoing challenges such as finding instructors to teach the sequence, selecting suitable textbooks, and training of biology faculty on the new mathematics topics are discussed.

Keywords: Mathematics Courses for Life Science Majors, Applied Calculus, Assessment, Faculty Training

1 Introduction

California State University Los Angeles (CSULA) is one of the 23 campuses of the California State University system, and is on a quarter schedule. We are a minority-serving institution with students primarily from within a 10 mile radius. In Fall 2011, approximately 62% of the students were Hispanic, with the remainder made up of Asian (19%), non-Hispanic White (13%), and African-American (6%) students. Biology majors show similar ethnic distribution (see Figure 1).

The large majority of CSULA freshmen need remediation in mathematics, English, or both. For biology majors, about 50% of the declared majors who enter CSULA as freshmen need at

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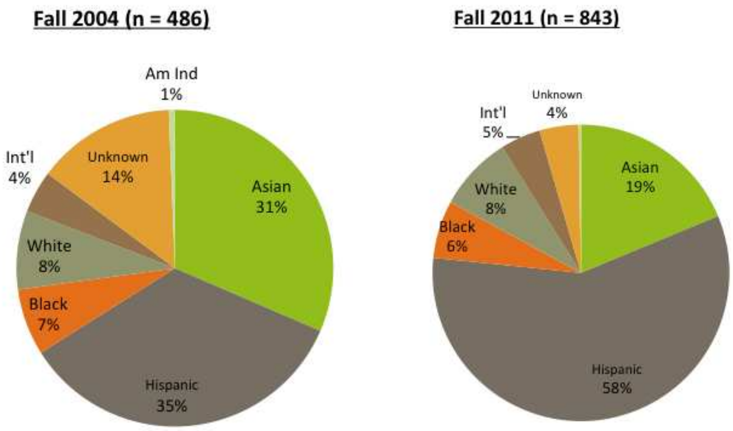

Figure 1: Ethnicity of incoming biology freshmen.

least one quarter of remedial mathematics, while between 5% and 10% need a full year of remedial mathematics (Math 89, 90 and 91). Figure 2 shows the placement distribution in 2004 and 2005 (before we received the grant) and in 2011 and 2012, the years in which the new mathematics sequence was offered. While the number of declared biology majors entering CSULA as freshmen has increased nearly four-fold, the mathematics preparation of the incoming class has not changed.

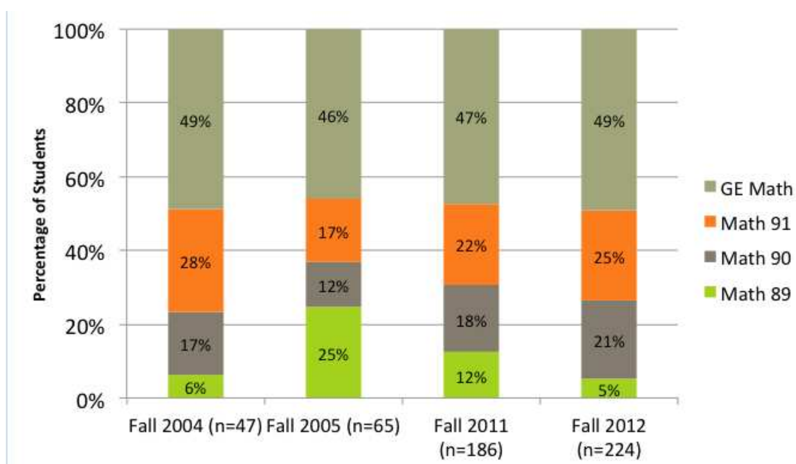

Figure 2: Placement of incoming biology freshmen into mathematics courses.

In 2005, the Department of Biological Sciences undertook an assessment of the quantitative skills of their majors, in response to the BIO 2010 report [9] which had appeared in 2003. The main concerns were that students were not able to use what they had learned in their mathematics courses, and/or that they had not taken their required mathematics courses by the time they enrolled in their upper division biology courses. Even if students had taken the mathematics courses, they seemed to be unable to translate their knowledge and skills to problems in biology, for example to solve genetics problems or to interpret graphs.

At the same time, the NIH training division issued a request for proposals to improve the quantitative skills of life science majors to better prepare them for advanced degrees, and to broadly affect the next generation of life science majors. A group of faculty from biology, mathematics, physics, biochemistry, and computer science applied for and received (in 2008) a five-year NIH T36 grant to support curricular changes. We proposed three major projects: 1) modifications in the introductory biology, physics, and mathematics sequences for life science majors; 2) an interdisciplinary research seminar connecting the disciplines; and 3) the creation of a new bioinformatics minor. Here we report on the changes in the mathematics curriculum for life science (biology, microbiology and exercise science) majors.

