Supplemental Material

CBE—Life Sciences Education

Aikens *et al*.

SUPPLEMENTAL MATERIALS

The Case for Biocalculus: Improving Student Understanding of the Utility Value of Mathematics to Biology and Affect toward Mathematics

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Appendix A: Pre-Survey
Questions analyzed in this study are highlighted in yellow.

ID #:_____
MMDDSS

MATHEMATICS PRE-ASSESSMENT OF BELIEFS SURVEY SPRING 2014

Course _MTH 201_____ Section number___EBI_____

We are interested in your ideas about mathematics and this class. Your answers to the questions that follow will help us understand what you think mathematics is all about.

This questionnaire in not something to be graded and your answers are completely anonymous. Please tell us what you really think by circling the correct number according to the following scale: 1=Strongly Disagree, 2=Disagree, 3=Undecided, 4=Agree, or 5=Strongly Agree. Thank you for your help!

Question	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
1. Mathematics is enjoyable and stimulating to me.	1	2	3	4	5
2. Mathematics is not important in everyday life.	1	2	3	4	5
3. In mathematics you can be creative and discover things by yourself.	1	2	3	4	5
4. I have never liked mathematics.	1	2	3	4	5
5. There is nothing creative about mathematics; it's just memorizing formulas and things.	1	2	3	4	5
6. Students who have understood the mathe-matics they have studied will be able to solve any assigned problem in five minutes or less.	1	2	3	4	5
7. I try to learn mathematics because it helps develop my mind and helps me think more clearly in general.	1	2	3	4	5
8. Mathematics is my most dreaded subject.	1	2	3	4	5
9. Using the web (or a computer) is a good way for me to learn mathematics.	1	2	3	4	5

ID #:_____
MMDDSS

Question	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
10. Everything important about mathematics is already known by mathematicians.	1	2	3	4	5
11. Mathematics makes me feel uneasy and confused.	1	2	3	4	5
12. Mathematics is needed in order to keep the world running.	1	2	3	4	5
13. Mathematics is a solitary activity, done by individuals in isolation.	1	2	3	4	5
14. Mathematics is less important than art or literature.	1	2	3	4	5
15. Mathematics is important for my chosen profession.	1	2	3	4	5
16. Mathematics is needed in designing practically everything.	1	2	3	4	5
17. Studying with other students helps my performance in mathematics.	1	2	3	4	5
18. My attitude towards mathematics affects my ability to do mathematics.	1	2	3	4	5
19. I am interested and willing to acquire further knowledge of mathematics.	1	2	3	4	5
20. Real mathematics problems can be solved by common sense instead of the mathematical rules you learn in school.	1	2	3	4	5

ID #:_____
MMDDSS

Question	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
21. My ability to do mathematics affects my attitude towards mathematics.	1	2	3	4	5
22. The skills I learn in this class will help me in other classes for my major.	1	2	3	4	5
23. Ordinary students cannot expect to understand mathematics, they expect simply to memorize it and apply what they have learned mechanically an without understanding.	1	2	3	4	5
24. I learn mathematics well from	1	2	3	4	5
25. The skills I learn in this class will help me in my career after college.	1	2	3	4	5

26. My intended (most likely) majo

_____

27. I am a

1. Freshman 2. Sophomore 3. Junior 4. Senior

28. I am a

1. Female 2. Male

29. My overall GPA is about

1. 2.0 to 2.9
2. 3.00 to 3.24
3. 3.25 to 3.49
4. 3.50 to 3.74
5. 3.75 to 4.0

30. I expect the following grade in this class

1. F
2. D
3. C
4. B
5. A

31. Compared to other students in mathematics ability I am

1. In the top 10%
2. Above average
3. About average
4. Below average
5. In the bottom 10%

32. Compared to how hard other students work at mathematics I am

1. In the top 10%
2. Above average
3. About average
4. Below average
5. In the bottom 10%

33. During this semester, I plan to complete the work assigned in this class.

1. Always
2. Most of the time
3. About half the time
4. Once in a while
5. Almost never
6. Never

34. How important is it for you to do well in math?

1. Very important

2. Sort of important

3. Not very important

4. Not important at all

---

35. I intend to take another mathematics or statistics class after this one.

1. Yes 2. No

Please give a short explanation of your answer to Question 35.

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36. I have taken calculus before. 1. Yes

Please list all calculus courses you have taken, including where they were taken.

Short Answer Questions: Please provide as much information as possible for the following questions.

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1. Describe your past experiences with mathematics. Have they been mostly positive or mostly negative?

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2. Why have you enrolled in this class? Is it required for your major/minor? If so, why do you think it is required?

