2015-2016 Collaborative Faculty-Student Project Award

Cover Page & Abstract (must include chair's signed approval)

Faculty #1 Information

Name Andrew Long Email longa@nku.edu

Department Mathematics and Statistics Office phone X5794 Office address MEP443

Faculty #2 Information

Name Steve Wilkinson Email wilkinson@nku.edu

Department Mathematics and Statistics Office phone X5775 Office address MEP480

Student #1 Information

Name Madison Culbertson Email culbertsom1@mymail.nku.edu

Major Mathematics Degree B.S. Graduation date 5/2018

Student #2 Information

Name Laura Farro Email farrol1@mymail.nku.edu

Major Physics/Statistics Degree B.S. Graduation date 5/2018

Student #3 Information

Name Email

Major Degree Graduation date

Department Chair's Information

Name Roger Zarnowski Dept. Mathematics and Statistics

Signature/approval: Roger Zarnowski e-mail zarnowskir1@nku.edu date 2/10/16

Project Information

Project title Modelling and Predicting the Consequences of Climate Change:
from seasonal changes in Nova Scotia to the spread of the Zika virus

Total budget requested $ 4999.30

Is IACUC (animal use) clearance required? No

Is IRB (human subjects) clearance required? No

Abstract

(100 word maximum length)

Global climate change – its causes and consequences – is arguably humanity's greatest challenge today. Global climate data permits us to understand how the Earth has changed and is changing; models based on data permit us to predict how the Earth will change. Both missions are critical.

Starting from an amazing and largely unexplored data set of phenological (seasonal) changes in Nova Scotia (dating from 1901 to 1923), we will search for signals of early climate change; then we will extrapolate, to explore how we can predict climate impacts such as the spread of the Zika virus inside its mosquito host.

Collaborative Faculty-Student Project Award -- Proposed Budget 2015-2016

Please complete the budget form below following the budget-related instructions detailed in the Proposal Guidelines.

		Comments / Details	CFSPA Grant	Funding source #2 *	Funding source #3
A.	**Stipends**				
	Andy Long	14 weeks, $33.22/week	$465		
	Steve Wilkinson	14 weeks, $33.22/week	$465		
	Madison Culbertson	12 hr/w, 14 weeks, $11.05/hr	$1857	$1500 (stipend)**	
	Laura Farro	12 hr/w, 14 weeks, $11.05/hr	$1857	$1500 (stipend)**	
	Subtotal:		$4644.00	$3000	$0
	Associated FICA tax:				
	Faculty #1	Add 7.65% for summer effort	$35.58		
	Faculty #2	Add 7.65% for summer effort	$35.58		
	Student #1	Add 7.65% to stipend	$142.07		
	Student #2	Add 7.65% to stipend	$142.07		
	Subtotal:		$355.30		
	Stipend + FICA:		$4999.30	$3000	$0
B.	**Materials & Supplies (e.g., materials, equipment, printing, software, or other consumables) Limited to $500**				
	Item:				
	Item:				
	Item:				
	Item:				
	Subtotal:				
C.	**Travel**				
	Airfare			$1000	
	Ground transportation			$100	
	Lodging			$800	
	Food			$300	
	Other				
	Subtotal:			$2200***	
D.	**Other (e.g., conference registration, equipment rental fees, or other non-consumables)**				
	Item:				
	Item:				
	Item:				
	Subtotal:				
TOTAL FUNDING (add A-D)			$4999.30	$5200	
TOTAL FUNDING FROM ALL SOURCES:					$10199.30

IDENTIFY FUNDING SOURCE #2 *: Department of Mathematics and Statistics (Sehnert Fund, BCC)
IDENTIFY FUNDING SOURCE #3

Please indicate any other funding for this project (ALL SOURCES including private, University, State, or Federal):

- Pending

The Chair of Mathematics and Statistics has agreed to a departmental matching grant, contingent upon a successful application for this grant. Details are included in our proposal. “I wholeheartedly support the accompanying proposal submitted by Dr. Andrew Long and Dr. Steve Wilkinson. Their project will provide an extraordinary opportunity for two enthusiastic and very capable students to develop valuable research skills while contributing to our understanding of an interesting and important problem in applied mathematics.” Roger Zarnowski, Chair, Department of Mathematics and Statistics.