Our overarching design principle was to identify the mathematics topics that would be relevant for life science majors in their biology courses. We started from the initial assessment of the quantitative skills of biology majors, and took into account the BIO 2010 report [9]. In addition, the Mathematical Association of America had issued a counterpart to the BIO 2010 report, Math & Bio 2010 [8], which provided examples of mathematics curricula for life sciences majors. It became quickly apparent that a discrete mathematics component was missing, while the typical topics in a trigonometry course (a prerequisite of the standard calculus courses) for the most part are not used in biology courses. As a result, we designed a new three quarter sequence consisting of a discrete modeling course to replace the trigonometry course, followed by two applied calculus courses. All three courses have a dynamical systems approach, and all topics are introduced and used in a biology context. We have attended each other's classes, which allowed us to find good topics to make connections between the mathematics and biology courses. The new course sequence was first taught in AY 2011/12, with a staggered introduction of the new courses: Math 105 started in Fall 2011, Math 204 started in Winter 2012, and Math 205 started in Spring 2012. Each course has now been taught at least six times, and we have assessed students in each course in each quarter.

We give an overview of the new curriculum and how it compares to the old one, discuss the process of curricular change, and report on assessment of the new course sequence. We also discuss the challenges we have encountered and provide information on how we responded to these challenges.

2 The New Course Sequence

2.1 Required and Prerequisite Courses

Prior to the newly developed course sequence, biology majors were required to take two quarters of mathematics, Calculus I (Math 206) and Calculus II (Math 207). The prerequisites to the calculus courses are Precalculus: College Algebra (Math 104A) and Precalculus: Trigonometry (Math 104B). The required courses for microbiology majors were the two precalculus courses, Math 104AB. The only mathematics prerequisite in the biology curriculum was the trigonometry course (Math 104B) for the upper division biometrics course. This prerequisite was not so much a content prerequisite, but rather a"maturity" requirement to ensure that students enrolled in the biometrics course had passed at least the prerequisites to the required mathematics courses. Connections between mathematics courses and biology courses were virtually non-existent. Furthermore, students delayed taking the calculus courses until they were seniors, which led to a high percentage of course repeats as students had forgotten what they learned in the precalculus courses.

The new course sequence replaces the trigonometry course (Math 104B) with a discrete modeling course, and the Calculus I and II courses with a new sequence called Applied Calculus I and II that connects the mathematical topics to biological applications. Table 1 shows the old and the new course sequences, both of which have Math 104A as a prerequisite.

Table 1: Comparison of old and new courses sequences

Old Course Sequence	New Course Sequence
Math 104B: Precalculus -Trigonometry	Math 105: Intro. to Mathematical Models in Biology
Math 206: Calculus I	Math 204: Applied Calculus I
Math 207: Calculus II	Math 205: Applied Calculus II

With the new courses, the mathematics requirements for biology majors became Math 204 and Math 205 (with Math 104A and Math 105 as prerequisite courses), which did not change the number of required mathematics courses. On the other hand, microbiology majors are now required to take Math 105 and Math 204, with Math 104A as the prerequisite. This amounts to an increase of one quarter of mathematics for microbiology majors.

2.2 Course Descriptions

Our goal was to make the mathematics meaningful for biology students. The biggest difference to the prior curriculum is the first course in the new sequence, Math 105, Introduction to Mathematical Models in Biology, while the subsequent courses, Math 204 and Math 205, Applied Calculus I and II, are more closely related to the courses they replace.

In Math 105, the overarching theme is how to develop discrete models for quantities of interest, either from physical and biological principles, or from measured data. The first approach leads to a discrete dynamical system (DDS), a recursive equation of the form $x_{n+1} = f(x_n)$ with initial value x_0, where $f(x)$ is the *updating function*. On the other hand, to build a model from measured data, we identify the type of function that a graph of the data suggests, and then use a least squares fit to obtain the function (model) parameters. The course starts with a quick review of linear, exponential and logarithmic functions by showcasing biological applications that can be modeled using these functions. In addition, we introduce radian measure and the general sine and cosine functions, but we leave out the other trigonometric functions as they do not arise in biological applications. Another important aspect is conversion of units, and the consistent use of units in formulas and answers.