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3. What is the first thing that comes to mind when you here the word "mathematics"? What comes to mind when you hear the word "calculus"?

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4. What, if anything, do you hope to get out of this class?

5. In your opinion, is the knowledge of mathematics beneficial to biologists? Why or why

6. How, in your opinion, could your perception of mathematics change for the better? If you do not feel this is possible, why do you feel that way?

7. What are your long-term goals?

8. Additional comments:

Appendix A: Post-Survey
Questions analyzed in this study are highlighted in yellow.

Student Code:_____
MM/DD/SS

(THIS CODE IS **NOT YOUR STUDENT ID**. It is your 2-digit birthday month, day, then last two digits of your Soc.Sec. #)

MATHEMATICS POST ASSESSMENT OF BELIEFS SURVEY SPRING 2014

Course __MTH 201 (BioCalc)_____ Section number_____ABI_____

We are interested in your ideas about mathematics and this class. Your answers to the questions that follow will help us understand what you think mathematics is all about.

This questionnaire in not something to be graded and your answers are completely anonymous. Please tell us what you really think by circling the correct number according to the following scale: 1=Strongly Disagree, 2=Disagree, 3=Undecided, 4=Agree, or 5=Strongly Agree. Thank you for your help!

Question	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
1. Mathematics is enjoyable and stimulating to me.	1	2	3	4	5
2. Mathematics is not important in everyday life.	1	2	3	4	5
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6. Students who have understood the mathe-matics they have studied will be able to solve any assigned problem in five minutes or less.	1	2	3	4	5
7. I try to learn mathematics because it helps develop my mind and helps me think more clearly in general.	1	2	3	4	5
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9. Using the web (or a computer) is a good way for me to learn mathematics.	1	2	3	4	5

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Question	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
10. Everything important about mathematics is already known by mathematicians.	1	2	3	4	5
11. Mathematics makes me feel uneasy and confused.	1	2	3	4	5
12. Mathematics is needed in order to keep the world running.	1	2	3	4	5
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17. Studying with other students helps my performance in mathematics.	1	2	3	4	5
18. My attitude towards mathematics affects my ability to do mathematics.	1	2	3	4	5
19. I am interested and willing to acquire further knowledge of mathematics.	1	2	3	4	5
20. Real mathematics problems can be solved by common sense instead of the mathematical rules you learn in school.	1	2	3	4	5

Student Code:_____

MM/DD/SS

(THIS CODE IS **NOT YOUR STUDENT ID**. It is your 2-digit birthday month, day, then last two digits of your Soc.Sec. #)

Question	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
21. My ability to do mathematics affects my attitude towards mathematics.	1	2	3	4	5
22. The skills I learn in this class will help me in other classes for my major.	1	2	3	4	5
23. Ordinary students cannot expect to understand mathematics, they expect simply to memorize it and apply what they have learned mechanically an without understanding.	1	2	3	4	5
24. I learn mathematics well from lectures.	1	2	3	4	5
25. The skills I learn in this class will help me in my career after college.	1	2	3	4	5

26. My intended (most likely) major is

_____

27. I am a

1. Freshman 2. Sophomore 3. Junior 4. Senior

28. I am a

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32. Compared to how hard other students work at mathematics I am

1. In the top 10%
2. Above average
3. About average
4. Below average
5. In the bottom 10%

33. During this semester, I did the work assigned in the class.

1. Always
2. Most of the time
3. About half the time
4. Once in a while
5. Almost never
6. Never

34. How important is it for you to do well in math?

1. Very important

2. Sort of important

3. Not very important

4. Not important at all

35. I intend to take another mathematics or statistics class after this one.

1. Yes 2. No

Please give a short explanation of your answer to Question 35.

Short Answer Questions: Please provide as much information as possible for the following questions.

1. Describe your past experiences with mathematics. Have they been mostly positive or mostly negative?

2. What is the first thing that comes to mind when you here the word "mathematics"? What comes to mind when you hear the word "calculus"?

3. Why did you enroll in this class? Is it required for your major/minor? If so, why do you think it is required?

4. What, if anything, do you believe you got out of this class?

Student Code:_____

MM/DD/SS

(THIS CODE IS **NOT YOUR STUDENT ID**. It is your 2-digit birthday month, day, then last two digits of your Soc.Sec. #)

5. In your opinion, is the knowledge of mathematics beneficial to biologists? Why or why

6. Do you feel that your attitude towards and/or beliefs about mathematics has changed over the course of this semester? Why or why not?

7. If you answered "yes", to number 6, what has most influenced any changes in your attitude or beliefs about mathematics?