The source of the funds is the department’s endowment (the Sehnert fund), either directly, or as a part of the budget of the Burkardt Consulting Center, which is run and partially funded by the department. The breakdown of the funding offered by the department is as follows:

** As with other STEM departments, our department prefers to pay students with stipends rather than hourly wages for research projects of this nature. The use of stipends was discussed in conversation with Judy Voelker while preparing this grant application.

*** The travel funds will cover the expenses for the students, who will attend, participate in, and present the results of this project at the four-day national Joint Mathematics Meetings in Atlanta, in January of 2017. The estimates are for both students ($1100 per student) and are based on recent costs of a similar student trip.

- Current

N/A

Proposal Narrative

1. Purpose and Significance:

The smaller objective of this project is to analyze a relatively unexplored yet exceptional data set of seasonal data from Nova Scotia from 1901-1923. Alexander MacKay, superintendent of public schools in Nova Scotia at that time, struck upon the extraordinary idea of turning his school children into citizen scientists, by having them record seasonal occurrences and trends for plants, animals, agricultural practices, and weather[Fenech]. MacKay himself compiled the data from as many as a thousand schools, annually, for more than 20 years.

MacKay was focused on a north-south difference in seasonal timings, and coined the term "phenochrons" to indicate places with commonly timed seasonal events; there is no evidence that he was focused on climate change (although MacKay, as a brilliant scientist in his own right[MacKay], may well have been aware of the exciting work already underway at that time). We plan to re-examine his data with the objective of determining whether there was a signal of climate change already apparent in Nova Scotia in the early part of the 20th century.

Our students will benefit from the experience of working with this noisy spatial data, learning to manipulate it, visualize it, analyze it, and interrogate it, with an eye to detecting a signal hidden in the noise – a signal indicating that climate was clearly changing even 100 years ago.

The larger objective is to use ideas gleaned from the study of this important historical data to turn our attention to modern examples of phenological change, such as are suspected, if not implicated, in the spread of the Zika virus. The *aedes aegypti* mosquito, which transmits Zika, is the same mosquito which transmits dengue fever. Any change in the climate which facilitates the movement of this mosquito is a threat (and, conversely, change which impedes the mosquito is a benefit). For example, climate change may increase the risk of drought; drought increases the chance that people store water; the storage of water leads to stagnant pools in which mosquitoes breed; and facilitating the breeding of mosquitoes leads to increases in dengue and Zika.

So changes in precipitation and temperature patterns will lead to changes in mosquito populations, and hence changes in the diseases to which humans fall victim. This is just one example of the impact of climate change upon our lives and activities. Changes in agriculture due to a changing climate will require a dramatic redesign of our food choices and delivery systems. For example, the drought in California has resulted in higher food prices, and threats to whole industries such as almonds[Kerlin]; the midwest may sometime soon no longer be the corn belt – it may have moved to Canada, along with the pine bark beetle, which is devastating Canada's southern forests (having already eaten through our own). The disappearance of species under pressures of climate change is also happening in the most catastrophic way: through extinction. The Earth has entered the sixth great mass extinction event in the history of life on Earth (the first driven by a single species), in part due to climate change[Barnosky].

This data of Alexander MacKay may help provide insight into how species evolve under even modest changes in climate, and may help provide training and tools to current and future scientists as we wrestle with one of the most important problem of our time: human-induced climate change.

