AC 2010-2133: GO WITH THE FLOW: DESCRIBING STORM WATER RUNOFF RATES USING THE DERIVATIVE

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Go With the Flow:
Describing Storm Water Runoff Rates Using the Derivative

Abstract

This paper presents an innovative teaching approach, how it was implemented, student responses, results of the implementation, and the assessment of impact on student learning. The findings are based on surveys given to the students before and after the lesson taught in partnership with university and community members.

The purpose of this lesson was for students to discover how engineers use derivatives to solve real-world engineering problems. Students measured urban, sub-urban, and rural storm water runoff volume to generate three different storm water runoff graphs using Microsoft Excel. Next, students generated the derivative graph to discover differences in rates of change of water runoff within these three watershed scenarios. The class then discussed how to relate their storm water runoff data to watershed characteristics, identified challenges associated with increased runoff rates in a urban setting such as Cincinnati, Ohio and recommended appropriate management practices for its control. This unit concluded with a trip to the award-winning, Sanitation District 1 in Fort Wright, Kentucky where students observed storm water management technologies used in the real-world. Analyses of pre- and post-assessment performance revealed that students performed statistically significantly higher on post-assessments in both calculus sections, suggesting that this lesson improved student understanding of how derivatives are used to model change within environmental systems.

This type of an innovative teaching approach, supported by research on inquiry lessons, provides a more memorable experience for the students – actually experiencing storm water management technologies that they would only read about in textbooks and articles. This paper will provide other instructors with ideas to incorporate into their classes and will showcase both successes and challenges from the teacher's and students' perspectives.

Project STEP

The chief goal of this National Science Foundation (NSF) Graduate STEM Fellows in K-12 Education (GK-12) funded project STEP (science and technology expansion project) is to produce scientists, engineers, and secondary mathematics and science educators who are experienced in developing and implementing authentic educational practices. The graduate students, called STEP Fellows, are the main focus of the grant. The STEP Fellows, 15 in the last three years, are trained to bring their complex graduate research to an understandable and interesting K-12 level. This process instills better communication skills in the STEP Fellows and breaks any reservations of working with the K-12 environment once employed as a university faculty member. The secondary goal of Project STEP was to impact student learning by relating

STEM content to urban city issues through the use of hands-on, technology-driven, inquiry-based projects that also relate to desired curriculum standards. Students need an understanding of STEM and the reasons to pursue STEM careers; over 3,000 students have been exposed to STEM lessons in the past three years with Project STEP. Teachers of these students are involved in this process as well, and 36 different teachers have participated in the STEP program since 2006. Lastly, Project STEP focuses on the sustainability of the program itself. The university faculty participants, six primary investigators and four coordinators, play a large role in facilitating the promotion of community partnerships with teachers, K-12 students, and Fellows. In this paper, we outline an innovative teaching approach, how it is implemented, student response results of the implementation, and the assessment of impact on student learning. The findings are based on surveys given to the students after the taught in partnership with Project STEP members.

Lesson Creation

Each STEP Fellow creates at least five major STEM lessons, most including several days of teaching, during one academic year. Project STEP lessons are created by the Fellow, but are enhanced by the K-12 teachers, university faculty working with the grant (Principal Investigator or PI and Co-Principal Investigators or Co-PI), grant coordinators, and university faculty working directly with the graduate Fellows on their studies (Research Advisors). The teacher identifies the need for a lesson in the curriculum map for the course, and the Fellow develops the ideas and contents of the lesson in consultation with his/her research advisor and project PI/Co-PIs, which are finally checked for correctness by one of the Co-PIs. Pre- and post-test are part of the lesson development. The teacher leads the effort to develop the post-test for the lesson. A well-defined template is used by the Fellow to create the lesson, which can be disseminated on the project's website soon after its implementation. This template consists of the following blocks: 1) Summary – goal to be achieved by students; 2) Objectives – skills to be acquired by students; 3) Standards to be addressed; and 4) Lesson Information – Grade Level, Subject Area, Duration, Setting, Materials Needed, Background Knowledge, Lesson Plan(s) details, and Additional Resources (learning objects, timelines, assessment rubrics, surveys, etc.). Item 4 includes detailed information provided via hotlinks. The Fellow submits the final lesson to the Grant Coordinator for checking and approval before implementation. On the average it takes about six weeks to develop a lesson before implementation.