8. What are your long-term goals?

9. Now that you have taken this course, what advice would you give a future biocalc student? What do you wish you would have done differently?

10. Additional comments:

Appendix B: Codebooks

Codebook for open-response question #1:
In your opinion, is the knowledge of mathematics beneficial to biologists? Why or why not?

Responses (n = 118) were first coded with one of the following three *a priori* codes:

Code	**Definition of Code**	**Percent (no.) of students in pre-survey**	**Percent (no.) of students in post-survey**
Beneficial	Student expresses that math is useful or valuable for biology.	94% (111)	99% (117)
Not beneficial	Student expresses that math is not useful or valuable for biology.	3% (3)	1% (1)
Not sure	Student is not sure whether or not math is useful or valuable for biology.	3% (4)	0% (0)

If a response was coded as “Beneficial” (n = 111 in pre-survey; 117 = in post-survey), the following initial codes were used to code for why a student reported mathematics is beneficial to biologists. Percent of students with codes in pre-survey and post-survey is greater than 100% because student responses could contain multiple reasons why mathematics is beneficial to biologists.

Initial Code	**Definition of Initial Code and Inclusion/Exclusion Criteria**	**Percent (no.) of students in pre-survey**	**Percent (no.) of students in post-survey**
Intrinsic utility	Student expresses that math is generally useful or good to know. This includes thoughts about math being needed to be a well-rounded person. Code is to be used alone (no other codes in entire response) to represent vague usefulness; if anything more specific could be coded anywhere in the response, this code is not used.	11% (12)	6% (7)
Science utility	Student expresses that math is generally useful for understanding science broadly and the natural world. Code is not to be used if biology or anything biological is mentioned somewhere in the entirety of the response. Code is to be used alone to represent vague usefulness in science; if anything more specific could be coded anywhere in the response, this code is not used.	5% (6)	5% (6)
Biology utility	Student expresses that math is generally useful for understanding biology but does not discuss specific subdisciplines, aspects, or examples of when it would be useful. Code can be used in the same response as Experiment utility, Lab utility, or Chemistry utility. If any more specific codes related to biology could be coded anywhere in the response, this code is not used.	13% (14)	9% (10)
Experiment utility	Student expresses that math is useful for conducting experiments or doing research. If any specific skill (calculation, data analysis, modeling, etc.) could be coded anywhere in the response, this code is not used.	5% (6)	2% (2)
Lab utility	Student expresses that math is useful for lab settings in biology. If any specific skill (calculation, data analysis, modeling, etc.) could be coded anywhere in the response, this code is not used.	1% (1)	0% (0)

Ecology	Student expresses that math is generally useful for understanding ecology. Includes mentions of field biology.	0% (0)	1% (1)
Evolution	Student expresses that math is generally useful for understanding evolution.	3% (3)	0% (0)
Chemistry utility	Student expresses that math is generally useful for understanding chemistry broadly or the chemistry that is related to biology.	5% (6)	0% (0)
Calculations	Student expresses that math is useful for doing calculations, computations, or making estimations in biology.	8% (9)	3% (4)
Logical reasoning	Student expresses that math is useful for reasoning logically.	2% (2)	1% (1)
Problem-solving	Student expresses that math is useful for general problem-solving or critical thinking.	5% (6)	5% (6)
Forming hypotheses	Student expresses that math is useful for creating hypotheses.	0% (0)	1% (1)
Collecting data	Student expresses that math is useful for making measurements and obtaining data in a variety of ways. This includes mentions of math being important for field work.	5% (6)	5% (6)
Data analysis	Student expresses that math is useful for processing data, doing statistics, and interpreting data.	17% (19)	18% (21)
Graphing	Student expresses that math is useful for making graphs.	2% (2)	1% (1)
Using and creating models	Student expresses that math is useful for using models or for doing modeling in biology.	6% (7)	15% (18)
Making	Student expresses that math is useful for making predictions.	4% (4)	16% (19)