2. Review of Literature:

Long discovered the MacKay data while on sabbatical in Canada (2013-2014), in a children's book on global warming[Cherry]. Fascinated, he approached Adam Fenech about obtaining the data. Fenech produced a useful first study of a few of the variables in this data set from Nova Scotia[Fenech], and provided Long with the data when Long traveled to Prince Edward Island to visit with Fenech. While there, Long also began his study of the life of Alexander H. MacKay, which is fascinating in its own right. Phenological changes of the type we expect under climate change, resulting in the disappearance of species [Pounds] or the movement of species beyond historical borders[USDA], are numerous. Long and Tyson[Long] have summarized projections of expected climate change under "business-as-usual"

scenarios[IPCC], and argued for the incorporation of explicit models of expected human behavior into general models of climate systems. Zika and its mosquito vector are moving in part because of climate change[Rocha], but our climate is changing largely due to human behavior – so our actions today will help to determine the course of the Zika virus for the future. Therefore, we must act wisely.

3. Expected Outcome(s):

The first goal is to train our students in data analysis, mathematical modeling, and preparation and presentation of research results. Concrete results include a paper on the analysis of the MacKay data, as well as a poster and talk to be delivered by the students at the MAA-AMS Joint Mathematics Meetings in Atlanta, in January of 2017. In addition, we hope that our work will entice further funding. Skills that our students will acquire include data cleaning; data manipulation (e.g. moving between formats, handling missing data, incorporating data into Geographic Information Systems, etc.); spatial data analysis (e.g. interpolation, multivariate correlation); data visualization (e.g. choropleth maps, dynamic simulations); data modeling, with an eye toward signal detection (i.e. that climate change can be detected in this historical data); public speaking and preparation of professional papers, presentations, and posters; and grant writing.

The next step is then to turn our attention to those results and techniques we can transfer from our study of the historical MacKay data to the study of important climate-induced changes in other species (e.g. the Pika, an alpine mammal, or the resplendent quetzal in Costa Rica) or diseases.

4. Other Support or Commitments:

We propose that this grant fund our students' work throughout the summer, faculty support throughout the project, and then that the students will continue work in the fall semester through funding from the Burkardt Consulting Center (BCC), departmental support, or some combination of the two. The BCC is run by the Department of Mathematics and Statistics: we hire our best students to consult on projects through the Center. This project is an appropriate focus for the department; therefore, contingent upon receipt of this collaborative grant and a successful summer experience, our students will complete and extend the project through the fall with the support of the department.

Our primary objective for the dissemination of results is presentation at the national Joint Mathematics Meetings to be held in Atlanta in January of 2017. This is a four-day conference that will provide the students with an opportunity to experience first-hand what life as a professional mathematician will look like – see talks, make presentations, and perhaps begin the process of thinking about graduate school and life beyond NKU. The Department has committed to providing support for the students to attend this conference, again contingent upon receipt of this important initial award and successful work throughout the summer and fall.

Part of the students' focus during the summer will be the pursuit of additional funding. The National Oceanic and Atmospheric Administration (NOAA) has several relevant grants with deadlines within the next month or two that are appropriate for our team; but we would prefer to use this grant, with departmental matching support, as a “proof of concept” that we can use to entice external funding in the next round. Many other federal opportunities, e.g. the U.S. Fish and Wildlife's grant F16AS00086 (to develop and or improve climate change actions' affect on linkages between ecological and human resources), also exist. These are the types of grants that we will pursue.

5. Procedure:

Steve Wilkinson will shoulder the primary responsibility of guiding the students during the summer. The students will focus on getting the data into the R statistical programming environment, data analysis, and data visualization (one of Wilkinson's strengths). Weekly meetings will be held to monitor progress, which Long will attend via Skype (since he will be in Canada for much of the summer). The students will work together on every task, but will also be given individual tasks of their

own to shepherd. For example, there are many variables in the data set, and subsets can be distributed separately to each student for similar treatment. We will use a wiki to organize ourselves, to share results, and to craft and continually update the publication as it evolves out of this work.