Linear functions feature prominently in the derivation of the least squares fit and also in growth models. Specifically, for a linear DDS of the form $x_{n+1} = a \cdot x_n + b$ with initial value x_0, the explicit solution (that is, expressing the quantity as a function of time as opposed to a function of the value at the previous time) is an exponential function. We introduce the notion of an equilibrium value and its stability in the context of linear DDS, since in this instance general formulas can be found for the equilibrium value and easy rules for determining the stability. For non-linear systems, we solve for the equilibrium value algebraically and use a graphical approach, cobwebbing, to determine stability. Least squares fit is used not only for data that follows a linear trend, but also for enzyme kinetics, where a rational function can be transformed into a linear function in new variables, and for allometric models, where the logarithms of the original data follow a linear trend. For data that is periodic in nature we use Mathematica to find a best fit cosine function. Besides linear growth models, we discuss models with non-linear growth functions, such as growth rates that depend on time or population size. Examples of the latter are the logistic growth model, as well as Ricker's and Hassell's models. The last part of the course focuses on basic probability theory such as computing probabilities when outcomes are equally likely, basic rules for computing unknown probabilities from known ones (e.g., $P(A^c) = 1 - P(A)$), conditional probability, independence, and Bayes' Law. Applications are primarily from genetics.

The focus of Math 204 is differentiation. We start with the definition of the instantaneous rate of change as the limit of the average rate of change and the geometric interpretation of these rates as the slopes of secant and tangent lines. The usual rules of differentiation (derivatives of specific types of function, product, quotient and chain rules) are motivated with relevant examples of biological functions. We also use the derivative to assist in graphing a function of interest and discuss how we can read off the behavior of a function from a graph of its rate of change and vice versa. Applications of the derivative include optimization, Newton's method for numerically solving an equation by finding the zero of the associated function, and the stability of an equilibrium value. The notion of limit is used in the definition of the instantaneous rate of change, and is also used to investigate the long-term behavior of a system. Throughout, we use the vocabulary of the life sciences, referring to the derivative as rate of change. The course ends with an introduction to differential equations, which arise naturally when developing continuous models from physical or biological principles, just as the recursive equations arise in the discrete case.

In Math 205, we introduce integration as a method to solve the problem of deriving a function for a quantity of interest when its rate of change is given. Here, as in the discrete setting, biological or physiological processes allow us to easily derive a model in one form (as a recursive updating function or in the form of a differential equation), but we much prefer to find a more useful form for computations, namely an explicit function, usually of time. We derive antiderivatives of power, exponential, logarithmic, and sine/cosine functions, and develop methods of integration such as integration by parts, u-substitution, and separation of variables. Euler's method for pure time and autonomous differential equations of one variable, as well as for systems of equations, is introduced and used to find numerical solutions if all else fails. We also explore models in two variables such as predator-prey and competition models and derive their equilibrium values. We build on the ideas underlying Euler's method for solving systems of two differential equations to create vector fields showing the direction of the rate of change. These vector fields are then used to determine the stability of equilibrium values as well as long-term behavior of solutions.

All three courses incorporate technology in the form of Excel and/or Mathematica as a tool to simulate and explore. With the grant support, we purchased several laptop carts that can be used in any classroom, eliminating the bottle neck of a limited number of computer labs on campus. Students work on an activity in class, and then have a group homework assignment that is based on the activity. Examples of activities are producing graphs of multiple data sets, using formulas and named cells, adjusting a template for a different problem, exploring Malthusian and logistic growth, fitting a cosine curve to cyclic data, exploring limits of functions, connecting the graph of a function and the graph of the function's rate of change, evaluating stability of equilibria, using Newton's method to find zeros of a function and Euler's method to solve different types of differential equations, and using vector fields to analyze the dynamics of systems of two variables.

Even though the Vision and Change report [2] did not exist when we embarked on this curriculum development, the new courses meet several of its recommendations. The report states that "Studying biological dynamics requires a greater emphasis on modeling, computation, and data analysis tools than ever before" (page 3). It proposes five core concepts and six core competencies, two of which are quantitative in nature, namely the abilities "to use quantitative reasoning" and "to use modeling and simulation."

3 Challenges

When undertaking curricular change, there are many challenges: Who will teach the course? What text to use? What are the implications of this change on the department as a whole? Can this change be sustained? That is, will a course cease to exist when the faculty member who developed it leaves? We encountered all of these and more, as this is a set of courses taught by one department for majors in another, introducing additional complexity.

3.1 Challenge # 1: Instructors and Text Books

When the courses were first proposed and reviewed by the curriculum committees in the two departments, there were several concerns:

- Would the creation of a special calculus sequence for biology majors spawn requests from other departments for their own tailor-made sequences? The same concern was also raised at the College level, as a proliferation of special course sequences has fiscal implications, and we were in the middle of a major budget crisis. We argued successfully that biology majors differ from other majors who take calculus in that they only take two quarters of calculus, while all other majors take four quarters.

