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## **Green Space Based Learning Model for Repurposing Underutilized Green Spaces within School Campuses**

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### **ABSTRACT**

The Green Space Based Learning (GSBL) is an educational model to mainstream green infrastructure within urban environments that builds on a long-term partnership between a Research I university, surrounding underserved community, and local school district with a portion being piloted through a federally funded Research Experience for Teachers (RET) program. The RET program provides an opportunity for graduate students and professors to share their field of knowledge with teacher participants in two intensive 6-week summer research experiences. This content knowledge is then translated by the participating teachers into grade specific lessons that support the development of interactive and sustainable green spaces within their school campus. Stakeholder groups participate in academic year components, bringing their expertise into the K-12 classroom. Ultimately, K-12 students are guided through the design/build of a green infrastructure improvement project, transforming an underutilized green space within their school campuses into a multi-use educational environment. Phenomenological based interviewing methods allowed RET participants to reflect on their experience and provide feedback on the impact that the GSBL had on them, their teaching, and their community. Participating teachers expressed improved pedagogical practices through their experience in the GSBL model across several thematic groups, including authentic research experience, contextualized learning, teacher's contribution to research, practical applications to classroom, professional development, and green infrastructure awareness.

**Key words:** Human centered design, Green Infrastructure, Environmental engineering



## INTRODUCTION

The United States (U.S.) has a positive public perception of the impacts that investments in science and technology has on the nations citizenry, economy, and environmental resources (OECD, 2016a). However, the U.S. economic advantage and role in innovation and technology advancement is uncertain as K-12 students currently rank 48th in quality of mathematics and science education, 38th in mathematics, and 24th in science globally (World Economic Forum, 2012; OECD, 2016b). To ameliorate this downturn, the federal government released a Five-Year Strategic Plan for Federal Science, Technology, Engineering, and Mathematics (STEM) Education to develop federal programs designed to improve instruction, sustain youth and public engagement, enhance experience of undergraduates, serve historically under-represented groups, and design graduate education for tomorrow's STEM workforce (NSTC, 2013). The 2016 Budget included a major new investment of \$3.1 billion in federal programs in STEM education, seeking to advance a government wide goal to increase the number of well prepared college graduates with STEM degrees by 1 million over the next decade.

Preparing the next generation of critical thinking scientists and innovative engineers is essential given U.S. urban infrastructure is in dire need of improvement without adequate funding for system upgrades (ASCE, 2017). Given the scope, the American Society of Civil Engineers (ASCE) estimates that a capital investment gap exceeding \$240 billion over the next ten years exists for gray infrastructure for stormwater. Gray infrastructure in this context is defined as any traditional engineering-based method for managing stormwater runoff, consisting of both storm sewer and combined sewer systems, detention/retention ponds, pumps, and curbs with gutters.

Current research shows that an alternative approach to gray infrastructure is the use of green infrastructure (GI) for stormwater management, a decentralized approach for restoring the hydrology and water quality to that of predevelopment conditions (Davis, 2009; Hunt, 2012). Green infrastructure reduces the peak flow rate and volume of runoff discharging to traditional stormsewer systems, reducing the demand for system upgrades and capital costs. There are many opportunities to implement green infrastructure in such a way that it meaningfully engages community stakeholders. Likewise, there are numerous publications that support social, environmental, educational, and human health benefits associated with vibrant, interactive green spaces within a community (Taylor et al., 1998, Taylor et al., 2001; VanWoert et al., 2005; Maas et al., 2006; Aldous, 2007; Verheij et al., 2008; Arbogast et al., 2009; Seymour et al., 2010; Van den Berg & Custers, 2011; Keniger et al., 2013).

The Green Space Based Learning (GSBL) is an educational model to mainstream green infrastructure within urban environments that builds on a long-term partnership between a Research I university, surrounding community, and local school district with a portion being piloted through a federally funded Research Experience for Teachers (RET) program. The RET program provides an opportunity



for graduate students and professors to share their field of knowledge with teacher participants in two intensive 6-week summer research experiences. This content knowledge is then translated by the participating teachers into grade specific lessons that support the development of interactive and sustainable green spaces within their school campus. Stakeholder groups participate in academic year components, bringing their expertise into the K-12 classroom. Ultimately, K-12 students are guided through the design/build of a green infrastructure improvement project, transforming an underutilized green space within their school campuses into a multi-use educational environment.

This paper describes the GSBL model and answers the question of how to sustainably translate K-12 STEM teachers research experience and new knowledge of engineering and technological innovation to the K-12 classrooms. It (1) provides historical context to GSBL development, (2) defines the relationship between the engineering design process, authentic scientific inquiry, and GSBL components, (3) outlines the GSBL model Primary and Secondary Phases, (4) presents phenomenological interview data after using the model with K-12 STEM in-service teachers, and (5) discusses the opportunities for GSBL stakeholder groups and the indirect impacts of improved pedagogical practices on student learning.

### **History of the Local Community Partnership and The Green Space Based Learning Model**

The foundation for the GSBL model began in 2008 under an Environmental Protection Agency (EPA) P3: People, Planet and Prosperity student design competition for sustainability, Water Awareness, Research and Education (WARE). The WARE program was initiated to raise environmental awareness around non-point source pollution within a large metropolitan area in the southeastern United States, using stormwater ponds as an initial focal point. Stormwater ponds were selected as they are part of an aging infrastructure, typically disconnected and inaccessible from this community, and in many cases the only sizeable green space within the urban landscape (Wright et al., 2012). The university partnered with local community groups to transform a community stormwater pond from an unusable and dilapidated space to a community resource with an exercise trail, workout area, gazebos for holding events, and an educational kiosk (Thomas et al., 2009). This community driven beautification project established the GSBL project criteria to repurpose underutilized green space into multi-use environments (e.g. formal, informal) as a nexus for sustainable healthy communities.

The stormwater pond project is located within a short distance of a local magnet middle school, providing the authors the opportunity to partner with and create 7th and 8th grade math and science curriculum around traditional stormwater infrastructure, stormwater runoff, and water quality. Multiple Outcome Interdisciplinary Research and Learning (MOIRL) is an approach that has been used to describe this research and education model in which K-12 teachers and pupils engage in authentic science experiences as participants in a scientific research project (Feldman, 2012).



In 2012, the National Science Foundation funded a Research Experience for Teachers in Engineering and Computer Science site, Water Awareness Research and Education (commonly referred to as WARE-RET), at the University of South Florida (NSF, 2012). The goal of WARE-RET is to provide a proactive and well-structured research, education, and professional development experience for middle and high school science and mathematics teachers. The research was framed around three of the National Academy of Engineering Grand Challenges for Engineering (NAE-GCE): (1) manage the nitrogen cycle, (2) provide access to clean water, and (3) restore and improve urban infrastructure.

### **Engineering Design Process**

The application of engineering is a critical component for integrating STEM content within K-12 schools, and the Engineering Design Process (EDP) is viewed as one of the fundamental components of K-12 science education (NRC, 2011; NAE, 2010). Engineering provides real world context to both science and math subjects and is a central focus of successful technological based education (Hill, 2006, Lewis, 2004). This integrated understanding has prompted the Next Generation Science Standards (NGSS) to incorporate engineering with sciences, and as a result requires engineering to be taught in the K-12 classroom (NAE, 2010, Roehrig et al., 2012, Carr et al., 2012, Hsu & Cardella, 2013). The EDP is an iterative, creative and non-linear decision-making process, in which science, math, and engineering concepts are applied to develop optimal solutions to a given problem or objective (Mangold & Robinson, 2013, Burghardt, 2013). Optimal solutions are iterative and can change, leading to modified or different solutions altogether. This contrasts traditional scientific and mathematical instruction where questions are typically structured around getting the “right” answer.

K-12 teachers' educational background often provides them with limited exposure and familiarity with engineering pedagogy and content (Yasar et al., 2006; Hsu, 2011; Burghardt, 2013). Teacher misconceptions about engineering often include building and constructing, leading to traditional assembly type classroom activities (Jarvis & Rennie, 1996; Cunningham et al., 2006, Capobianco et al., 2011). Therefore, it is important to provide teacher professional development that emphasizes the EDP and the tools to design appropriate lesson content and activities (Mangold & Robinson, 2013).

### **Scientific Inquiry, Inquiry Learning, and Inquiry Teaching**

The use of inquiry within the literature refers to scientific inquiry, inquiry learning, and inquiry teaching. The National Research Council views inquiry as a cornerstone for students' comprehensive understanding of authentic scientific investigation and the nature of science (NOS) and recommends that students learn scientific concepts and principles, learn to develop methods for scientific investigation, and understand the nature of science (NRC, 2000b).