Most of the lessons that have been created since 2006 focus on secondary STEM content. The results obtained by reviewing these lessons indicate that 59, 62, 66, and 78% of STEP lessons analyzed contain components of mathematics; engineering, technology, and science, respectively (Figure 1). Interestingly, 97% of lessons at least partially contain components from at least three of these disciplines. When evaluating lessons that definitely contain elements from, science, technology, engineering, and/or math, 82% contain content from at least two of these four STEM areas, suggesting a trend that STEP lessons are interdisciplinary.

Component	% of lessons that addressed this component	% of lessons that partially addressed this component
Science	78.13%	3.13%
Technology	65.63%	25.00%
Engineering	62.50%	34.38%
Math	59.38%	21.88%
Oral assessment	3.13%	3.13%
Written assessment	90.63%	3.13%
Misconceptions	15.63%	18.75%
Review/Essential Questions	31.25%	21.88%
PowerPoint	59.38%	0.00%
Multiple learning styles included	59.38%	37.50%
Pictures and/or diagrams	84.38%	12.50%
Application	93.75%	6.25%
Social impact	59.38%	25.00%
Career connection	34.38%	31.25%

Figure 1: Percentage of lesson components.

More than 97% of lessons address or partially address the use of multiple learning styles, and more than 93% of STEP lessons contain a real-world application. While nearly 60% of lessons deal with societal or social impacts, less than one-third of the STEP lessons focus on connecting the material to potential careers. Of interest was that only 16% of STEP lessons address potential misconceptions associated with lesson content, which may be explained by the evolution of the lesson plan development requirements as Project STEP has itself evolved over the last eight years.

Innovative Lesson

Project STEP's Civil and Environmental Engineering Fellow, Gina Lamendella, worked in partnership with Norwood High School teacher, Brad Hunt, to implement and critique this lesson in a Calculus course.

In traditional Calculus courses students are taught the concept of derivatives through the definition and a multitude of computational methods to calculate derivatives. However, many students never connect the derivative to its real world application and miss the magnitude of its importance in science, engineering and business. They do not understand the physical meaning of a derivative and its application. The purpose of this lesson was to allow students an opportunity to discover how engineers use derivatives to solve real-world engineering problems.

The goal of this lesson was for students to understand the meaning of the derivative in terms of rate of change and be able to use the derivative to solve a variety of real-world environmental engineering problems. Upon completion of the lesson's activities students were able to:

