Supplemental Material

CBE—Life Sciences Education

Eaton *et al.*

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Quantitative Content Survey (Calculus Topics)

Please rate each subject area on a scale of 1 to 4, 1 NEED, 2 WANT, 3 IF THERE IS TIME, 4 NO INTEREST.

Informed Consent documentation can be found here: http://goo.gl/RzN4n

* Required

Have you read and understood the information provided above and allow your survey results to be used in research? *

- Yes
- No

Affiliation

Field? *

Research Interests/Speciality

Derivative *

rate of change, instantaneous rate of change, population growth rate, instantaneous growth rate, instantaneous velocity, tangent line at a point, slope, increasing, decreasing, velocity

	1	2	3	4	
NEED					NO INTEREST

Second Derivative *

Rate of change of slope, greatest rate of change, concave up, concave down, acceleration, change in velocity, slowing down vs speeding up growth rate

	1	2	3	4	
NEED					NO INTEREST

Qualitative Behavior *

Graphing solutions to differential equations

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Qualitative Behavior *

Graphing functions from first and second derivative information

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Exponential Function *

Exponential growth, feedback loops, positive and negative, growth rate proportional to current population size, kinetics, diffusion

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Maximum, minimum, *

Global and local, maxima/minima, optimizing, objective function, biomechanics (migration, foraging, energy solutions), optimal harvesting

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Implicit Differentiation *

Understanding relational change, how does total length grow with respect to carapace length

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Multidimensional Calculus *

Change along a cross section, like for multidimensional surfaces

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Population Growth Models *

Logistic growth, Von Bertalanffy, exponential growth, Gompertz growth, allele effect, migration, emigration, birth-death, interactions, for species of animals as well as chemicals, harvesting

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Equilibrium Analysis *

Equilibria, stable state, qualitative analysis, unstable state, exponential decay to stable equilibrium, carrying capacity, exponential growth away from unstable equilibrium, snowball earth, steady state, conservation of energy, potential vs kinetic energy

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Growth Models with Interactions *

2 variable differential equation models, arms race, predator-prey, coevolution, eigenvalue, matrix

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Growth Models of Interactors *

Stable oscillations (predator-prey cycles), dampened oscillations, expanding oscillations, cycles, boom bust economics

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Growth Models with Outside Influences *

Population and economic bust due to over harvest, tipping points, multiple steady states, equilibrium changing from stable to unstable (snowball earth, climate change), bifurcations

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Growth Models with Multiple Interactors and Outside Influences *

Multivariable differential equation models, SIR disease modeling, human epidemics and zoonoses, reproductive number of disease, multiple strain or species interactions

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Partial Differential Equations *

Spatial models, traveling waves of disease or invasion

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Continuous/Discrete *

Continuous versus discrete models

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Discrete Models *

Difference equations, iterations, programming, analogous growth models

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Discrete Model Equilibria *

Equilibria in difference equations, chaos

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Discrete Matrix Models *

Age-structured models, tree matrix models for forest health, different size plants or larvae, eigenvalues, matrices, eigenvectors

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Fitting Data to a Model *

Log transform data, regression, exponential model fitting, model fitting

	1	2	3	4	
NEED	○	○	○	○	NO INTEREST

Integration and Probability *

Probability distribution functions, cumulative probability, integral, finite integral, approximating a finite integral, area under the curve, finding number given a density function over soil depth or water depth, sieve filtering curves

	1	2	3	4

NEED	◯	◯	◯	◯	NO INTEREST

Integration and Physics *

Work, water, pressure, center of mass

	1	2	3	4	
NEED	◯	◯	◯	◯	NO INTEREST

Integration and Antiderivatives *

Analytic/Quantitative Solutions to simple growth equation models

	1	2	3	4	
NEED	◯	◯	◯	◯	NO INTEREST

Limits *

Limits, average growth vs instantaneous growth, carrying capacity

	1	2	3	4	
NEED	◯	◯	◯	◯	NO INTEREST

Computer Skills *

Excel, matlab, programming, symbolic math program, TI-83

	1	2	3	4	
NEED	◯	◯	◯	◯	NO INTEREST

Modeling *

Appropriate Growth and Interactions Model selection and/or development

	1	2	3	4	
NEED	◯	◯	◯	◯	NO INTEREST

Theory Behind Current Science *

Reading current theoretical literature

	1	2	3	4	
NEED	◯	◯	◯	◯	NO INTEREST

Thank you so much! Any other feedback/suggestions for content?

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Table S1

Table S1a. Content of redesigned calculus courses at Unity College.

UC Calculus I Topics (3-credit)	**Topics in terms of biological concept**	**UC Calculus I Assignments (3-credit)**
Sequences	Notation, understanding of time series data	*Low-stakes reflectionary writing*
Linear discrete-time dynamical systems	Recursive or iterative processes, where populations reproduce or are managed in at once per time step (year or generation, etc.). Precursor to Leslie matrix models or stage-based models, where an important difference in long-term behavior/equilibrium is characterized by whether λ <1 or > 1.	*Weekly practice – homework or quizzes* *Group mathematical explorations*
Limits and Continuity	Long-term behavior/outcome of processes such as population growth, and relaxing assumptions to allow birth or death to happen at any time, not just once per year or generation.	*Group professional report* *Group lab report* *Group slide presentation*
Derivatives	Describing change in continuous processes	*Individual presentation of research article*
Exponential models with data integration and as differential equations	Describing exponential models as models in which the rate of change is proportional to the current size or per capita growth rate is constant. Applications also include Newton's Law of Cooling, which can be used to determine animal death time to determine illegal hunting activity.	*Computing skills: Excel and Wolfram Alpha, Google Docs/Spreadsheets*
Modeling with 1-D ordinary differential equations	The effect that parameter r >0 or <0 has on long-term outcome for exponential growth, logistic growth and interpretation of r and K, simple climate modeling, and tipping points.	*Other assessments: Two exams and a final exam, each half in-class, half take-home.*
Optimization	How form reflects the optimization of important functions (*e.g.*, Why are single celled organisms often rods or spheres?). Finding optimal solutions for other situations (minimizing cost, supplies, or net energy gain).	
Partial derivatives	Change along a three-dimensional surface. Understanding how to talk about slope on a real landscape. Multi-dimensional applications include optimization of models with multiple parameters and sensitivity analysis, which are not covered in the class, but referenced in terms of where they will see it in other classes.	