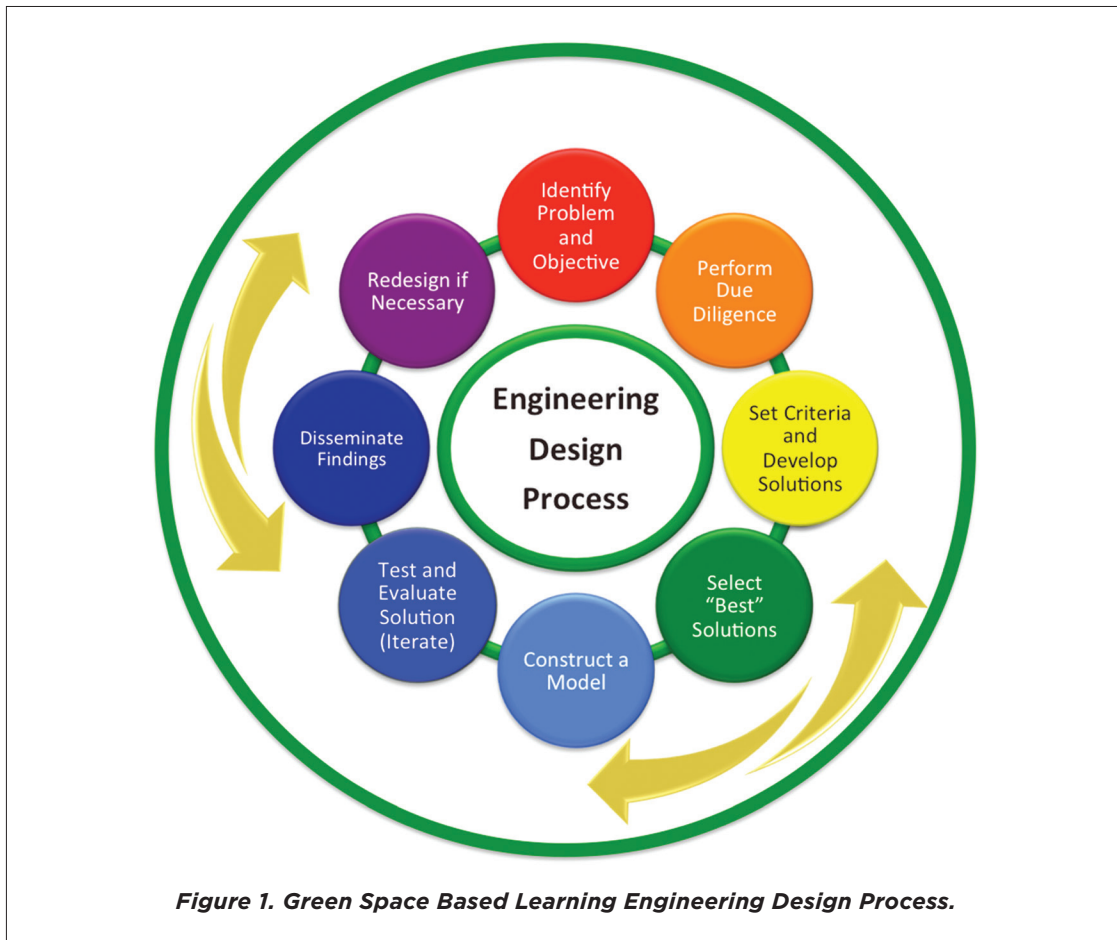
To inquire is to learn and scientific inquiry refers to the way in which scientists pose questions about the natural world and explain observed phenomena based on evidence derived from their research (Crawford, 2007). Scientific inquiry is viewed as research that “real” scientists do when they do science (Anderson, 2002; Feldman et al., 2009). Inquiry teaching is open-ended and depends on a teacher’s subject matter content knowledge, experience with inquiry based pedagogy, and support from other teaching professionals (Anderson, 2002). The National Science Education Standards (NSES) define differing degrees of inquiry teaching, from “open inquiry” to “structured inquiry” (NRC, 1996). The former allows students to generate authentic questions from their experiences, design an experiment, record and interpret data, develop an approach that supports their investigation, and disseminate findings; in the latter the instructor defines the question or problem and the procedures for the investigation.

## METHODS

### **The Green Space Based Learning Model Primary Phase**

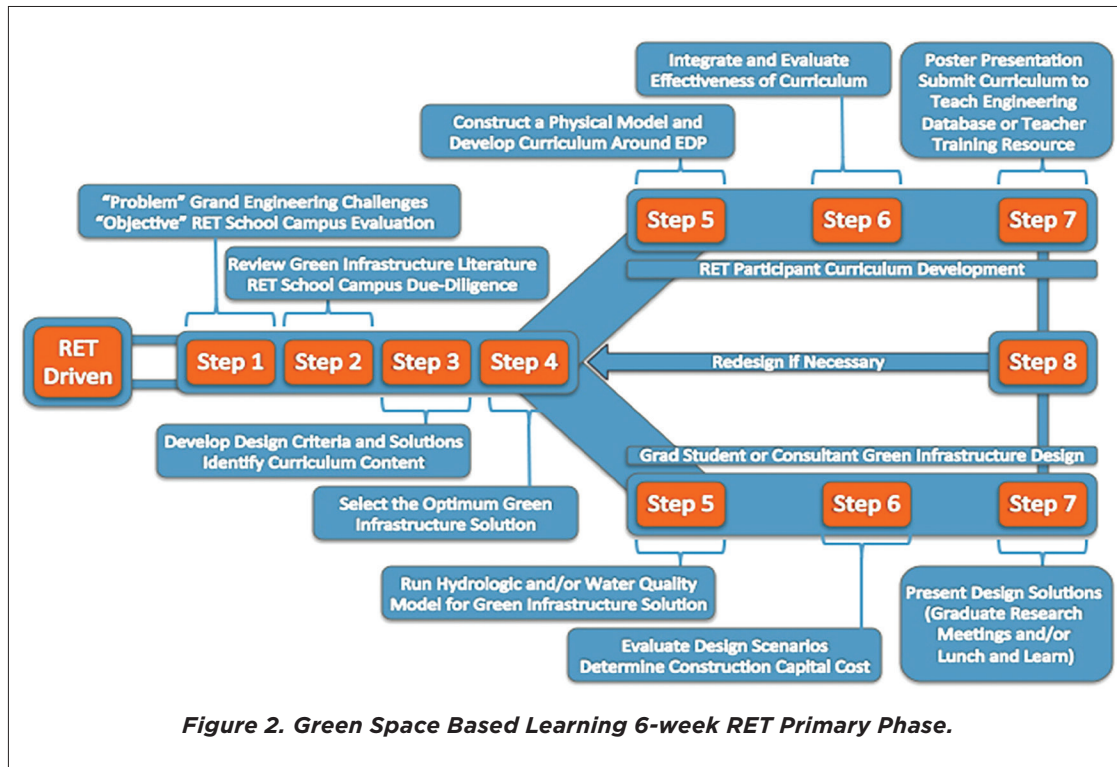
The authors used the EDP and experience with K-12 outreach from spring 2011 to summer 2012 to develop the GSBL model for mentoring teachers between summer 2012 and spring 2015 in the formal WARE RET program. The RET program provides two years of teacher support, much of which occurs during a six-week summer session each year. The National Science Foundation (NSF) RET program started in 2001 with teacher follow up during the school year being a major challenge (Russel & Hancock, 2007) that was subsequently addressed by NSF with new site proposal criteria stressing engagement beyond the summer program (Klein-Gardner et al., 2012; NSF, 2012). The WARE RET program began in summer 2012 and the GSBL model was used with the 2013 and 2014 cohort of teachers working in the authors’ research group. Prior to summer 2012, the authors worked with teachers at a particular middle school on curriculum development, some of which was integrated with the GSBL model.

Various engineering design approaches developed and used with professional engineers, college-level engineering students, and K-12 students were combined to define the engineering design process, (Figure 1) for the Green Space Based Learning Primary Phase (Ertas & Jones, 1996; Yasar et al., 2006; Atman et al., 2007; Hynes et al., 2011; Capobianco et al., 2011; Lammi & Denson, 2013; Wilson et al., 2013). This process was translated into a GSBL primary phase for first year RET participants that is presented in Figure 2. Each step of the outlined EDP provides RET participants with the data and materials required to produce an effective and defensible poster written in the context of the scientific method.



### Step 1: Identify and Define the Problem and Objective

The “problem” is presented to the teachers as one of the two Grand Engineering Challenges, (1) restore and improve urban infrastructure, or (2) manage the nitrogen cycle, and is placed in a global and then local context. This is similar to research in Texas where an evolving curriculum process with K-12 schools was developed to incorporate Grand Challenges as the framework for design and pedagogical theory (Talley, 2013). Unlike Talley’s approach, GSBL is locally focused with tangible GI implementation. The “objective” is to visit the RET participant’s school and identify a current campus design issue, campus sustainability initiatives, and/or campus needs that relate to one of the two grand engineering challenges. The school site visit is usually done by the teacher and university researchers and includes meetings with other school officials like the principal, science coach, and facilities personnel.



**Step 2: Perform Due-Diligence**

RET participants review literature on green infrastructure, Grand Engineering Challenges, and traditional stormwater infrastructure. In addition, RET participants perform due-diligence at their school campus to account for infrastructure, existing permits, and permit requirements for modifying existing infrastructure. In the case of bioretention installation, a type of green infrastructure studied by the authors, the school district gave the University researchers permission to submit permit applications to the local Water Management District on their behalf. These applications were completed and submitted by the University researchers, with designs based on spaces identified by teachers, school facilities, and principals.