predictions			
Evaluating changes	Student expresses that math is useful for generally examining change in biological systems. This does not include specific examples of change, such as population growth.	0% (0)	2% (2)
Explaining patterns	Student expresses that math is useful for understanding and explaining biological patterns.	0% (0)	3% (4)
Exponential functions	Student expresses that math is useful for understanding exponential functions used in biology.	1% (1)	0% (0)
Rates	Student expresses that math is useful for using and understanding rates.	2% (2)	2% (2)
Rates of change	Student expresses that math is useful for handling rates of change and dynamical systems.	2% (2)	3% (4)
Carbon dating	Student expresses that math is useful for understanding problems related to carbon dating.	1% (1)	0% (0)
Cell signaling	Student expresses that math is useful for understanding cell signaling.	0% (0)	1% (1)
Drug dosage	Student expresses that math is useful for calculating drug dosages.	2% (2)	0% (0)
Equilibria	Student expresses that math is useful for understanding equilibrium in biology.	0% (0)	1% (1)
Game theory	Student expresses that math is useful for understanding problems related to game theory.	1% (1)	0% (0)
Population dynamics	Student expresses that math is useful for understanding problems related to population size and growth.	9% (10)	20% (23)
Biochemical Systems	Student expresses that math is useful for understanding chemical, enzymatic, and other biochemical reactions and processes.	1% (1)	2% (2)

Bioinformatics	Student expresses that math is useful for doing bioinformatics.	0% (0)	1% (1)
Health/medical	Student expresses that math is useful for understanding epidemics, mechanisms of the body, or other health and medical-related topics. Drug dosage is not included in this.	3% (3)	7% (8)
Technology	Student expresses that math is useful for using technology in biology. Does not include specific examples (e.g., bioinformatics).	0% (0)	2% (2)
Appeal to authority	Student expresses that math is useful for biology because others have told them that.	1% (1)	0% (0)

The following categories were created to group the initial codes above into more meaningful units. Percent of students with codes in pre-survey and post-survey is greater than 100% because student responses could contain multiple reasons why mathematics is beneficial to biologists (n = 111 in pre-survey; 117 = in post-survey).

Category	**Definition**	**Initial Codes Subsumed**	**Percent (no.) of students in pre-survey**	**Percent (no.) of students in post-survey**
Broad utility	Student expresses that mathematics is useful for daily life or science broadly. However, there is no specific reference to biology anywhere in the response.	Intrinsic utility; Science utility	16% (18)	11% (13)
Biology utility	Student expresses that math is useful for understanding biology concepts, understanding a broad subdiscipline of biology, or doing biology experiments or research. However, no specific examples of how math is used in research or specific topics that math is useful to help understand are mentioned anywhere in the response.	Biology utility; Experiment utility; Lab utility; Ecology; Evolution	15% (17)	9% (10)

Chemistry utility	Student expresses that math is generally useful for understanding chemistry broadly or the chemistry that is related to biology.	Chemistry utility	5% (6)	0% (0)
Calculations	Student expresses that math is useful for doing calculations, computations, or making estimations in biology.	Calculations	8% (9)	3% (4)
General analytical skills	Student expresses that mathematics is useful for general problem-solving, critical thinking, or reasoning skills.	Logical reasoning; Problem solving	7% (8)	5% (6)
Science process skills	Student expresses that mathematics is useful for specific skills associated with doing science research.	Forming hypotheses; Collecting data; Data analysis; Graphing; Using and creating models; Making predictions; Evaluating changes; Explaining patterns	32% (35)	48% (56)
Specific applications	Student expresses that mathematics is important for doing specific functions or solving specific biological problems.	Exponential functions; Rates; Rates of change; Carbon dating; Cell signaling; Drug dosage; Equilibria; Game Theory; Population dynamics; Biochemical systems; Bioinformatics; Health/medical	15% (17)	31% (36)
Technology	Student expresses that math is useful for using technology in biology. Does not include specific examples (e.g., bioinformatics).	Technology	0% (0)	2% (2)
Appeal to authority	Student expresses that math is useful for biology because others have told them that.	Appeal to authority	1% (1)	0% (0)

Codebook for open-response question #2:

Do you feel that your attitude towards and/or beliefs about mathematics has changed over the course of this semester? Why or why not? If you answered "yes", what has most influenced any changes in your attitude or beliefs about mathematics?

Responses (n = 116) were first coded with one of the following three *a priori* codes:

Code	**Definition**	**Percent (no.) of students**
Attitude improved	Student's attitudes and beliefs toward math were more positive at the end of the semester.	47% (55)
Attitude stayed the same	Student's attitudes and beliefs toward math were the same at the end of the semester.	44% (51)
Attitude worsened	Student's attitudes and beliefs toward math were more negative at the end of the semester.	9% (10)

If a response was coded as "Attitude improved" (n = 55), one of the following codes was used to code for why a student's attitude improved. Percent of students is greater than 100% because student responses could contain multiple reasons why their attitude improved.