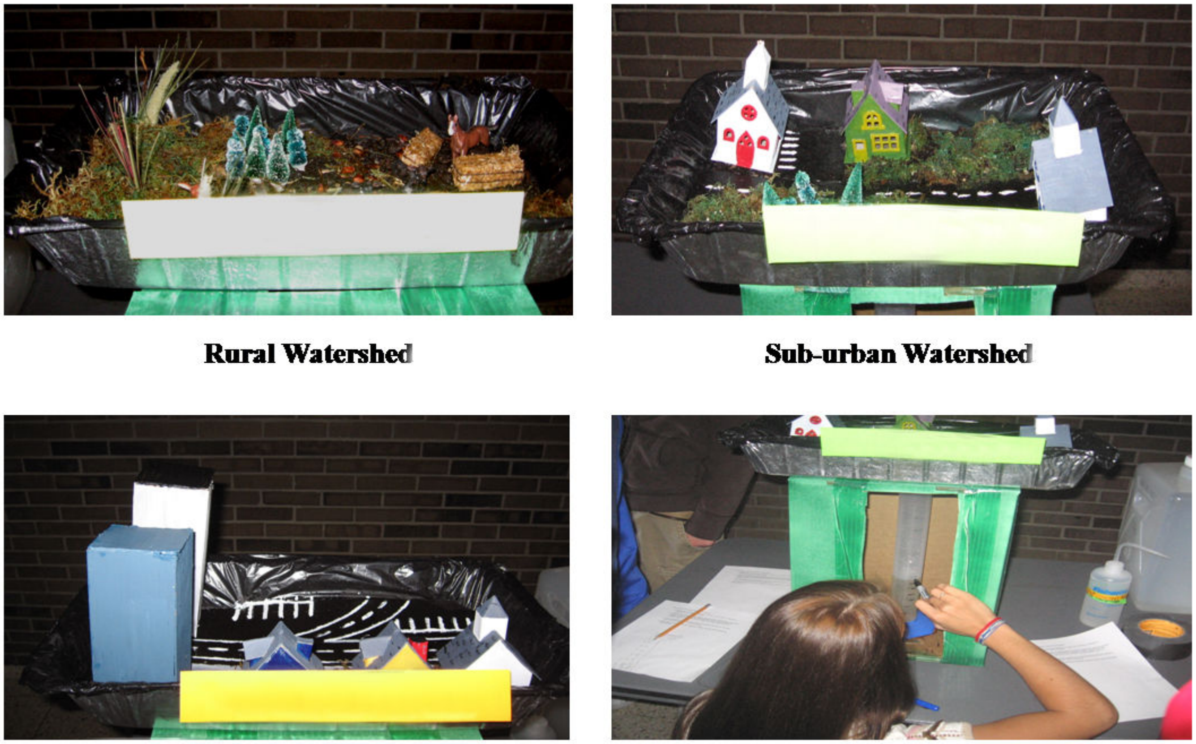
1. Explain how engineers use derivatives to solve environmental engineering problems.
2. Generate a graph representing storm water runoff data to create a graph representing the derivative of that function.
3. Compare instantaneous rates of change in runoff across three different graphs representing different watershed scenarios and relate these different values to watershed characteristics.
4. Recommend appropriate storm water management technologies for reduction of urban runoff in a city such as Cincinnati, Ohio, and how these management practices might impact the hydrographs they have created.

Through this lesson, students utilized urban, suburban and rural storm water runoff data to generate three different mathematical functions. Using the derivative, students discovered differences in the instantaneous rate of change of rainwater runoff within the three environmental settings. Students then correlated water runoff rate data to watershed characteristics, identified challenges associated with increase runoff rates in an urban setting such as Cincinnati, Ohio.

The students then suggested appropriate best management practices for water runoff control. The lesson concluded with a field trip to the award winning Sanitation District 1 in Fort Wright, Kentucky for a tour of storm water management technologies utilized for the reduction of urban runoff. Further details of each of the above activities follow.

The lesson began with the class observing a "rain fall event." This event was simulated using two prepared models of different environmental settings. One model was made of blacktop and model buildings to depict an urban setting. The other model had turf and a house to simulate a suburban setting. Further physical details of the two models are presented in the paragraph that follows. Students were invited to pour 500ml of water from a watering can onto the models and record their observations. Students observed that each model has a different runoff rate. The class discussed the different rates and the causes for those differences. Students were then given a pre-assessment to ascertain their present level of understanding of the derivative and the connectivity to fields in engineering particularly in storm water runoff.

The class was divided into three groups to work on separate model simulations. The models were created using 11 in. x 14 in. x 3 in. cooking trays. Each tray represented a different watershed (urban, suburban and rural) and was lined with pea gravel and one inch deep play sand. A layer of one inch top soil was also added to each tray. The rural model was topped with grass; moss and hay over the soil, toy farm animals and a barn were added for effect. The suburban watershed was made to appear like a suburban neighborhood with a mixture of permeable (e.g. grass) and impermeable (e.g. shingles) materials. The urban model was covered with impermeable (e.g. blacktop, shingles) material and made to look like the downtown of a major city. A 1/8 in. hole was drilled in the bottom center of each model to simulate drainage. Figure 2 shows pictures of the two models used.