**Step 3: Develop Specific Requirements/Criteria and Possible Solutions**

A list of site constraints, objectives, and assumptions are generated from Step 1 and Step 2 to create a list of specific requirements and possible design solutions for selecting and sizing an appropriate green infrastructure design. This step identifies several components (e.g. evapotranspiration, hydrology, materials) of the green infrastructure design solution upon which curriculum content will focus.





### **Step 4: Select a “Best” Solution**

Several constraints to consider in selecting a “best” solution is the overall scale of the green infrastructure project, capital costs of construction, runoff characteristics, and how well the curriculum fits into the existing Next Generation Science Standards (NGSS) and/or Common Core Standards. Each solution should be normalized and evaluated to determine an optimum solution. One method for determining the optimum solution is to use a decision matrix chart with specific requirements/criteria on one axis and the possible solutions on the other. A numeric evaluation scale can be used to compare which design solution is “best” (e.g. 2 = meets requirements/criteria, 1 = somewhat meets requirements/criteria, 0 = does not meet requirements/criteria).

### **Step 5: Construct a Model**

A physical model is a visual representation and operational version of the optimal solution. GSBL teacher participants create a physical model that represents the content they plan to cover and use this model to guide them in the development of their curriculum. This physical model allows the GSBL participant to gain valuable feedback from university professors, graduate mentors and peers within the program. Teachers develop a prototypical lesson based on the physical model, guiding students through the EDP. Each lesson is accompanied by a minimum of one hands-on activity that relays current engineering principles and practices covered in the lesson. The curriculum must meet NGSS, Common Core, and apply to green spaces within their school campus. A computer simulation is an abstract model used to simulate a system. The graduate assistant and/or consultant may be requested to utilize the data collected in Steps 1 through Steps 4 to run a model for the proposed green infrastructure improvement project. Consultants are important stakeholder groups, providing in-kind professional services to track the fate and transport of pollutants and meet site-specific hydro-modification requirements for the region of implementation.

### **Step 6: Test and Evaluate Optimal Solutions**

Testing and evaluating optimal solutions gives teachers the opportunity to instruct their students through the curriculum they developed. Teachers are given the opportunity to modify their curriculum based on student feedback, time constraints, and what worked and didn’t work in the classroom. This step occurs during the fall or spring semester of school year following participation in the 6-week summer program.

The graduate assistant and/or consultant may be requested to use the model to run and evaluate different scenarios to obtain an optimal design solution. A budget for the construction of the optimal design may then be calculated and provided to the teacher. It is the responsibility of the teacher to





schedule a construction date post curriculum implementation and secure funding through external sources.

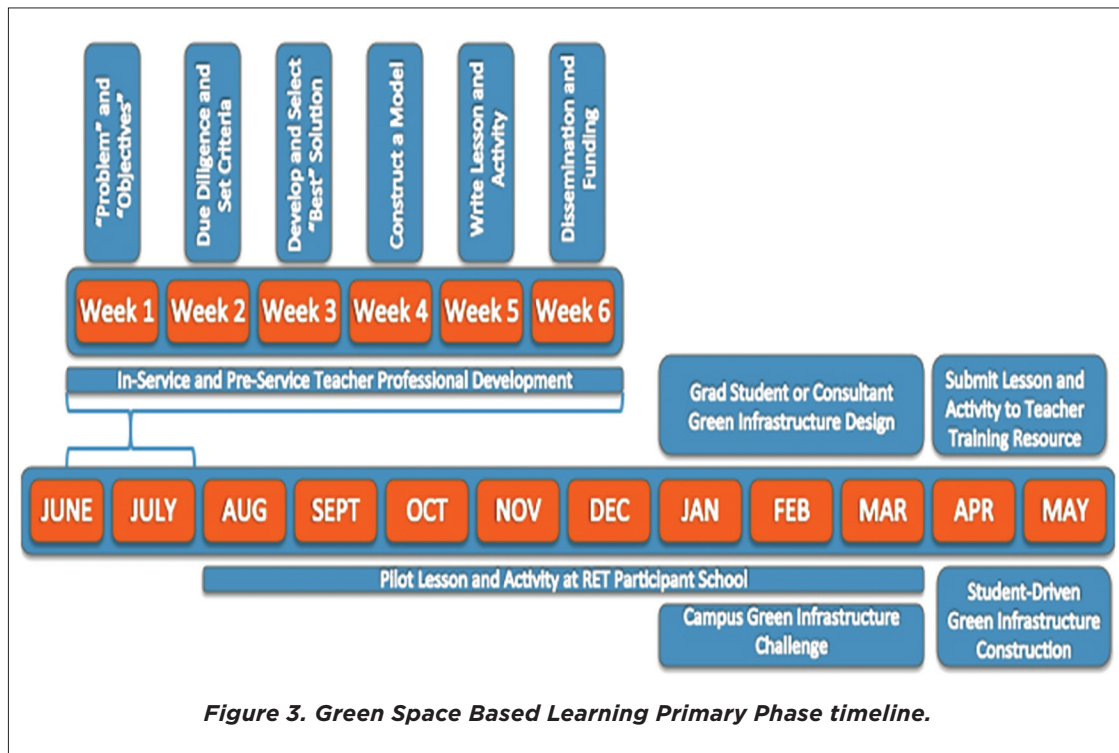
**Step 7: Disseminate Findings**

Dissemination of findings is the most critical component of the design process if true social change is to be realized. Teacher participants present a poster during the last week of their 1st year summer program. The poster session highlights the EDP steps for developing a green infrastructure improvement project on their school campus. Teachers submit their curriculum to teachengineering.org, a teacher training resource, after testing and evaluating with their class the following year. Optimal design solutions are then presented during research group meetings or a lunch and learn for graduate student mentors and consultants respectively.

**Step 8: Redesign if Necessary**

Redesigning is the final step in the EDP and an important iterative component for finding optimal solutions. In the case of a redesign, refer to Step 4, Figure 2.

Figure 3 shows the GSBL Primary Phase timeline which covers one calendar year, beginning with the first six-week summer in the RET program. The primary phase outputs include professional teacher





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development that results in: teacher driven lessons and curriculum writing, a poster presentation, graduate assistant or consultant green infrastructure design, application for external funding, Campus Green Infrastructure Challenge funding, curriculum piloting at teacher’s school, student-driven construction of green infrastructure design, and submission of lessons and curriculum for publication to a teacher training resource like teachengineering.org.

### Green Space Based Learning Model Secondary Phase

GSBL Primary phase teacher participants are eligible for a second summer of participation in the RET program and the GSBL secondary phase takes advantage of this teacher-university partnership. During the second 6-week summer RET program, teacher participants, with direction from a graduate mentor, develop strategies for implementing an open-inquiry or structured-inquiry project that encompasses one academic year. The on-campus green infrastructure project at the participant teacher’s school allows his/her students to participate in authentic scientific inquiry. The initial student project is considered structured because the subject area and constraints (i.e. green infrastructure improvement, project category) have been pre-selected for them. However, students and their teachers have the unique opportunity to work alongside their local university to gather valuable research data and be acknowledged in scientific papers and discourse.

The one-year GI project includes two lessons (Figure 4), the first is designed to engage student participants in collecting system function, monitoring, and performance data and the second is structured around student driven campus and community dissemination. The selected GI project