Throughout the fall we will continue with weekly meetings and presentations within our group, and switch to modeling (which will include knowledge transfer to the students as well as their application of techniques we discuss on this particular data set). At this point we will incorporate climate data (e.g. solar insolation, ocean temperatures, surface temperature, etc.) into the analysis.

We will submit at least one external grant proposal to fund the project into the future (in particular, the signal detection component and the application to general diseases and geographical implications portion), and we expect the students to learn how to identify and apply for grants – so we will incorporate this training into the project. In point of fact, our students are actively involved in the preparation of this grant proposal. They have been given the task of writing the budget, for example, and to the creation of a "non-technical" summary of the project starting from a more technical one.

As we transition to the modeling phase into the fall term, we will also shift to finalizing our paper, as well as the poster and talk that we plan for the students to deliver at the Atlanta math meetings.

6. Timeline:

May 7th -June, 2016: software and MacKay data preparation and exploration;
June-July, 2016: data visualization and statistical analysis;
July-August, 2016: phenochron and climate signal exploration and detection;
August-October, 2016: summary of MacKay analysis, conclusions, and paper preparation;
October, 2016: paper and poster proposal for national math meetings to be held in January, 2017;
October-December, 2016: extrapolation of results to modern cases of climate-change induced phenological changes and their impacts (e.g. spread of Zika, Lyme disease, changes in forest composition due to drought or fire, pine bark beetle, etc.).
2017: Joint meeting presentation, Celebration of Student Research and Creativity, etc.

7. References Cited:

[Barnosky] Barnosky, A.D., et al. *Has the Earth's sixth mass extinction already arrived?* Nature. Vol. 471 (7336). 2011:51–57.

[Cherry] Cherry, Lynne, and G. Braasch. *How We Know What We Know About Our Changing Climate: Scientists and Kids Explore Global Warming*. 2008:10-11. Dawn Publications, Nevada City, CA.

[Fenech] Fenech, Adam, Don MacIver, Heather Auld, and Stu Beal. *Impact of climate on changes in the seasonal timing of life cycle events of eastern Canada from 1901 to 1923.* Chapter four in A. Fenech, D. MacIver, H. Auld and R. Hansell (eds). 2005. Integrated Mapping Assessment, Environment Canada. Toronto, Ontario, Canada. 186 p.

[IPCC] Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis*. IPCC Fifth Assessment Report (AR5). 2013.

[Kerlin] Kerlin, Kat. *Drought impact study: California agriculture faces greatest water loss ever seen*. July 15, 2014. U.C. Davis Report.

[Long] Long, A. E., and R. Tyson. *Integrating Homo sapiens into ecological models: Imperatives of climate change*. Ecological Complexity. Vol. 20, 2014:325-334.

[MacKay] [A. H. MacKay's] President's Address, Proceedings of the Nova Scotian Institute of Science, Vol. 10, 1898:i-xiiii.

[Pounds] Pounds, J.A., Fogden, M.P.L., Campbell, J.H., Biological response to climate change on a tropical mountain. Nature. Vol 398 (6728), 1999:611–615.

[Rocha] Rocha, Jan. *Warming linked to spread of zika virus*. February 5, 2016. Climate News Network.

[USDA] Samenew, Jason. *New USDA plant zones clearly show climate change*. January 27, 2012. Washington Post.

Personal Information:

Faculty:

Dr. Wilkinson is a geometer by training and his research focuses on visualizations and the use of technology in making those visualizations. Much of his teaching has focused on technology. In particular, he was one of the main developers of NKU courses CSC 260L: Object-Oriented Programming Laboratory, and CSC 270: Mathematics Software Programming. He has worked with fourteen students in the last eight years, on projects that had visualization, analysis, or geometric components. Titles of these projects include “Visualizing the 4D Mandelbrot set”, “Magnetic Pendulum”, “Smart Plotters”, “Adjustable Meshes”, “Instruction with Open Source Software”, “Darboux Helices”, “Reflective Properties for Conic Sections Demo”, “Self-Curvature Curves”. All of these have resulted in posters or talks.