Rural Watershed **Sub-urban Watershed**

Urban Watershed **Measuring Storm Water Volume**

Figure 2: Stormwater simulation activity.

Each student group was comprised of a timer, a marker, a recorder, an overseer and a rain pourer. Students then simulated a rainstorm event by pouring 500ml of water from a watering can onto their model. The storm water runoff was collected into a graduated cylinder under the model. Students measured cumulative water volume over time. Time intervals and water volume were recorded onto a student data sheet.

After the data collection was complete, the class moved to the computer lab to view the simulation results using Microsoft Excel. Each student used Excel to create a spreadsheet and graph of his/her data with time as the independent variable on the x axis and cumulative water volume as the dependent variable on the y axis (see sample plot in Figure 3). Using the discrete data students calculated slopes of the tangent lines over different intervals. Students then used the slope values to create a graph of the derivative (see Figure 4) of their watershed and analyzed the results using a question guiding worksheet. The student's next task was to use Excel to generate a continuous polynomial function and an equation for that function using the regression analysis curve fitting option in Excel. Using the equations that they generated the students analytically determined the first derivative function.

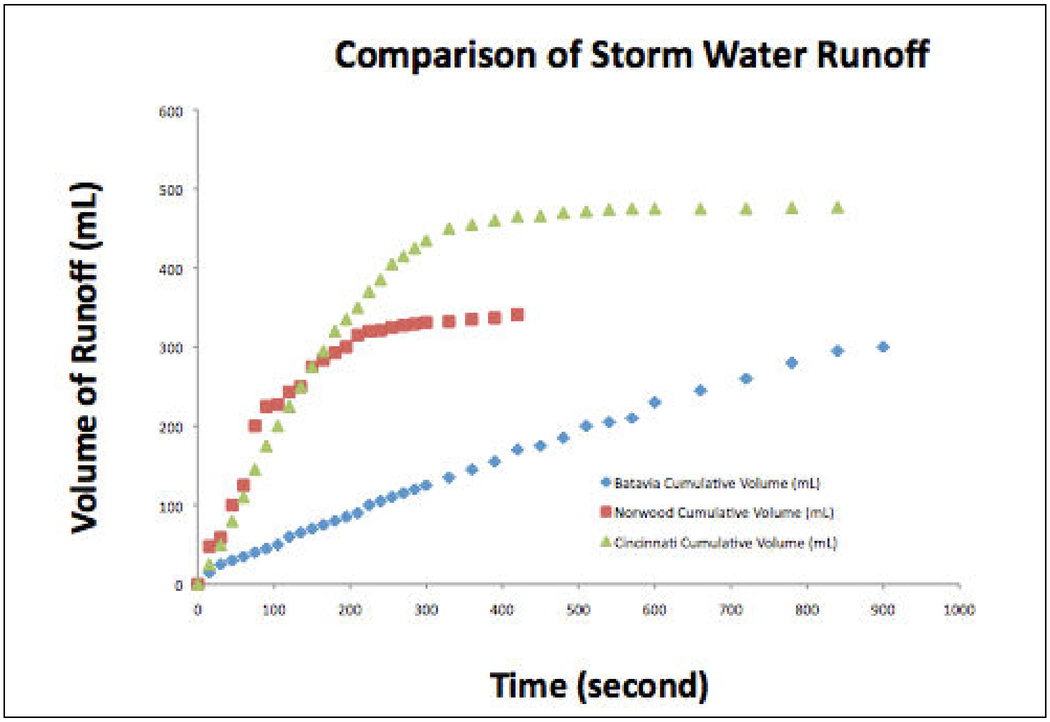


Figure 3: Student-generated cumulative stormwater runoff volume in three different watersheds.