UC Calculus II Topics (3-credit)	**UC Calculus II Topics (3-credit)**	**UC Calculus II Assignments (3-credit)**
Integration and series, continuous probability distributions	Finding cumulative counts under data plots, such as accumulated degree days. Also extended to approximating cumulative counts under continuous curves (such as probability distributions). Improving approximation by using smaller intervals aided by mathematical identities and computer algorithms.	*Weekly journal article or relevant reading discussion* *Weekly homework* *Individual lab reports with peer review (Eaton and Wade, 2014)* *Individual research project with oral presentation at research conference* *Computing tools: MATLAB (with an option for R)*
Antiderivatives and exact solutions to 1-D autonomous ordinary differential equations (ODEs)	Connection of integration to "reversing" the process of finding derivatives. Introduces some mathematical techniques which allow us to make generalizations when the processes we are interested in have unknown parameters (*e.g.*, solution curves of the exponential growth and the logistic differential equation).	
Numerical solutions and qualitative analysis of 1-D and 2-D autonomous ODEs	The effect parameters can have on long-term outcomes and the role of mathematical modeling in aiding intuition and ecological theory. 1-D limited growth models, 2-D predator-prey and competitive exclusion models, introduction to multi-species interactors. The goal is to introduce mathematical approaches to systems thinking.	

Table S1b. A comparison of content of traditional and redesigned calculus courses at the University of Portland.

UP Calculus I Topics (4-credit)	**UP Calculus I Assignments**	**UP Calculus I (Bio) Topics (4-credit)**	**UP Calculus I (Bio) Assignments**
Limits Continuity Derivatives Applications of derivatives Integrals Applications of integrals Antiderivatives	*Webwork problems to test basic skills* *Written homework selected from the textbook* • *Most problems are short answer* • *Some application problems from physics and engineering; few that require interpretation of results.* *Other assessments: Three exams and a final exam, all in-class; weekly quizzes*	Discrete-time dynamical systems Limits Continuity Derivatives Applications of derivatives and dynamical systems Antiderivatives Differential equations Integrals Applications of integrals and differential equations	*Reading assignments from mathematical biology literature* *Reflectionary journal assignments* *Written homework from the textbook* • *Few short answer problems to test basic skills* • *Majority of problems are application problems, all with an emphasis on applications to the life sciences; most require interpretation of results.* *Computing tools: Problems requiring use of Mathematica, Excel, and Geogebra to aid in model exploration* *Other assessments: Three exams and a final exam, all in-class; weekly quizzes*

Table S1. List of mathematics topics and types of assignments/activities in each Calculus I course at UP and in each Calculus course at UC. Table S1a presents the mathematical content, the corresponding biological interpretation/application, and the pedagogical scaffolding. Table S1b compares the traditional Calculus I course mathematics content at UP with the mathematical content of the Bio section of Calculus I at UP. Yellow highlighting indicates concepts added to the (Bio) section content list.

Supplementary Materials Table S2

Transition Stage	Semester	DWF % (W)	N	CCI adj.	Adoption Notes
Before	Fall 2010	31% (23%)	13	n/a	Traditional content 3-credit calculus course
Before	Spring 2011 (2 sections)	25, 37.5% (0, 25%)	20,8	n/a	Traditional content 3-credit calculus text with some applied activities
During	Fall 2011 (2 sections)	7, 15% (0, 0 %)	15, 20	n/a	Adopted new life sciences text and associated syllabus with writing integration
During	Spring 2012 (2 sections)	57, 35% (0, 12%)	7, 17	n/a	Before registration for fall, new majors and requirements introduced to students – Biology dropped the Calculus I requirement, and Wildlife introduced a management track without a Calculus I requirement. The track that retained Calculus I, allowed for Calculus II to also satisfy a menu requirement in the major.
During	Fall 2012 (2 sections)	27, 30% (9, 20%)	11, 10	27, 33% (N=10,8)	Existing students were still offered transition plans into majors defined in the 2012 catalog.
After	Spring 2013	0% (0%)	9	15%	Gateway exam utilized
After	Fall 2013	19% (0%)	16	14%	Gateway exam utilized
After	Spring 2014	0% (0%)	16	23%	Gateway exam no longer utilized
After	Spring 2015		12	27% (N=10)	Analyzed additional CCI data to replicate "after," but without gateway exam. Marine Biology added Calculus I to major requirements list, effective Fall 2016.

Table S2. Summary of DWF, withdraw rates, and adjusted CCI scores in each class at UC over 9 semesters and 13 classes. The resulting analysis of trend for DWF rates is shown in Figure 1a in the paper. The figure showing adjusted CCI results is in Figure 2. All courses during this time were taught by the co-author at Unity College. A noted difference in N for the CCI results versus the DWF rates is due to either withdrawing students (as in the case of Fall 2012) or students that did not consent to having their data used for educational research (as in Spring 2015).