Dr. Long received his Ph.D. in applied mathematics from the University of Arizona, with a focus on geostatistics – which describes a class of methods for mapping and analyzing spatial data. While at Arizona, Long worked as a consultant with the USGS, and after graduation he worked as an educator, as a modeler with a team of epidemiologists at Loyola University of Chicago, and at the Institute of Mathematics and Physical Sciences in Benin, West Africa. Upon his return to the U.S., he spent two years on a post-doc in the School of Public Health at the University of Michigan, where he helped design and run a course on spatial analysis in epidemiology, while simultaneously working as a software consultant at BioMedware. He helped create NKU's Burkardt Consulting Center, and was its co-director for its first three years. He has worked with numerous students while at NKU, but most pertinently worked on a rabies epidemic modeling project with Beth Whittle, and studied cicada-killer wasps with a pair of students on a Center for Undergraduate Research in Mathematics grant, resulting in a publication with NKU biologist Jon Hastings. Long is intimately familiar with the spatial analysis and visualization software that the team is planning to use for this project. For the last seven or eight years, Long has come to the realization that global climate change is the most important problem facing humanity. While teaching at NKU, Long decided that he should learn more about the ecological problems facing the planet, and so earned a masters degree from Miami University (2011) in their Global Field Program. His studies included summer field trips to three World Heritage sites (in Baja, Mexico; Belize; and Costa Rica). His focus within that program was, unsurprisingly, climate change.

Students:

Madison Culbertson is an Applied Mathematics major and Environmental Science minor, excited to join this project and thrilled to be able to apply her background in multivariate calculus, statistics, linear algebra, Mathematica programming, chemistry, and differential equations. While taking multivariate calculus with Dr. Long she found someone with similar interests in the environment. Madison attended a Thomas More STEM Camp and was able to participate in and gain insight into research. She saw how humans affect the Ohio river, for good and for ill. With a growing love for the environment Madison is excited to dive into this important project, and to gain experience she will use for future research and for her career.

Laura Farro is a Physics and Statistics double major. She has taken courses in calculus (including multivariate, with Madison, under the instruction of Dr. Long), as well as statistics, linear algebra, and differential equations. She is currently a member of the SOAR Program at NKU. While this research may pertain more to her major in Statistics, she believes that her major in Physics has taught her the problem-solving skills and the perseverance she will need when working with this “noisy data”, as Dr. Long describes it. Laura is excited to be working with Madison and Drs. Long and Wilkinson on this research project, as it will be a great way for her to get valuable research experience.

Appendix A: Faculty Vita

Curriculum Vitae

Andrew E. Long

Department of Mathematics and Statistics
Northern Kentucky University
Highland Heights, KY 41099
(859) 572-5794
longa@nku.edu

Education

Miami University, Oxford, OH - Global Field Program
M.A., Zoology, 2011
The University of Arizona, Tucson, AZ -
Ph.D., Applied Mathematics, 1994
Dissertation: "Cokriging, Kernels, and the SVD:
Toward Better Geostatistical Analysis"
Director: Dr. Donald E. Myers
The University of Arizona, Tucson, AZ -
M.S., Applied Mathematics, 1991

Research and professional interests

Global Climate Change, Environmental Mathematics, Math Modelling,
Geostatistics and Spatial Analysis, Mathematical Biology,
Computers in Math Instruction and Research, Numerical Analysis

Honors

Member, MAA Committee on Mathematics and the Environment (2003-2005).
Outstanding Junior Faculty Member Award 2002-2003, Arts and Sciences, NKU.
Senior Fulbright Scholar, Benin, West Africa. 1997-1998.
Phi Kappa Phi Graduate Fellowship, 1984.
Phi Kappa Phi and Phi Beta Kappa, 1983.