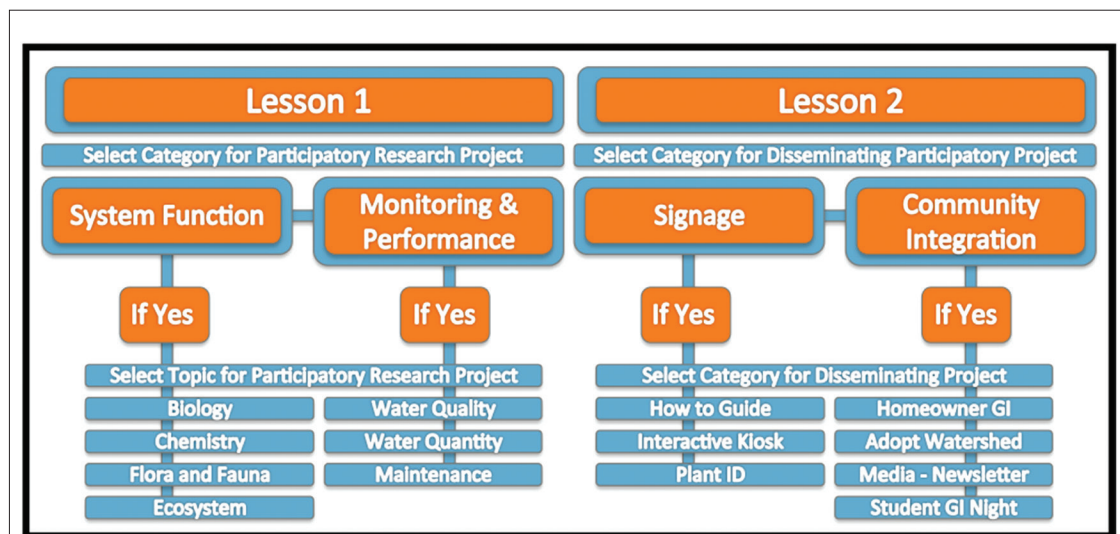
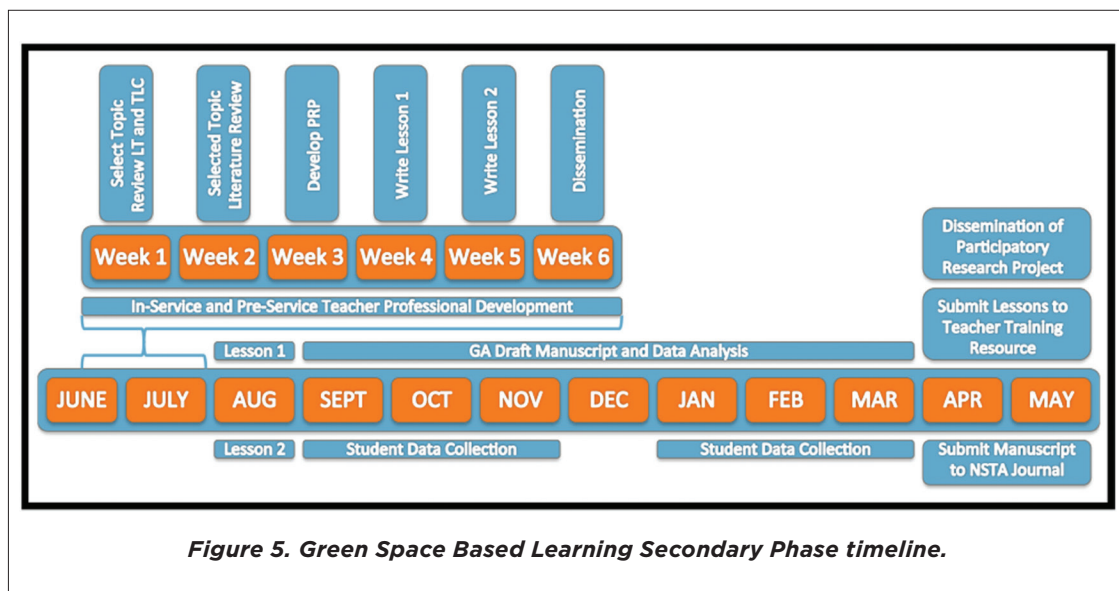


Figure 4. Green Space Based Learning 6-week RET Secondary Phase.



and dissemination lesson allow teachers to introduce new content that aligns with NGSS and/or Common Core standards.

The GSBL model is designed to be self-sustaining and it is the goal of the Secondary phase to strengthen the GSBL participants' ability to perform and instruct engaging scientific lessons and facilitate "open" and "structured" inquiry-based practices beyond the limits of the established program. Like the Primary phase, the Secondary phase covers one calendar year (Figure 5).



**Figure 5. Green Space Based Learning Secondary Phase timeline.**

Within this timeframe, teacher participants introduce students to the green infrastructure project and develop a class schedule for collecting data. Teachers collect this data from their students and provide quarterly data reports to their graduate mentor. The graduate mentors' role is to assist each teacher in submitting lessons/activities and a scientific research manuscript to a peer reviewed journal and teacher training resource.

**Phenomenological Interviews**

Phenomenological based interviewing methods combine life-history interviewing and focused, in-depth interviewing informed by assumptions drawn from a subjects' perspective, allowing for participants to reconstruct and reflect upon their experience within the context of their lives (Bertaux, 1981). Using Seidman's (2006) guidelines for phenomenological interviewing and anecdotal experience with first and second year GSBL participants, six of the RET participants at various stages within the GSBL model (i.e. first year, second year) were asked questions associated with their progress within the program at the end of the summer 2014 RET program during a single 30-90-minute interview.



Individual profiles, were crafted to display coherence in the constitutive events of a participant's experience, to share the coherence the participant expressed, and to link the individual's experience to the context that is being evaluated (Seidman, 2006). Thematic phenomenological evaluation was also completed using open coding on portions of an interview that covered a more limited aspect of a participant's experience (Seidman, 2006). Qualitative analysis software HyperResearch and data processing software were used to analyze the data.

## RESULTS

Table 1 summarizes the GSBL outputs from twelve teacher participants from spring 2011 to spring 2015. During this period, seven bioretention cells were constructed at three public school campuses. Eight of the twelve GSBL participants were part of the RET cohort and took part in the GSBL primary phase (2013/2014). Four non-RET participants either piloted portions of the GSBL model (2011-2013) or instructed informal Green Infrastructure Science Summer Camps (Summer 2013, 2014). All RET participants developed a lesson plan or activity and presented a poster as part of the GSBL 6-week summer primary phase.

### **GSBL Primary Phase Output: Urban Stormwater Management Curricular Unit**

GSBL participants B#, P#, W, and B (Table 1) developed the Urban Stormwater Management Curricular Unit (USMCU) between 2011 and 2013 during two 7<sup>th</sup> and 8<sup>th</sup> grade math research classes and two 6<sup>th</sup> grade agriculture classes. The USMCU includes 2 lesson plans and 5 associated activities (Locicero et al., 2014a-g) to advance students' understanding of urban hydrology and green infrastructure practices, providing them with a real-world application for solving the NAE-GCE. This curricular unit was designed to meet state mandated standards and to be taught within the constraints of the academic year (Table 2).

The curricular unit was also used as instructional material for the 2013 and 2014 GI Science Summer Camp and submitted by GSBL participants W and B after their 6-week summer 2013 RET program. A case study developed by these participants may be found at [teachengineering.org](http://teachengineering.org) and as part of supplemental materials (Appendix A) to this paper.

The USMCU introduces students to the sub-units of the hydrologic cycle and urban stormwater management through two lessons: Natural and Urban "Stormwater" Water Cycles and Green Infrastructure and Low-Impact Development Technologies. Students are introduced to the EDP, design optimal solutions to media type, pervious pavement mix combinations, and plant selection. They first approach the water cycle, and then measure transpiration rates and compare native plant species.

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**Table 1. Green Space Based Learning Participant Primary Phase Outputs. #Teachers participated in either the initial piloting of the program or informal summer program and were not a part of the RET cohort. \* Funding was by outside sources prior to application, \*\*GSBL participant received funding through the RET program to construct their green infrastructure improvement projects.**

GSBL Participant	(C) Curriculum, (L) Lesson Plan, (A) Activity Implementation	Dissemination: (P) Poster, (I) Informal, (F) Formal	Campus Green Infrastructure Challenge	Received Funding	Personal Rain Garden (No. PRG)	Submitted Lesson to Teacher Training Resource
<b>B#</b>	(C) Urban Stormwater Management Curricular Unit	(I) Green Infrastructure Science Summer Camp	Yes (Pilot)	Yes (\$6,300)	Yes (50)	Yes
<b>P#</b>	(C) Urban Stormwater Management Curricular Unit	(F) Piloted Urban Stormwater Management Curricular Unit	Yes (Pilot)	Yes (\$4,300)	Yes, (5)	Yes
<b>W</b>	(C) Urban Stormwater Management Curricular Unit	(I) (P) Green Space Based Learning (GSBL): Implementation of Urban Stormwater Curricular Unit	No	Yes (\$4,300)	Yes, (10)	Yes
<b>B</b>	(C) Urban Stormwater Management Curricular Unit	(I) (P) Green Space Based Learning (GSBL): Implementation of Urban Stormwater Curricular Unit	No	No	Yes, (10)	Yes
<b>M</b>	(L) Demystifying Civil and Environmental Engineering: Unveiling the mystery behind the profession	(F) (P) Green Space Based Learning (GSBL) Framework Implementation	Yes	Yes (\$3,100)	No	No
<b>N</b>	(L) Grand Engineering Challenges: Manage the Nitrogen Cycle and Restore and Improve Urban Infrastructure (A) Leaf Stomata Lab	(F) (P) Green Space Based Learning (GSBL): Stomata Quantities of Florida Native Plant Species	Yes	Yes (\$500)**	No	No
<b>S</b>	(L) Using Existing Green Infrastructure to Understand the Engineering Design Process	(P) Understanding the Engineering Design Process within the Local Watershed	No	No	No	No
<b>J</b>	(L) Rain Gardens Air Quality Impact of Rain Gardens	(F) (P) Weather Stations and Rain Gardens: Linking Climate Change and Adaptation	No	Yes (\$300)**	No	No
<b>K</b>	(L) Reducing Flooding in Urban Green Spaces: An Analysis of Media Fill Composition	(F) (P) Reduce Flooding in Urban Green Spaces Using Rain Gardens: An Analysis of Media Fill	Yes	Yes (2,000)	No	No
<b>T</b>	(L) Water Quality of Urban Rain Gardens	(F) (P) Water Quality Analysis of Urban Rain Gardens	No	Yes (\$1,700)	No	No
<b>S#</b>	(C) Urban Stormwater Management Curricular Unit	(I) Green Infrastructure Science Summer Camp	Yes	Yes (\$1,000)	Yes, (30)	N/A
<b>D#</b>	(C) Urban Stormwater Management Curricular Unit	(I) Green Infrastructure Science Summer Camp	Yes	Yes (\$1,000)	Yes, (15)	N/A