- Who would teach these course? How many sections would there be? In addition to the first author, who created the sequence, the Department of Mathematics had recently hired two applied mathematicians with research interests in mathematical biology. These faculty members were obvious candidates for teaching the courses. However, a major increase in the number of biology majors (from 47 and 65 freshmen in the Fall Quarters of 2004 and 2005 to 186 and 224 freshmen in the Fall Quarters of 2011 and 2012) required more sections and therefore more instructors. Additional demand for Math 105 came from the Department of Exercise Sciences, who became aware of the new course and decided they would change their requirement from Math 104B to Math 105. This was a surprise as that department had not been involved in the development of the course, but they obviously liked the more relevant mathematics topics in Math 105. Also, the newly hired faculty needed to teach some graduate courses, diminishing the number of sections they were able to teach. We therefore recruited some of our long-time part-time instructors who had an interest in applications and knowledge of Excel and Mathematica (or willingness to learn) to become faculty whose main teaching assignments would be the new course sequence. This was a win-win situation for the department and the instructors: The department knew it would have a stable pool of very good instructors, and the instructors were almost guaranteed to get courses each quarter as they now had created a niche for themselves. The first author worked with the part-time instructors in the development of the courses, giving these instructors a stake in the continued success of the sequence. In Fall Quarter 2013, three sections are taught by tenured/tenure-track faculty and five sections by part-time faculty.

- Finally there is the question of finding a suitable text, one that matches the ideas of the course designer. Often, a new course starts with lecture notes that eventually grow into a textbook. Since we wanted to assess the effect of the change for all biology majors, this approach was not feasible in the time-frame we had set for ourselves. So we were looking for available textbooks geared toward the life sciences. What we found was that many of the calculus texts for life science majors were either specialized texts targeting both business and life sciences, or they followed the standard calculus approach, but added examples and problems that had biological applications. The number of texts with a dynamical system approach was rather limited. We choose Adler's book [1] and supplemented the text with our own notes on sine and cosine functions as well as radian measure. With those supplements we were able to use the text for all three courses (Chapter 1 and Sections 6.1 - 6.5 for Math 105, Chapters 2 and 3 for Math 204, and Chapters 4 and 5 for Math 205). We used Adler for the first two academic years the new courses were offered, but found that the level was more suited for upper-division/graduate level courses, so we searched again. This time we took advantage of the ability to rearrange and combine texts. Joseph Mahaffy, who teaches a calculus sequence with a dynamical systems approach at San Diego State University had created custom edition texts, [3] and [4], based on his lecture notes. Unfortunately, they were organized for a two semester sequence, while we needed to have them organized for a three quarter sequence in a somewhat different order. In addition, the Mahaffy texts were missing the desired introduction to probability theory. With the aid of the publisher, we rearranged the Mahaffy texts and added relevant sections on probability from Neuhauser [7]. This also allowed us to break the full text into a first volume on discrete models for Math 105 [5], and a second volume on continuous models for Math 204/205 [6]. We started to use the CSULA version of the Mahaffy custom edition for Math 105 in Fall Quarter 2013 and it is working out well so far. Of course, creating a custom text from different books or rearranging a text is a major task, as one has to ensure that there is still consistency in terms of referencing and defining terminology before it is used.

3.2 Challenge # 2: Training Biology Faculty

Another challenge was the need to familiarize biology faculty with the contents of the new course sequence, so they would be able to build on it in their biology courses. Some of those topics might be new to the faculty members, while others may have been forgotten. We offered three workshops, each on a different theme. The first workshop focused on exploring a linear discrete dynamical system with Excel. Faculty learned about the relevant theory and then worked through the Excel activity and worksheets, just as the students would in Math 105. The second workshop focused on basic probability, and the applications of conditional probability and independence to problems related to genetics. The third workshop focused on continuous models, with a refresher on derivatives followed by an Excel activity related to a growth model. In each workshop, the mathematics instructors worked in teams with the biology instructors and the feedback was enthusiastic. Many of the life sciences faculty members indicated that they were now better prepared to incorporate quantitative activities and topics into their classes. In fact, in the probability workshop one of the activities focused on identifying which probability applications might be introduced into biology and microbiology courses.