Relevant Employment

2005-present: Associate Professor of Mathematics, NKU
2000-2004: Assistant Professor of Mathematics, NKU
1998-2000: Senior Post Doctoral Fellow, Department of Epidemiology,
University of Michigan, and Research Scientist, BioMedware, Inc.
Ann Arbor, MI.
1997-1998: Senior Fulbright Scholar, Institute of Mathematics and Physics,
Porto Novo, Benin, West Africa.
1996-1997: Loyola University Medical Center, Chicago, IL
Research Associate, Department of Preventive Medicine and Epidemiology

Relevant Publications

Long, A. E., and R. Tyson. *Integrating Homo sapiens into ecological models: Imperatives of climate change*. Ecological Complexity, Vol. 20, 2014:325-334.

Hastings, J. M., C. W. Holliday, A. Long, K. Jones, and G. Rodriguez. *Size-Specific Provisioning by Cicada Killers, Sphecius speciosus, (Hymenoptera: Crabronidae) in North Florida*. Florida Entomologist, Vol. 93, #3, 2010:412-421.

Lucey, B. T., D. Smith, C. A. Russell, M. L. Wilson, A. Long, L. A. Waller, J. E. Childs, and L. A. Real. *Spatio-Temporal Analysis of Epizootic Raccoon Rabies Propagation in Connecticut, 1991-1995*. Vector Borne and Zoonotic Diseases, Vol. 2, #2, 2002:77-86.

Long, A. E., T. E. Prewitt, J. S. Kaufman, C. N. Rotimi, R. S. Cooper, and D. L. McGee. *Weight-Height Relationships among Eight Populations of West African Origin: the Case against Constant BMI Standards*. International Journal of Obesity, 22:842-846, 1998.

Long, A. E., J. G. Brown, and D. J. Gellenbeck. *Statistical analysis of nitrate in ground water, West Salt River Valley, Arizona*. U.S. Geological Survey Water Resources Investigations Report 97-4185, 38 p. 1997.

Relevant Grants, Projects, or Talks

2015: *Climate Conversations: Monthly Discussions of Climate Change*. With CINSAM and NKU's Center for Environmental Education

2014: *Planetary Emergency: the Carbon Crisis Across the Curriculum*. CINSAM Series on Transdisciplinarity.

2013: *Global Climate Destabilization: Optimal Opportunity for the Mathematics of Planet Earth*. Joint Mathematics Meetings, San Diego, CA.

2012: CINSAM Course Release Grant, awarded to permit me time to create a course on global climate change for STEM majors.

2012: Sabbatical, Fellowship, and Project Grant, 2013-2014. Theme: Global climate change, particularly in the forests of Canada. In association with the Canadian Ecology Centre, Mattawa, ON.

2011: *Global Warming-based Calculus*. Joint Mathematics Meetings, New Orleans, LA.

2008: CURM (Center for Undergraduate Research in Mathematics) mini-grant for 2008-2009 (supported three undergraduate researchers).

2008 (invited talk): *Lies, Damned Lies, and Spatial Statistics: Can Variance Be Our Friend?*. The Confluence of Biology and Mathematics in the Commonwealth. Murray State University.

2005: *Raccoons Gone Mad! Modeling an Epidemic of Raccoon Rabies.* Joint Mathematics Meetings, Atlanta, GA; MAA Session on Environmental Mathematics and the Interdisciplinary

2001: "Summer Experience for Young Scientists" CINSAM grant, with Macel Wheeler (History and Geography).