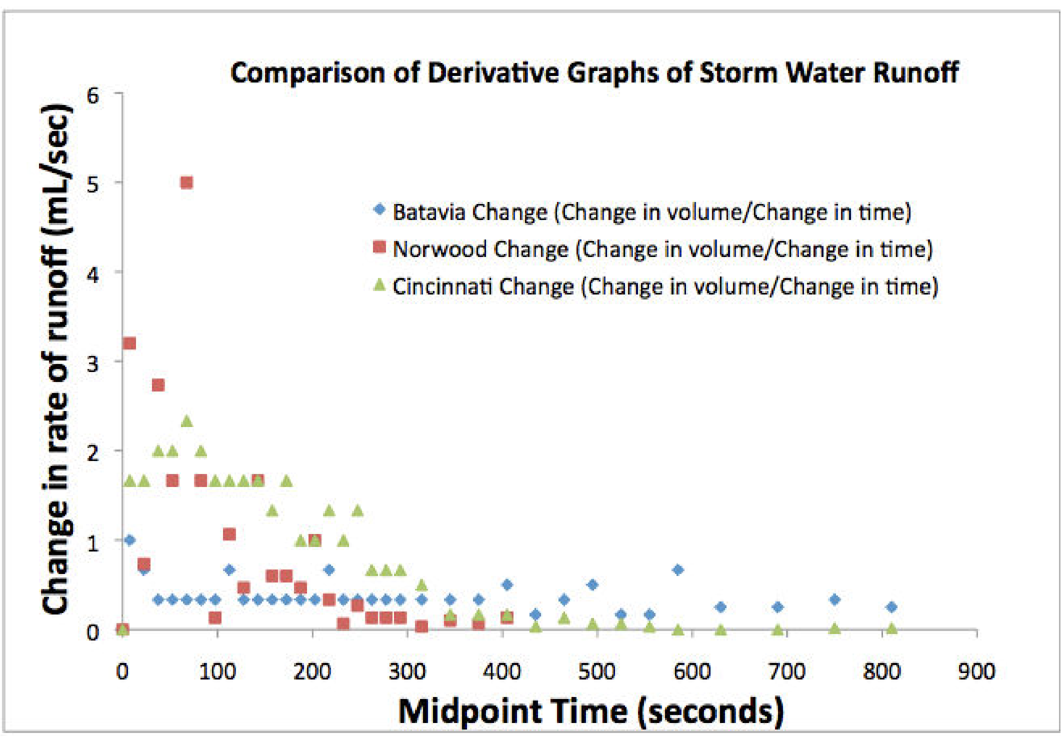


Figure 4: Student generated derivative graph

On completion of the Excel activity the storm water graphs and derivative graphs were compared. The class then discussed conclusions that can be made such as maximum rate of storm water runoff for each watershed scenario. The class was asked to determine potential watershed characteristics that might be responsible for the different rates of change in storm water runoff within each of the three different watersheds. (Find the full lesson plan and supporting documents at http://www.eng.uc.edu/step/lessonsbyfellow.html under *Storm Water Runoff* by Gina Lamendella.) Lastly, the students discuss problems that might occur with runoff rates and the possible solutions to those problems.

The lesson concluded with a field trip to Sanitation District 1 in Fort Wright, Kentucky. At Sanitation District 1, the students met a panel of scientists and engineers to hear about their educational goals, training, experience and continual professional development. The panel also discussed their day to day responsibilities and research at the district. Next, the students participated in a guided tour to observe storm water management practices that might exist and that are being developed for future implementation. Students observe impacts of green roofs, porous pavements, detention ponds, wetlands and riparian zones. Students then discussed the pros and cons of each water management practice they have observed. Students finalize the lesson by completing a post-assessment.