3.3 Challenge # 3: Implementing Changes in the Biology Curriculum

The final curricular challenge still lies ahead: to more fully modify the biology curriculum. We have integrated some quantitative exercises, such as graphing and basic statistical analysis of data that students collect, into the laboratories associated with the introductory biology sequence. Some of these exercises were developed by us after we attended each other's courses to identify topics that could be discussed in both mathematics and biology courses to make connections. Other exercises came from the online text that was used in the introductory biology course. With the impending change to the semester system at CSULA, the biology department will have the opportunity to re-evaluate the topics and methodology in the introductory biology sequence. We are confident that a more quantitative curriculum will emerge.

4 Assessment

A big part of any curricular modification is the assessment as to whether this modification has accomplished the stated goal. To this end, we assessed several aspects of the curriculum changes.

4.1 Description of the Assessment Protocol

A big part of the assessment consisted of student surveys in all the courses affected by the curricular changes. For the new mathematics sequence, we surveyed students in each section of the three courses in all quarters, with pre- and post-surveys in some courses. More specifically, we gave a pre- and a post-survey in Math 105, and then post-surveys in Math 204 and Math 205. In Math 205, the survey also asked about the whole sequence, not just the individual course. Questions focused on students' views about mathematics and its importance to biology, specific assignments (to help us refine the curriculum), the interconnection between the two disciplines, and how valuable the course was for their major. We also looked at pass rates in the new courses as compared to the pass rates for biology majors in the corresponding trigonometry and standard calculus courses in previous years. Finally, we assessed at which point in their academic careers life science majors now take the calculus sequence, again comparing the status quo at the time we received the grant with the results over the last two years.

4.2 Student Survey Results

We tried to gauge the impact of the courses on students' attitudes toward mathematics, and whether their perception of its importance in biology had changed. Figure 3 shows responses to the question *What is your attitude regarding mathematics?* Note that at the end of Math 105, 43% of the students like or love mathematics, and that this percentage increases from 43% in Math 105 to 53% in Math 205.

With regard to the importance of mathematics for biology, we asked the question *From the mathematics courses you have taken so far, how useful do you think mathematics is for a career in*

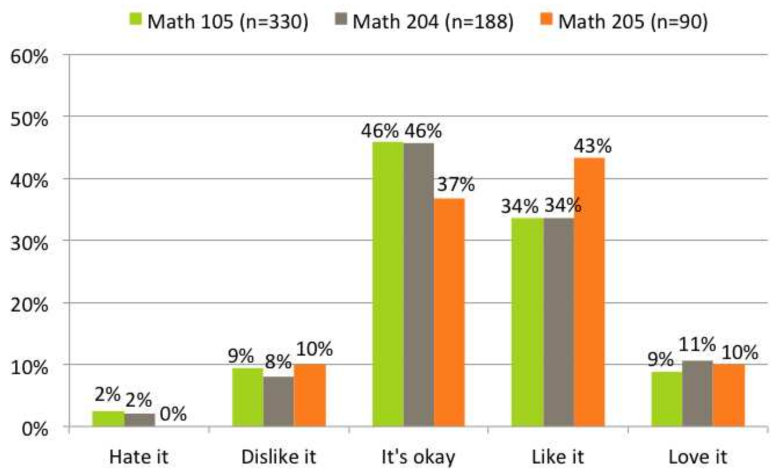

Figure 3: Attitudes toward mathematics.

biology? Figure 4 shows the changes from the pre-survey to the post-survey in Math 105, the first course in which the mathematics topics were tied very closely to the biological applications. The pre- and post-survey results show that there was a drop in the perception that mathematics is either not useful or only useful in specialized areas of biology (from 44% to 37%). On the other hand, these surveys showed an increase in the view that mathematics is useful or essential in many areas of biology (from 56% to 63%). This occurred after just a single course! When we asked the same question in Math 204 and Math 205, the results were similar, with a clear majority of the students (58.5% in Math 204 and 62.2% in Math 205) considering mathematics to be useful in many areas or essential in biology.

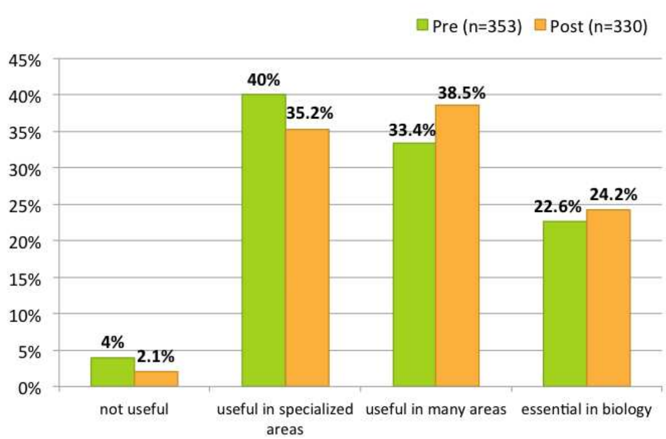

Figure 4: Importance of Mathematics for biology

We also asked students an open-ended question: *Please elaborate on why (or why not) you think mathematics is important to your biology degree and career goal. Feel free to give an example of a particular math topic that you have seen in a biology course.* This question produced a range of answers of which we show a small selection. Some of the answers indicate that students made the connection to specific topics in their biology courses, while others show an understanding of the long-range importance:

- Math is essential to biology for figuring out probability of alleles and genetics ... Until this class I didn't know exactly how essential math was to biology.