**Table 2. Urban Stormwater Management Curriculum satisfies state and national mandated standards.**

Urban Stormwater Management Curriculum	Next Generation Science Standard Florida Next Generation Sunshine State Mathematics Common Core
Natural and Urban “Stormwater” Water Cycle	MS-LS1-6, MS-ESS3-4, MS-ESS2-4, SC.6.E.7.In.2, SC.7.E.6.6, SC.7.L.17.3, SC.8.L.18.1 (Locicero et al., 2014a)
Natural and Urban “Stormwater” Water Cycle Model	MS-ESS2-4, SC.6.E.7.In.2, SC.7.E.6.6 (Locicero et al., 2014b)
Green Infrastructure and Low-Impact Development Technologies	MS-LS-2-5, MS-ESS3-4, MS-ETS1-1, SC.7.E.6.6 (Locicero et al., 2014c)
Just Breathe Green: Measuring Transpiration Rates	MS-LS2-5, MS-LS1-6, MS-ESS3-3, MS-ESS2-4, MS-ETS1-1, MS-ETS1-3, 6.RP.A.1, 6.RP.A.3, 7.RP.A.2, 8.EE.B.5, 8.F.B.4, 8.SP.A.2, SC.6.E.7.In.2, SC.7.E.6.6, SC.7.L.17.3, SC.8.L.18.1, SC.8.P.8.4 (Locicero et al., 2014d)
Does Media Matter? Infiltration Rates and Storage Capacities	MS-ESS3-3, MS-ESS2-4, MS-ETS1-1, MS-EST1-2, MS-ETS1-3, 6.RP.A.1, 6.RP.A.3, 7.RP.A.2, 8.EE.B.5, 8.F.B.4, 8.SP.A.2, SC.6.E.7.In.2, SC.7.E.6.6, SC.7.L.17.3, SC.8.L.18.1, SC.8.P.8.4 (Locicero et al., 2014e)
Making “Magic” Sidewalks of Pervious Pavement	MS-ESS3-3, MS-ESS2-4, MS-EST1-2, MS-ETS1-3, 6.RP.A.1, 6.RP.A.3, 6.SP.B.5, 7.RP.A.2, SC.6.E.7.In.2, SC.7.E.6.6, SC.7.L.17.3, SC.8.L.18.1, SC.8.P.8.4 (Locicero et al., 2014f)
A Guide to Rain Garden Construction	MS-LS2-5, MS-LS1-6, MS-ESS3-3, MS-ESS3-4, MS-ESS2-4, MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4, 6.RP.A.1, 6.RP.A.3, 6.SP.B.5, 7.RP.A.2, 7.NS.A.3, 7.EE.B.4, 7.G.B.6, 8.G.C.9, SC.6.E.7.In.2, SC.7.E.6.6, SC.7.L.17.3, SC.8.L.18.1, SC.8.P.8.4 (Locicero et al., 2014g)

They investigate the differences in infiltration rates and storage capacities between several types of planting media before designing their own media mixes to meet design criteria. Then they design and test their own pervious pavement mix combinations. In the culminating activity, teams create and install personalized rain gardens (Figure 6). The unit prepares the students and teachers to take on the design and installation of a bigger green infrastructure project to manage stormwater at their school campuses, homes and communities.




**Figure 6. Urban Stormwater Management Personal rain garden activity.**





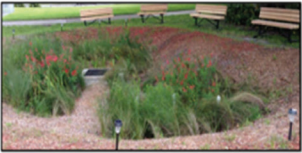
**GSBL Primary Phase Output: Campus Green Infrastructure Challenge**


A second output of the GSBL Primary Phase includes the Campus Green Infrastructure Challenge. The Campus Green Infrastructure Challenge was modified from the EPA RainWorks Challenge 2012 first prize winner, The University of Florida (EPA, 2012b). Student participants were presented with a campus site map (Figure 7), plant selection list, and index cards to record responses to prompted questions. The students selected the site location, debated their concept designs, used a scale drawing to layout their design, excavated the site, integrated vegetative and engineered media layers and installed native and regionally friendly vegetation.



**Overview:** This Challenge provides You, the student, the opportunity to learn more about your local environment, participate in your stormwater management plan, and select a site on campus to build a rain garden.

**Rain Garden:** A rain garden collects stormwater, provides infiltration, evapotranspiration, and groundwater recharge on-site where stormwater runoff is generated.





**Activity 1:** Draw regular routes between classes to reveal the most frequently traveled areas.


**Activity 2:** Place a sticky dot on the site map of an outdoor green space area that you really enjoy and an area that you feel needs some improvement.

● Enjoy      ● Needs Improvement



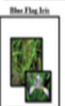









**Activity 3:** Write what you like about your school's campus and what you would like to see in other areas around school. "I like..." "I would like to see..."

**Activity 4:** Draw what you think the campus rain garden should look like. What is your favorite shape?

**Activity 5:** Place a star in the box of your three favorite native Florida plants.



**Plant Selection**

*Figure 7. Campus Green Infrastructure Challenge Activity poster board for student input.*

**Phenomenological Interviews: Individual Profiles**

Phenomenological interviews allowed RET participants to reflect on their experience and provide feedback on the impact GSBL had on them, their teaching, and their community. They were completed with six GSBL participating teachers from two high schools and two middle schools within



**Table 3. Phenomenological interview GSBL Primary Phase model buy-in.**

RET Participant	Phenomenological Interview Excerpt
Nina	“They (students) were more excited about this activity than other lessons/activities... They had a blast, when you have IB kids who are willing to come when they have the opportunity to do their homework during school and they rather do it at home because they want to build a rain garden, that’s buy-in.”
Kerry	“We want the rain to go through quickly so that we don’t have flooding but we don’t want it to go so quick that it is not taking any particulates out of the water or clarifying the water.”
Melissa	“The students had extreme buy-in by the time we did implementation of the project. Out of the total of 66 students that were taught, I had more buy-in with gifted (44) and out of them I had (30) who had complete buy in for after school.”
John	“I think it is upping my stakeholder reach... being a math teacher getting involved with science and actually building something on campus will make me much more visible. Installing signage will make more people aware and they will want to introduce it into their neighborhoods.”
Trish	“It’s awesome making a conscious choice of how to fix a problem that we created and reconstructed an ecosystem so that it is more beneficial to the people in the future.”

the local school district (Table 3). Two of the teachers, Nina, a Pre-IB Biology and Pre-IB Chemistry teacher and Kerry, an AP Environmental Science teacher work at High School A. High School A was one of two sites selected to participate in the Campus Green Infrastructure Challenge, an output of the GSBL model, (Figure 3). The second Campus Green Infrastructure Challenge site, Middle School B provided the GSBL program with two comprehensive science teachers, Melissa and Shawna. The remaining study participants, John, a mathematics teacher, and Trish a science teacher, work at high school C and middle school D respectively.

An individual profile is provided next, reflecting Nina’s experience after she completed her first year and second 6-week summer participation in the GSBL model. Here, the authors clarify their intentions and convey a sense of process and time while grouping responses into logical categories to tell her story.

#### **Individual Teacher Profile: Nina**

Nina, a high school pre-International Baccalaureate Biology and Chemistry teacher, participated in the GSBL model Primary and Secondary Phases between summer 2013 and summer 2015. Nina began her first 6-week research experience by reviewing current literature on bioretention systems and their applicability to solving grand engineering challenges. Nina’s second task was to work in the field at a bioretention research site collecting water quality samples from synthetic stormwater runoff. These samples were returned to the university environmental engineering research laboratory and processed for TN,  $\text{NH}_4^+$ , and  $\text{NO}_3^-$  concentrations. Nina continued to show interest in the research subject, requesting bioretention overview articles and laboratory-based research assignments. She