Curriculum Vita for

Steven V. Wilkinson

Department of Mathematics and Statistics
Northern Kentucky University
Highland Heights, Kentucky 41099
Phone: 859-572-5775
Email: wilkinson@nku.edu

Education

Rice University, Ph.D. Mathematics	1984
Tulsa University, B.A. Mathematics	1979

Academic Appointments

Professor of Mathematics, NKU	2008 to present
Associate Professor of Mathematics, NKU	1992-2008
Assistant Professor of Mathematics, NKU	1989-1992
Assistant Professor of Mathematics, University of Missouri-Columbia	1985–1989
Visiting Professor of Mathematics, UNC-Chapel Hill	1984-1985

Selected Research Related Visualization Publications

- S. Wilkinson, "Self-Curvature Curves" *Mathematics Magazine*, Vol. 82, No. 5, p. 354-359 (December 2009)
- R. Baker, S. Wilkinson, "Reflective Properties for Conic Sections," *Wolfram Demonstrations Project,* <http://demonstrations.wolfram.com/ReflectivePropertiesOfConicSections/> (2009)
- S. Wilkinson, "Intersections of Surfaces," *Mathematica in Education and Research,* Vol. 8, No. 2, p. 5-10 (Spring 1999)
- S. Wilkinson, "Numerically Parametrizing Curves," *The College Mathematics Journal*, Vol. 29, No. 2, p. 104-119 (March 1998)

Selected Pedagogy Related Visualization Publications

- R. Fox, K. Kirby, G. Newell, S. Rankin, S. Wilkinson, *CSC 260L: Computer Programming Lab*, published in-house for student use in NKU classes (2004)
- S. Wilkinson, "Graphing Calculators in High School Mathematics," *The Appalachian Journal of School and College Mathematics*, Vol. 2, Issue 1, p. 15-36 (1994)

Selected Related Visualization Presentations

- "Smart Plotters," KYMAA sectional meeting at Murray State (2014).
- "Self-Curvature Curves," KYMAA sectional meeting at NKU (2007).
- "Parametrizing Lathed, Extruded, and Lofted Surfaces," KYMAA sectional meeting in Lexington, Kentucky (2001).
- "Parametrizing Implicitly Defined Curves," KYMAA sectional meeting (1996).

Directed Student Research Projects With Visualization Components

- “Visualizing the 4D Mandelbrot set” with Daniel King, Rachel Driehaus and Brandon Henning (2015). Student outcome: Java and Mathematica code for displaying 3D slices of the 4D set.
- "Smart Plotters" with Nathan Dasenbrock-Gammon and Elsy Verdugo (2014). Student outcome: poster presentation at a 2014 NKU event, paper submitted with Wilkinson to a nationally known journal, and poster presentation at a 2015 national meeting.
- "Magnetic Pendulum" with Spencer Caudle and Timothy Wicklehaus (2013). Student outcome: poster presentation at NKU events.
- "Darboux Helices" with Zachariah Casey (2011-2012). Student outcome: two poster presentations at NKU events and two oral presentations at regional meetings.
- "Adjustable Meshes" with Jared Antrobus and Erica Gentile (2012). Student outcome: poster presentations by each student at an NKU event.
- "Reflective Properties for Conic Sections Demo" with Robert Baker (2008). Student outcome: online publication in *Wolfram Demonstrations Project*.
- "Instruction with Open Source Software," with Chris Fronk (2008). Student outcome: oral presentation at a local event.
- "Self-Curvature Curves," with Aaron Beetz and Jeremy Spitzig (2007). Student outcome: oral presentation at a regional meeting.
- *nkuGeometry*, with Elizabeth Whittle (2004). Student outcome: an interactive website hosted on an NKU server.
- *nkuGrapher* with Mario Cannon (2002). Student outcome: an interactive website hosted on an NKU server.
- "Graphics Programming," with Nathan Morenz and Keefe Roedersheimer (2000). Student outcome: poster presentations by each student at an NKU event.
- "Graphing calculator plotting routines," by Tate Hilgefort and Shannon Murphy (1993). Student outcome: several pieces of code for different calculators made available to schools in a consortium of schools from Kentucky and Tennessee.