- I have taken biology 100B and I had hard time with the part when it came to genetics and alleles. This class actually helped me understand how to compute the percentages of an offspring with certain phenotype qualities.

- It is extremely important, unfortunately. I have a hard time understanding math so while I know it is important it doesn't necessarily mean I enjoy it. But when applied to specific situations that are interesting it is less abstract and easier to understand.

- Mathematics is important to my biology and my career goal because I am interested in research and I believe that the more math I know, the more credible and valuable my future experiments can be.

- In chemistry and in my biology courses a lot of the conceptual topics that are taught to students are hard to understand and if they know the math behind it, it would make much more sense. Also, science requires factual evidence to make advancements, and to translate what biologists learn into applicable technologies for the population at large requires math!

Finally we investigated perceptions of the connection between the mathematics and biology concepts by having students respond to the statement *The course helped my academic skills in understanding the math behind biological concepts.* Figure 5 shows the results. The majority of students believed that the courses helped them greatly, and roughly 80% responded that the courses had a positive impact.

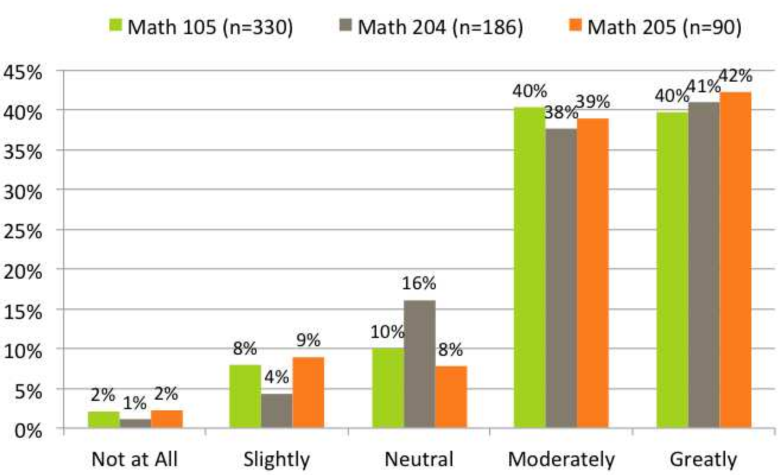

Figure 5: Understanding the mathematics behind biological concepts.

Other questions focused specifically on the course content. In each course, we asked what students liked best and least (the latter to be used to improve the courses). Here are some comments from students in Math 105, taken from responses to the two questions: *What did you like best about Math 105? What is the most interesting thing you learned in Math 105?* Sample responses include:

- I liked that I was able to learn how exactly math concepts were used in biology.

- Some interesting concepts that regard my career goal. Focuses on many other careers that involve biology besides the medical field.

- The most interesting thing I learned in Math 105 was how useful math is in the biological world & how it goes hand in hand.

- What was interesting was the majority of the material I learned applied to real life situations that I may run into in the workplace.
- Overall, how biology used in math is interesting and as a biology major I liked seeing how math is useful for once.

We also asked a similar question with regard to the whole sequence: *What did you like best about the Math 105, 204, 205 sequence?* Sample responses include:

- The transition of mathematical concept to real life situations.
- Being able to integrate math and biology together.
- I like how it applied math to biology.
- What was most interesting is how it's applied to biology, I never thought it would be connected the way it is.
- I liked the combination as math and biology, makes it more understandable. That it all related to my major.

4.3 Pass Rates and Progression Through the Mathematics Sequence

Besides students becoming much more engaged in the mathematics courses, we have also succeeded in steering students into taking mathematics courses much earlier in their careers. This is partly a result of better advising, and partly due to the new mathematics requirements for the introductory biology sequence. Math 104A (Precalculus: College Algebra) is now a pre-/co-requisite for the first of the courses in the introductory biology sequence Biol 100ABC, and Math 105 is recommended for Biol 100B. Once students have taken a mathematics course focused on biology applications they tend to continue with the sequence unless there are scheduling issues. During the recent budget crisis many courses were cancelled, so students had to enroll in whatever courses were available. Figure 6 shows the enrollment by academic status in the trigonometry (Math 103) and calculus courses (Math 206/207) in AY 2004/05, while Figure 7 shows enrollment in the corresponding courses of the new sequence in Academic Years 2011/12 and 2012/13. In AY 2004/05, the vast majority of students in each of the courses were seniors.