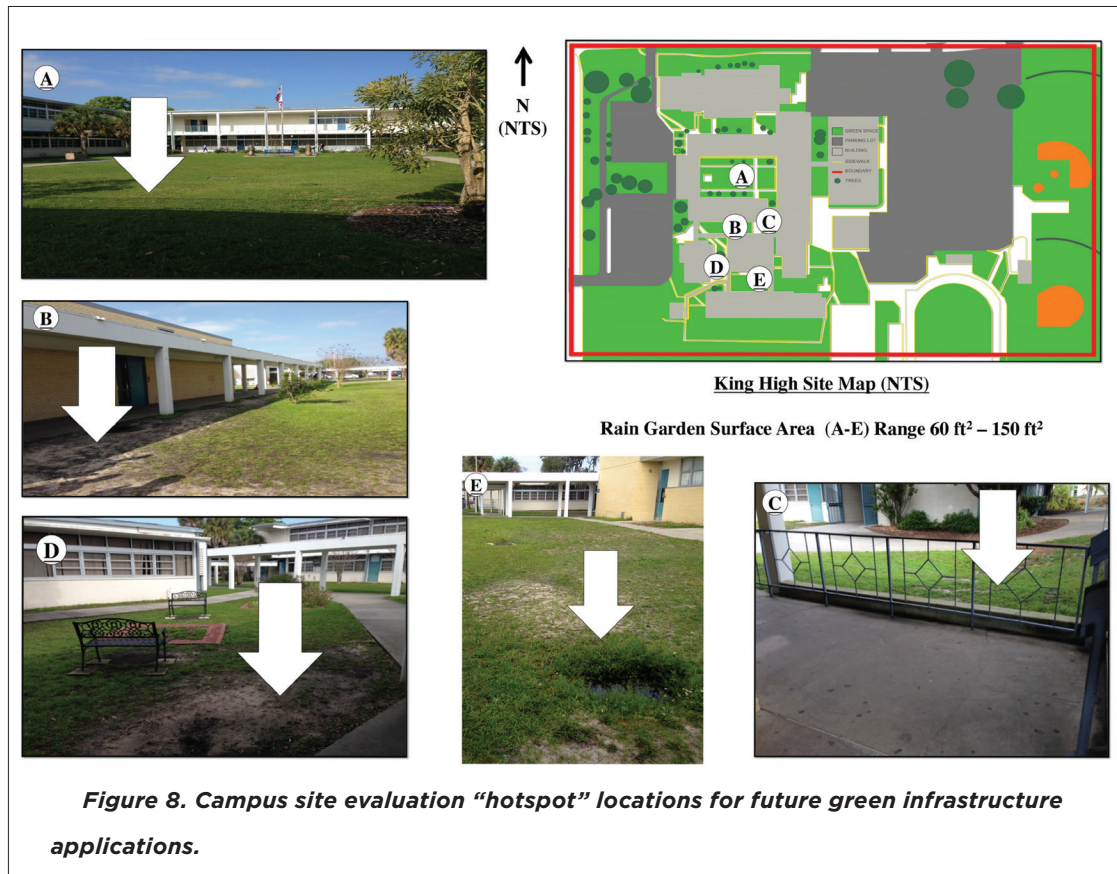


then designed a sampling port for a field-scale evapotranspiration experiment to measure transpiration rates of native plant species. She developed a hands-on activity to compare transpiration rates between native plant species that were currently being studied by her graduate mentor for quantitative performance. Nina developed a method for casting plant stomata using acetone and acetate, creating a surface that could be viewed under a 400X microscope. She developed the Leaf Stomata Lab which compliments the USMCU activity 2: Just Breathe Green: Measuring Transpiration Rates. The Stomata Lab allows students to evaluate the stomata density of different plant species and draw conclusions on shape, size, and quantity of stomata and the relationship to transpiration rates. This lab compliments the evapotranspiration research study at the university and field-scale bioretention site, connecting her students with university level graduate research. In Nina's final week in the summer program she finished installing the evapotranspiration experiment at the University Botanical Gardens and disseminated her experience during a poster symposium. Nina described this summer research experience as allowing her to connect with her students in a different way.

*I engaged them (students) with enthusiasm and in the beginning of the year I told them about working with USF and I have pictures of me with my goggles on, so showing them that I was in school over the summer and that I get to use it in the classroom... I emphasized that this is for research and a lot of them want to be doctors and in science so that helped them as well.*

Nina successfully implemented both the Lessons: Grand Engineering Challenges Restore and Improve Urban Infrastructure and Manage the Nitrogen Cycle, and Activity: Leaf Stomata Lab that she developed. Having significant buy-in from the teacher and traction within the school district prompted the primary author to further engage Nina's high school as a potential future field research site and location for a Campus Green Infrastructure Challenge. The site evaluation provided valuable insight into stormwater related challenges the school faced, locating areas on the school campus that both the principal and facilities personnel felt would be appropriate for green infrastructure application. Five areas were identified (Figure 8) as hotspots or potential areas for green infrastructure implementation and a permit was filed with the local water management district as is required when altering the flow path of stormwater runoff. The university research staff was granted permission by the local school district to apply for a permit on their behalf and was granted a de minimis exemption for proposed bioretention per section 373.406(6), F.S.

Nina's students participated in her Campus Green Infrastructure Challenge, identifying an area on their campus that would benefit from a green infrastructure improvement project. Over 100 students participated in the design and construction, selecting their school mascot as the shape for their system, finishing construction of the project within one school day. Students were directed through several



activities that included drawing regular routes between classes to reveal the most traveled areas, identifying areas on their campus that they really enjoyed and areas that they felt needed improvement. They were then asked to write what they liked about their school's campus and what they didn't like, and finally they were asked to draw how they would like their green infrastructure to look. This started the conversation on implementation and design and built off their stomata lab, which provided students the opportunity to utilize the engineering design process to select plants based on assumptions of evapotranspiration rates. According to Nina, “*They (students) chose the plants based on their characteristics... They had to make inferences based on the collected data and figure out what to use.*”

Nina expressed the value of working on a project that provided a solution to a real-world challenge with local context. In addition, her students were more engaged with the design and construction of the bioretention system than any other project presented to them over the course of the year.

*Being able to actually build the rain garden was an experience that I absolutely enjoyed as well as the kids; they got to feel like engineers. The excitement is the biggest thing; I was*



*actually surprised how excited they were. They were so excited... It made it a more real world application type of thing... it (bioretention system) was something bigger that I could use; it was something they could be proud of and see through the next four years... That's something they can see and say, "I made that."*

In her second year, Nina took on the role of a mentor in the research group, showing interest in facilitating the outputs of the GSBL model to other program participants.

*I've helped out a lot of people this year... from doing it last year, I don't feel as stressed about the lesson plans or the poster because I know exactly what I'm going to be doing.*

During the Secondary Phase of the GSBL model Nina investigated the system function of the implemented bioretention system installed during the Primary Phase Green Infrastructure Challenge. Her lesson: Rain Garden Performance: Vegetative Monitoring looks at the performance of plant species selected and monitors quantitative performance characteristics (i.e., height, canopy area, number of leaves, number of shoots) over the course of the academic year. In addition, Nina developed educational signage for the installed bioretention system and worked with another GSBL participant whom received external funding to install a second green infrastructure project on their school campus in the spring of 2015. Nina has shown interest in continuing to work with USF on curriculum development.

### **Phenomenological Interview: Thematic Grouping**

The phenomenological based interviewing methods allowed participants to reconstruct and reflect upon their experience. Participating teachers expressed their experience in the GSBL model across several thematic groups that are listed in Table 4 and discussed in the next sections.

### **Thematic Group: Understanding of Authentic Research Experience**

One of the objectives of the GSBL model is to provide participants with an understanding of an authentic research experience that they can then bring back and share with their students through lesson development and green infrastructure implementation. This model looks to achieve this objective by engaging teachers in active research projects where they take on the role of "novice researcher" within a university level research group (Feldman, 2012). Several participants had a limited view of what it meant to participate in research and how to translate that experience to their students. Nina intended to receive hands-on training with laboratory instrumentation, advancing her understanding of analytical equipment that her students would be using at the university level.



**Table 4. RET thematic grouping.**

Thematic Grouping	RET Experience
<b>Authentic Research Experience</b>	N and K believed research experience to be laboratory based and expanded their view of authentic research to include literature review, field work, and developing research questions.
<b>Contextualized Learning</b>	Field-scale construction bioretention system provided K the opportunity to build off of her current conceptual framework and develop ideas that align with her student’s objectives. Likewise, T “I really enjoyed that because I felt like I understood more of why we were doing this and how we could bring it to my school.”
<b>Teachers Contribution to Research</b>	M felt she helped facilitate the GSBL objectives by implementing the USMCU and Campus GI Bioretention Challenge within the school year.
<b>GSBL Model Buy-in</b>	K views GSBL as a solution to both educational and environmental challenges; M believes GSBL to be innovative, combining STEM principles, EDP and NOS; T feels confident in bringing engineering content back into her classroom.
<b>Practical Application to Classroom</b>	K readily connects GI and engineering to her environmental science students, M applied engineering design project with the principles of earth systems
<b>Professional Development</b>	K sees the GSBL as expanding her community of practice by championing GI projects throughout the school district; T increased her content knowledge that she now uses in curriculum development; N views herself as a mentor
<b>Green Infrastructure Awareness</b>	This experience provided both K and T with the knowledge and skills required to design a residential rain garden without the direction of the GSBL program experts. J is aware of stormwater runoff and potential GI sites within his community. Both J and N plan to install GI at their next residence.

*I thought I was going to be working in the lab doing some type of research like measurements and calculations and stuff like that, lab materials and techniques.*

Trish anticipated that the research experience would be developmentally inappropriate for her students.