Conclusion and Student Responses

Students were enthralled that calculus class was not in the traditional classroom for all components of this lesson. Students were very excited to perform the group work, in which they measured runoff from the models. Each group really worked well as a team, most likely because every individual's "job" was important and required precision in addition to good communications skills. In the second component of this lesson, students were in a computer lab where they once again had to work as a team to input data, create cumulative runoff and derivative graphs. The students found it particularly useful to compare the cumulative runoff graph and the derivative graph side-by-side in order to identify maximum rates of runoff. Students found the field trip one of the most exciting portion of this unit, as they were able to interview the county and state environmental scientists, engineers, and educators providing them with a clearer understanding of what environmental engineers and scientist do on a day-to-day basis. The field trip also provided tangible examples of how environmental engineering and science can provide solutions to problems such as stormwater runoff.

Impact on Student Achievement

The positive impact of this innovative, interdisciplinary lesson was illustrated by statistically significantly greater scores on student post-assessments in two separate Calculus classes (see Table 1 and Figure 5). Additionally, students provided much more detailed responses in defining the derivative, how to find the maximum rate of change, and prediction of how implementation of stormwater management could impact stormwater runoff rates.

In order to assess the students understanding of potential applications of the derivative a short 5-question pre and post assessment was given in conjunction with our lesson. The pre and post assessment questions were identical and guessing was discouraged in order to obtain more accurate data. As expected students understood the definition of the derivative (a knowledge and comprehension task in Bloom's Taxonomy) but they struggled with matching real-world applications of the derivative with associated professions (an application task in Bloom's Taxonomy). What follows is the question with the largest pre to post assessment improvement:

> Each of the following professionals uses derivatives to solve real-world problems in their respective discipline. Match the professional (on left) with how they might use derivatives to solve a real-world problem (on right).

Professional	**Can Use Derivative to:**
A. Chemical Engineer B. Environmental Engineer C. Civil Engineer D. Electrical Engineer	i. describe how fast a reactor can make a new petroleum product ii. describe how efficiently a GPS works iii. describe how a fluid moves inside a reactor iv. describe the concentration of chlorine in water distribution pipes v. describe the strength of materials

Table 1: One Question from the Pre and Post Assessment given to students.

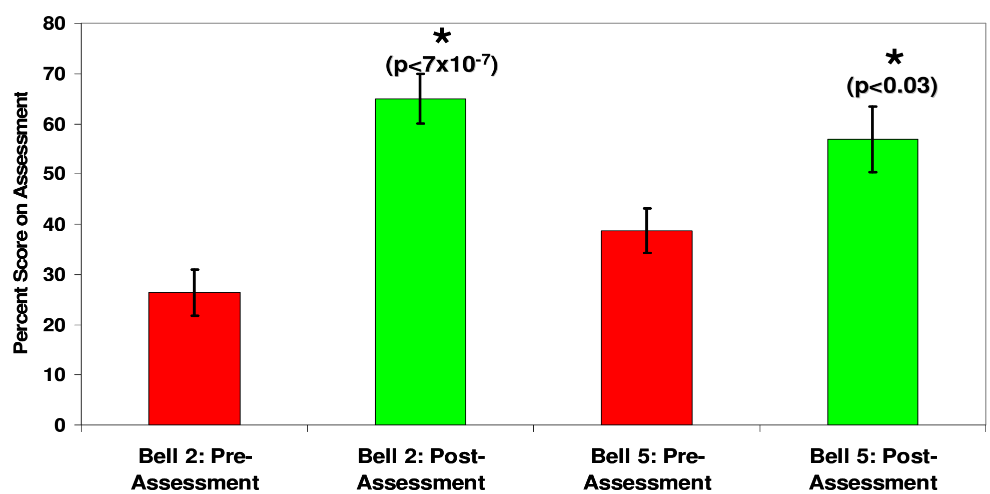


Figure 5*:* Statistical evaluation of student performance on pre and post-assessments. *indicates statistical significance (p-value<0.05) using a Student's T-test.

In the two bells in which the lesson was taught the overall average scores between the pre and post assessment increased from 27% to 64% and 38% to 59%; showing a statistical difference in performance, using an unpaired students T-test ($p < .05$).

Acknowledgement

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