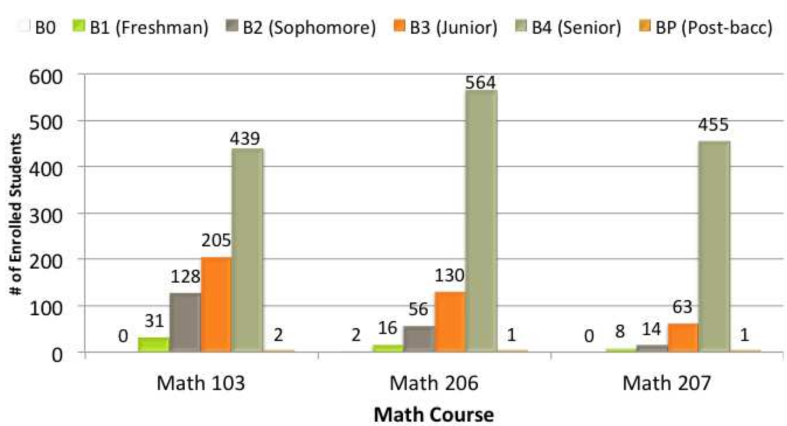

Figure 6: Enrollment in Math 103, 206, and 207 by academic level.

By contrast, in Academic Years 2011/12 and 2012/13, the majority of students in all three courses are sophomores, with freshmen a close second in Math 105. This is a significant shift that will allow us to make the biology curriculum much more quantitative.

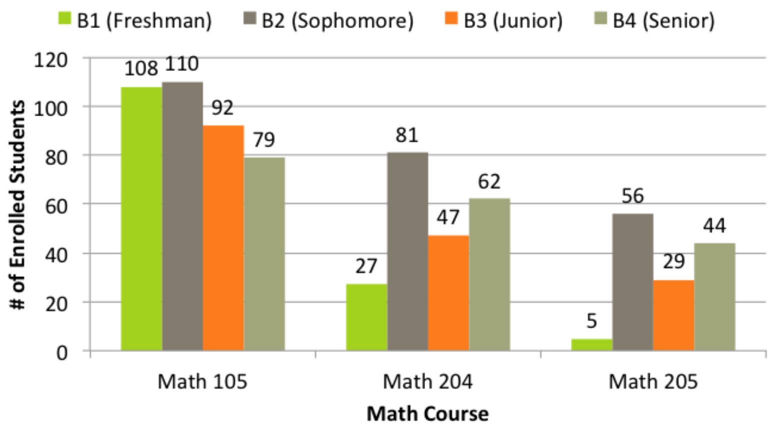

Figure 7: Enrollment in Math 105, 204, and 205 by academic level.

Further validation of the success of the curriculuar changes are the pass rates in the new course sequence. In AY 2011/12 only two instructors, the first author and a dedicated part-time instructor, taught the new courses. The pass rates in the new courses were significantly higher than the pass rates in the corresponding classes taken previously by biology majors. However, the number of students who took the new sequence in the first year was smaller (351 students in all courses combined) and most students were also able to take several courses with the same instructor, an aspect that is known to have a positive impact on pass rates. In the second year of offering the new course sequence, a larger group of instructors (3 tenure/tenure-track faculty and 3 part-time instructors) taught the courses, and a larger number of students (513 in all courses combined) were enrolled. Not surprisingly, the pass rates decreased a little, but the average pass rate over the two years is still significantly higher (by 8, 12 and 16 percentage points, respectively) than the average pass rate in prior years. Figure 8 shows the comparison of the average pass rates in the old courses from the years 2003-2008, the pass rates of the corresponding new courses in AY 11/12, and the pass rates in the new courses in AY 12/13. The percentages shown above the braces are the average pass rates for the two years from 2011 to 2013. Note that passing means a C or higher for Math 103/105 and Math 206/204, while a D or higher constitutes passing in Math 207/205.