*I expected to learn things that were way over my head... I was really worried about how I was going to take it down so much, because they are so low level, to be able to make my experience valuable.*

As with the scientific method and the nature of scientific knowledge, authentic research includes clearly defined objectives (e.g., literature review, laboratory work, community engagement). However, achieving research objectives is not obtained in any specified order and may include or exclude various methods of scientific evaluation. In her interview, Kerry believed this experience would be laboratory based.

*I expected to have some type of laboratory work... so I was thinking that was something we would do and then you come in and the first thing is the lab jacket and the safety training... and then you're reading articles for 2 weeks.*



Melissa, who recently graduated from the College of Education and participated in graduate level research groups prior to this research study, did not believe that research was restricted to a lab.

*Research is making an observation of something or identifying a problem, (you) observe something different, do background work/literature research to find out if others have noticed this, build a plan of action and implement plan of action.*

### **Thematic Group: Contextualized Learning**

As part of the GSBL model, all enrolled RETs were given the opportunity to participate in the construction of a field-scale bioretention system (i.e. Green Infrastructure Science Summer Camp) and encouraged to engage with the local community through ongoing outreach efforts. This contextualized learning experience provided Kerry the opportunity to build from her current conceptual framework and develop ideas that align with her students' learning objectives.

*One of the first things we did that week was go to (local school) and boom we are getting involved, we are building a rain garden. I knew what a rain garden was and now I had some ideas of different things to test; the plants, the soil, the fill, the water.*

Likewise, Trish benefited from interactions with the local community partnerships.

*I really enjoyed that because I felt like I understood more of why we were doing this and how we could bring it to my school... I've always thought that education shouldn't be just sitting in the classroom. There is so much outside that I can teach them exactly what I'm teaching them in the classroom. Let them hold it, touch it, see it. This is an awesome way for them to see it.*

This approach for contextualizing learning allows expert practitioners to provide guidance to the novice learner and is a key component of constructivism (Kerka, 1997). In constructivist pedagogy, the expert engages with the novice in an activity of mutual interest, allowing for the novice to add new experiences and understanding of new ideas onto their current conceptual framework, revising previous knowledge (Kruse, 2009; Salvin, 2003; Collins, 2002, Karplus, 1997). The process has been shown to be effective when incorporated in a manner where new knowledge and skills will be tested (Billett, 1996). In her interview, Trish stated the following.



*I liked working on the rain garden and being able to have conversations with you (GSBL Expert). We could do it this way or even talking about the lesson we could do hands on being there, having the opportunity to bounce ideas off you while we were actually making the rain garden.*

The contextualized learning experience provided both Kerry and Trish with the knowledge and skills required to design a residential-scale rain garden without the direction of the GSBL program experts, moving forward from novice researcher within the community of practice. In her interview, Kerry described her experience.

*We went home and built rain gardens... It doesn't have the plants in it yet but that's our next thing to do, we've worked on it for 3 weekends. The gutters were draining, coming from two portions of the roof down to one and it was... always flooded, it was muddy. There was no grass, so we were like, "lets just tear it up," we got the gravel, the sand, and we have a big pond and I was telling my husband what's going on, "its (stormwater) taking all the fertilizer," and we have a pest guy come out and spray the lawn...and all those pesticides and things going right into the water.*

### **Thematic Group: Teachers Contribution to Research**

The GSBL model applies the apprenticeship model, where teachers are paired with a graduate mentor to deliver authentic and original research (Hunter, 2006). The inquiry aspect of an authentic research experience and fast paced structure of the 6-week program left many participants unclear of their role in the first days and weeks of the program. Teachers often operate in a well-structured environment with prescribed objectives and timetables for deliverables.

*Nina: If you come in and you don't know what to expect and if you don't hear it or see it then you are confused for a while and then you get this resentment, why am I here, I don't know what I'm supposed to be doing, high frustration. Teachers are very structured, we must do this, this, this and this, so when you throw them in a situation where we might do this we might do that.*

Hunter, (2006) found in a large-scale Research Experience for Undergraduate (REU) study that practical understanding of how research is done contained personal-professional development. This thematic group included the coding, "confidence in ability to do research" and "contribution to research." Teachers quickly adapted to the GSBL community of practice and began to display signs of personal and professional development through reviewing relevant literature, design of experiments, and defining aspects of research to which they could contribute.





*Trish: The day that you showed you were missing water quality out of that big huge lesson plan, I was like, I did do something productive so I do feel like I contributed to it. I feel like there is more work to do but that I contributed... It helped when you were like make a physical model, I can do that. I needed a target of something to work on. I'm excited because I see it being used in my classroom and my kids understanding which was one of my concerns initially.*

*Kerry: I guess by reading the scientific articles the first weeks when we didn't really know too much in the beginning... (Advisor) keeps sounding interested in using clay in a different type of layer to put at the bottom instead of the plastic or the membrane layer that was more expensive. I feel I can contribute to that.*

*Melissa: I assisted with the goal and implementation, because you (GSBL Mentor) built a rain garden before, but being able to do it within the curriculum abiding by the principles (GSBL model). I feel that I've helped in implementing the vision... and we did it together and made it work, and it worked phenomenally well, we took what we learned from that and we were able to share that.*

#### **Thematic Group: GSBL Model Buy-In**

All the teachers interviewed bought into one or more aspects of the GSBL model. For instance, participants found the program to tie into their curriculum, bringing together STEM principles, the engineering design process, and nature of scientific knowledge.

*Kerry: I was very lucky that it is easy to tie into my curriculum and I feel like I have a very good understanding, a very deep understanding of it. I think this is something that we are going to see, you see it happening a lot in other states and different groups pushing them and I could see what we're doing getting the word out in different communities and when there is problem area, rain gardens could be the solutions.*

Traditional K-12 applications of scientific principles tend to be cookie cutter procedural instruction or generic in the sense that the referenced material does not apply to the region within which the subject is being taught.

*Trish: Florida is surrounded by water but it's not in the science curriculum in a way that is applicable and makes sense to our students. I like the fact that I have an environmental real world problem that is happening in my kids' community and I can say look this is what's happening,*



*this is what's occurring, how can we fix it and I can use the Nature of Science and the steps of scientific inquiry and I can help them understand a problem and lead them to solving a problem with the end goal being a rain garden. So they actually get to be involved in the steps and that is exciting to me, because I think too many times when we are teaching in the classroom, they are like this is pointless, "why are we doing this?"... Now I have something directly, "you want to know why, this is why we are doing it." I think the content is great but I think solving an actual problem has more value and seeing how the problem can be solved. That's my favorite part of the summer; I get to take engineering to my classroom but in a very real way*

One of the innovative elements that separate the GSBL model from other learning tools is the hands-on engineering application that benefits their local community. The model presents students with the opportunity to apply the engineering design process to not only design solutions to solve real world problems, but implement their design within their school campus.

*John: I think that is great when you're trying to do the project-based learning... I support sustainable initiatives, so to be involved in something that is impacting schools and then to have students bring it into their community, homes and such, I think it is a great idea. Through the research, the problem, the cost of stormwater runoff the way that is affecting our water quality I mean that, water is pretty important it is something that I have bought into.*

### **Thematic Group: Practical Application to Classroom**

The GSBL model identified the engineering design process (EDP) as a critical component for preparing K-12 teachers to teach engineering content and develop quality lessons and curriculum. The fundamental elements of the design process are to identify and define a problem or objective, perform due diligence, develop possible solutions or methodology, select a best solution based on a set of pre-determined assumptions and physical constraints, construct a model (physical prototype or computer), test and evaluate optimal solutions (iterate), disseminate findings, and re-design if necessary.

Teachers found the "problem," (1) restore and improve urban infrastructure, and (2) manage the nitrogen cycle, applicable to their field and content knowledge. As participants developed within their community of practice, they felt comfortable bringing their experience back to their classroom and applying it to the "solution" of green infrastructure.

*Kerry: There is a lot of interest between what it is that I am trying to learn to teach my environmental science students and the research within the rain garden. It is easy to make that connection and I will easily bring this back to the classroom and talk about*



*my experiences with it... Some of the topics include: water conservation, water quality, hydrologic cycle, percolation vs. stormwater runoff, where the water goes after it rains, soil composition, components of soil, the growing of the plants, the growing of the edibles and the herbs and the mosquito repelling plants and all of that.*

*Melissa: I want to focus on how the students are learning, and this project focuses on incorporating engineering within the current curriculum, I liked watching my students learn and have them use the techniques and skills that I taught them, thinking like a scientist, the principles of earth systems, and applying it to the engineering design project.*

*Trish: I have always been really interested in water and I used to teach AP environmental and all last spring I was like we have to do something outside, we have to do something with water, we have to get them outside they need to burn off some of this energy.*

#### **Thematic Group: Green Infrastructure Awareness**

The overarching goal of the GSBL model is to mainstream green infrastructure practices as a stand-alone or complimentary solution to managing stormwater runoff. This mainstreaming requires an innovative and collaborative approach to educating the public and the GSBL model was structured to increase community participation beginning with the well-structured K-12 environment. This approach allows the community to participate in the design, selection, construction, and maintenance of public space, transforming underutilized green spaces within a community into multi-purpose environments. The success of this and other outreach efforts is specifically important considering the state of our nation's infrastructure and decline in students' tendency to pursue careers within the STEM field. The educator is the first of a series of influential stakeholders who reach a large number of people within their community.