Code	**Definition**	**Percent (no.) of students whose attitude improved**
Relevant or applicable	Student's attitudes improved because they found the material or class to be relevant to their interest or major and/or applicable to their field of study.	45% (25)
Ability to comprehend the material	Student's attitudes improved because they felt like they understood the concepts, how to approach the problems, and/or materials presented in class.	35% (19)

Professor positive	Student's attitudes improved because of something about the professor and the way they teach.	35% (19)
Support structures	Student's attitudes improved because of structures in place in the course or at the university that help students to succeed.	4% (2)
Positive feedback	Student's attitudes improved because they received some form of positive feedback, such as encouragement.	2% (1)
Like-minded biology peers	Student's attitudes improved because they were in a class with other biology students that think like them.	2% (1)
Perseverance	Student's attitudes improved because of their own perseverance.	2% (1)

If a response was coded as "Attitude stayed the same" (n = 51), one of the following codes was used. Percent of students is less than 100% because some student responses did not include whether students felt positively or negatively about math.

Code	**Definition**	**Percent (no.) of students whose attitude stayed the same**
Positive math feelings	When attitudes stayed the same, the student expressed positive emotions associated with math.	31% (16)
Negative math feelings	When attitudes stayed the same, the student expressed negative emotions associated with math.	41% (21)

If a response was coded as “Attitude worsened” (n = 10), one of the following codes was used to code for why a student’s attitude worsened.

Code	**Definition**	**Percent (no.) of students whose attitude worsened**
Inability to comprehend the material	Student’s attitudes worsened because they felt like they did not understand the concepts, how to approach the problems, and/or materials presented in class.	80% (8)
Professor negative	Student’s attitudes worsened because of something about the professor and the way they teach.	10% (1)
Lack of motivation	Student’s attitudes worsened because they simply did not have the motivation for the class.	10% (1)

Appendix C: Results

Model selection and ordinal regression results are presented below for each of the four ordinal regression models: (A) Mathematics is important for my chosen profession (career utility value 1), (B) The skills I learn in this class will help me in my career after college (career utility value 2), and (C) The skills I learn in this class will help me in other classes for my major (major utility value), and (D) Mathematics is enjoyable and stimulating to me (interest),.

Table S1. Models with AICc values within 2 of the best model. These models are considered to be equivalent, and thus, the simplest model was chosen for further analysis (highlighted in yellow). For each regression, the full model was: dependent variable ~ time + institution + gender + final GPA + year in school + time*institution + time*gender + time*final GPA + time*year in school + (1|student). All regression models that we compared contained time as a fixed effect and student as a random effect. Final GPA was a student's self-reported GPA on the post-survey and consisted of categorical bins: 2-2.99, 3-3.24, 3.25-3.49, 3.5-3.74, 3.75-4.

Dependent Variable	Fixed-effects Included in Model	AICc
(A) Career Utility Value 1	time + institution	499.0
	time + institution + time*institution	499.3
	time + institution + gender	499.4
	time + institution + gender + time*institution	499.8
	time + institution + gender + time*gender	501.5
	time + institution + gender + time*gender + time*institution	501.9
(B) Career Utility Value 2	time + gender	522.3
	time	522.8
	time + institution + gender	522.8
	time + institution	523.0
(C) Major Utility Value	time + gender	528.9
	time + institution + gender	529.7
(D) Interest	time + institution + time*institution	601.1
	time + institution	601.3
	time + institution + gender + time*institution	602.3
	time + institution + final GPA + time*institution	602.4
	time + institution + final GPA	602.6

Table S2. Regression coefficients (B), standard errors (SE), *p*-values, and odds-ratios for each of the four ordinal regression models. Variables included in each regression model were determined using AICc values (see Table S1). Bolded rows represent statistically significant variables in the regressions using a Bonferroni correction for seven hypothesis tests ($p < 0.007$).

Model	Variable	B	SE	*p*-value	Odds-ratio (e^B)
(A) Career Utility Value 1	Time (ref: Pre)	-0.11	0.28	0.70	0.90
	Institution (ref: Unity)	**-1.69**	**0.56**	**0.002**	**0.18**
(B) Career Utility Value 2	Time (ref: Pre)	0.23	0.27	0.40	1.26
(C) Major Utility Value	Time (ref: Pre)	0.25	0.27	0.35	1.28
	Gender (ref: Male)	1.05	0.43	0.02	2.86
(D) Interest	**Time (ref: Pre)**	**1.02**	**0.29**	**0.0004**	**2.77**
	Institution (ref: Unity)	1.46	0.61	0.02	4.31

Figure S1. Percent of students choosing each Likert response (1 = strongly disagree; 5 = strongly agree) on the pre-survey and post-survey for the following questions: Career 1: Mathematics is important for my chosen profession; Career 2: The skills I learn in this class will help me in my career after college; Major: The skills I learn in this class will help me in other classes for my major.