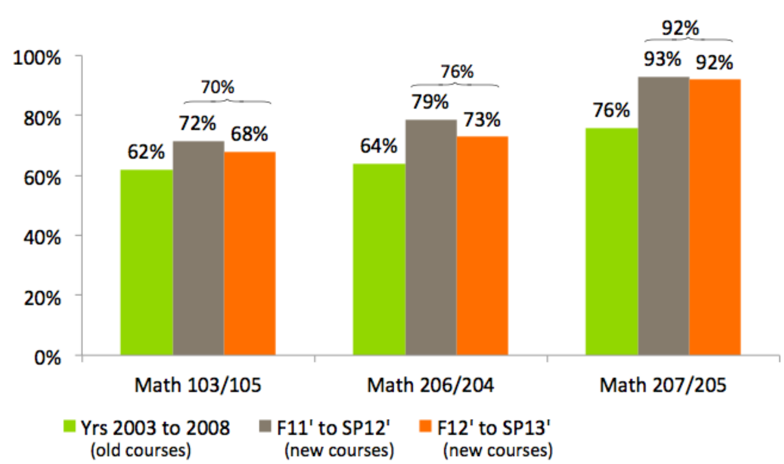

Figure 8: Comparison of pass rates for old and new course sequences.

4.4 Future Assessment

We have assessed students in the mathematics courses and have seen positive changes with regard to student attitudes toward mathematics, the time when the mathematics courses are taken, and the pass rates. All of these changes better prepare students for quantitative analysis in their biology courses. To measure the long-term impact of the new course sequence, we plan to come full circle by giving our original assessment survey in upper division biology classes to determine whether the change carries through to the biology courses. We also plan to evaluate whether students who took the new sequence perform better than their counterparts in relevant biology courses such as genetics and ecology. Finally, we plan to give exit surveys to graduating students and ask the following questions:

- In which biology courses did you use concepts from the mathematics sequence?
- In which biology courses did you use Excel or other tools to explore biological concepts?
- What was the most useful concept/skill you learned in the mathematics sequence?
- Did the (new) mathematics sequence influence your career choice?

5 Conclusion

The development and implementation of the new mathematics sequence was a large undertaking. It succeeded because the biology department wanted to improve the quantitative skills of their majors at a time when there was support in the form of the NIH T36 grant for faculty who were interested in making this change happen. However, even though both authors were very committed, challenges arose in the curriculum committees of both departments, and different practices with regard to the structure of the courses (number of units per course, lab/lecture combinations) had to be reconciled. There was also the concern about who would teach the courses and whether offering a specialized sequence to biology majors would open a Pandora's box. The latter concern turned out to be the biggest hurdle at the college level curriculum committee, but the teamwork of the first author (who was the Chair of Mathematics at the time) and the Chair of Biology made it finally happen. In short, it takes time and determination to undertake curricular changes at a larger level, with obstacles such as administrative rules that have nothing to do with specific modifications to be made. In our case, the hard work paid off. Life Sciences majors now have a much more integrated curriculum, and the faculty of the two departments have much closer relationships. In addition, several newly hired faculty in each of the two departments have worked together in faculty training workshops and have given talks in the CINQA (Center for Interdisciplinary Quantitative Analysis) seminar series, forming even stronger bonds. More detailed information such as course syllabi, computer activities and the faculty training workshop material can be found on the CINQA website (http://www.calstatela.edu/centers/cinqa).

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References

[1] F. Adler, 2013. *Modeling the Dynamics of Life*, 3rd Edition. Boston: Brooks/Cole.

[2] C. A. Brewer and D. Smith, eds. 2011. *Vision and Change in Undergraduate Biology Education – A Call to Action*. American Association for the Advancement of Science.

[3] J. M. Mahaffy and A. Chàvez-Ross, 2009. *Calculus – A Modeling Approach for the Life Sciences*, Vol I. Pearson Custom Publishing.

[4] J. M. Mahaffy and A. Chàvez-Ross, 2005. *Calculus – A Modeling Approach for the Life Sciences*, Vol II (Integral Calculus and Differential Equations). Pearson Custom Publishing.

[5] J. M. Mahaffy et al., 2013. *Mathematics for the Life Sciences – A Modeling Approach*, Volume I (Discrete Dynamical Models), Pearson Custom Publishing.

[6] J. M. Mahaffy et al., 2013. *Mathematics for the Life Sciences – A Modeling Approach*, Volume II (Integral Calculus and Differential Equations), Pearson Custom Publishing.

[7] C. Neuhauser, 2010. *Calculus for Biology and Medicine*, 3rd Edition. Pearson.

[8] L.A. Steen, ed., 2005. *Math & Bio 2010 – Linking Undergraduate Disciplines.* Mathematical Association of America.

[9] P. T. Whitacre, ed., 2003. *BIO 2010 – Transforming Undergraduate Education for Future Research Biologists.* National Academy of Sciences.