*John: Since the beginning of the GSBL project I am more aware of and mindful of the way I treat water and being wasteful, noticing rain gardens. I know a lot more about rain gardens and their impact, when I'm out driving and I see some natural plants and the way it is set up, I'm thinking, did they purposely make a rain garden, I see that in some highway construction where I live and I'm thinking, is that a rain garden. How big is that, how did they come up with that? ... I live in a community where I can't control any of the outdoor space (townhome). When I move into a different residence, it is something that I would consider, rain barrels, rain gardens, and going to implement this into my classroom, which then can affect exponentially because I'm teaching 170 students.*



*Trish: I made connections and relationships with people that I worked with that I really enjoy and I learned a new skill, how to build a rain garden, how to plan it out, how to apply it to my curriculum that I didn't have before. I really enjoyed it. I even tell my family about it... I got them excited and interested in it... There is a bad-flooding problem off of my aunt's roof, let me check with (GI Expert) and make sure it makes sense... I told my cousin and now we are going to build a rain garden in his yard. I was explaining it to him and he was like, that's what we need, right here. So, he's going to buy all the stuff and I am going to do the plan.*

*I brought my little cousin with me; I had so much fun. When I was taking my cousin home, we were talking about it, "You are going into 6<sup>th</sup> grade and this is something that you need to understand." He asked so many questions and science is something that really interests him, He was like, "that was really cool, thank you for taking me." He had a really good time and that made it valuable and exciting to me that he was learning because I could see my students doing the same thing.*

*Nina: I absolutely enjoyed it and learned something that I can use... when I buy a house I'm going to be putting a rain garden in because I can put the plants that I want to put in there and beautify it and I think they are great, less water, mini ecosystems.*

### DISCUSSION

#### GSBL Stakeholder Groups

At its full implementation, GSBL would combine K-12 students, teachers, and community members with local scientists, engineers, planners, municipalities, design professionals, graduate students, and professors in evolving transdisciplinary community-based participatory research projects with multiple symbiotic outcomes. The GSBL Model dependent groups are K-12 schools and a university or college with a National Science Foundation (NSF) funded RET summer teacher program or equivalent. The participation of the subsequent stakeholder groups benefits the longevity and resilience of GSBL, however group participation is independent of the potential success of outcomes from a science educator's perspective. Here we are specifically interested in how teacher and student participants are affected by GSBL projects.

The benefits (Table 5) of GSBL can be realized from a K-12 school perspective through teacher professional development, reduction in maintenance and energy demands, and promoting innovative educational experiences for attracting students. School campuses are typically underutilized as community spaces and innovative locations for research.



**Table 5. Green Space Based Learning model stakeholder benefits.**

<b>Green Space Based Learning Stakeholders</b>	<b>Stakeholder Benefits</b>
K-12 Schools (multiple school participation preferred but not required)	Teacher Training and Professional Development, Administration Attracting Students, School Board Site Maintenance, Heating and Cooling Savings
Universities and Colleges (RET program required for teacher training)	Community Participatory Research, Support Innovation, Long-term Monitoring, Thesis and Data Collection, Educational Outreach
Consultants	Competitive Marketing Strategy, Attract Clients and Federal and State Projects, Connect with Research University or College, Implement New Design and Construction Practices (low risk)
Municipality	National Pollutant Discharge Elimination System (NPDES) Annual Reporting, Total Maximum Daily Loads (TMDL) Requirement, New Numeric Nutrient Criteria Regulation
Water Management District	Educational Outreach, Long-term Monitoring for Reliability, Resilience, Vulnerability
Department of Environmental Protection	Educational Outreach, Long-term Monitoring for Reliability, Resilience, Vulnerability
County Extension Services	Educational Outreach, Homeowner Implementation and Workshops
Special Interest Groups	Educational Outreach, Water Quality Monitoring, Improved Community Space

Universities and colleges may benefit from K-12 student driven data collection through field research sites. Consultants can utilize the partnership as a marketing mechanism for attracting new clients and to obtain funding while at the same time participate in exploratory design and implementation for future projects in a low-risk environment. Municipalities may benefit from regulatory compliance through reducing stormwater runoff and improving water quality. Water management districts, environmental protection offices, and county extension services benefit may be realized as a result of increased educational outreach, homeowner implementation, and long-term monitoring of the systems for use in future permitting.

**Impact on Student Learning**

The findings of this paper describe a particular way in which a federally funded RET program can be structured to positively improve pedagogical practices in the traditional and outdoor classroom environment through the GSBL model; therefore, indirectly improving student learning of STEM concepts. Student learning can be reported both directly by means of evidence of student gains in achievement scores and indirectly through changes of teacher’s pedagogical practice, which in turn affects students’ learning (Petty et al., 2016). The latter supports the findings of a number of mixed methods studies evaluating the direct impact of RET learning models to analyze anticipated student achievement (Blanchard et al., 2008; Klein, 2009; Beilock et al., 2010; Hughes et al., 2011; High et al., 2012; Agarwal et al., 2015). These methodologies include measuring RET program



outcomes and raising student awareness, evaluating mentoring style and levels of participation, and improved teacher perception and increased understanding to engage students in meaningful classroom experiences.

The GSBL model participants reported that the 2-year experience affected their pedagogical practices by “bringing current real-world data and research into the classroom, and providing students with hands-on inquiry based application within a local and global context.” For example, one teacher described their experience as, “completely changing *their* pedagogical perspective.” Similarly, Petty (2016) found that teacher interviews provided insight into how the RET program has affected their teaching pedagogical practice and impacted student learning. Furthermore, GSBL model participants felt their students’ “hands-on experiences and real-world applications created increased ownership, imagination, creativity, and innovation.”

The GSBL model was designed around the Water Awareness Research and Education Research Experience for Teachers program with measurable outcomes detailed in Table 1. Teachers surveyed after participating in the design and implementation of a rain garden at their school campus (i.e. Campus Rain Garden Challenge) reported, “increased student’s level of engagement and buy-in, with students feeling empowered by doing something that benefits the environment, their school, and community.” Similarly, an RET site at Indiana University-Purdue University Indianapolis used high school students’ research projects and increased awareness of applications of current STEM research and careers to evaluate their program (Agarwal et al., 2015). The GSBL model experience changed several teachers’ view of science, increased perspectives of anthropogenic impacts to the environment, provided a greater understanding of the connectivity between engineering and science, and brought university level STEM research to the K-12 classroom.

The GSBL model participants identified one-on-one mentoring with graduate students, post-doc students, and faculty, and co-mentoring with other GSBL model participants to be “very insightful, providing opportunities to explore new ideas and engage in collaborative efforts.” Participants also found benefits from being engaged in a research group setting and enjoyed field experiences for conceptualizing research and coming up with new ideas. Hughes (2011) supports the claim that both mentoring style and level of participation in the community of practice, similar to the environment created through the GSBL model, affected teachers’ ability to translate practical experiences to their students. Likewise, Blanchard, (2008) found that immersion in RET experiences, coupled with appropriate follow-up activities during the school year, expands teachers’ professional skills and networks, and is thought to improve their students’ science learning.

Beilock (2010) found that teachers’ discomfort and lack of confidence in teaching math concepts have negative impacts on student learning and perception of STEM fields. Further, research on RET professional development and research experiences showed that engineering research positively



affects teachers' abilities to impact student learning (High, 2012; Klein, 2009). The GSBL model teachers have shown confidence in teaching STEM concepts, through increased content knowledge base, professional development, and understanding through participating in an authentic research experience.

## CONCLUSIONS

The Green Space Based Learning (GSBL) model provided K-12 teachers with a university research experience that supported the development of lessons and activities that introduced students to the engineering design process and scientific inquiry. The GSBL model has engaged nine in-service middle school teachers (grades 6-8), four in-service high school teachers (grades 9-12), three pre-service teachers, and a LEAD teacher from five different schools within the district. With approximately 400 K-12 students and teachers engaged in both formal and informal educational activities, the GSBL model has resulted in the design and construction of seven field-scale bioretention systems, completion of two Campus Green Infrastructure Challenges, publication of the Urban Stormwater Management Curricular Unit, funding for 3 green infrastructure projects, and implementation of approximately 70 personal bioretention systems.

Teacher participants successfully completed many of the GSBL outputs, including the development and implementation of both lessons and activities that support green infrastructure, facilitation of a Campus Green Infrastructure Challenge, a student driven design and construction of a bioretention system on their school campus, and lessons for evaluating the performance of the installed system as a continuation of the original design project. This experience was something that the teachers expressed as something they enjoyed and were excited to take part in, providing an engaging opportunity to work outside of the traditional classroom setting and solve real world problems.

While this study reported teachers' perceived impact of the GSBL model on student learning of nearly 400 students in the local school district, further research is needed on the actual impact on students. Additionally, research exploring the longevity of impact of the GSBL model would be a valuable contribution to the literature, especially as it relates to strengthening of pedagogical practices over time.

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