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## Fostering Significant Learning in Sciences

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## Fostering Significant Learning in Sciences

### Abstract

The new global economy depends on workforce competencies in science, technology, engineering and mathematics more than ever before. To prepare a strong workforce, attracting and educating underrepresented minority students in science is a challenge within our traditional American educational approach. To meet this challenge, fostering significant learning in science that nurtures 21<sup>st</sup> Century skills in students is crucial. The purpose of this study was to analyze the effectiveness of a set of teaching and learning approaches that foster significant learning in sciences. Using a new introductory environmental science course in urban water quality management, the effect of a set of learner-centered teaching approaches, including hands-on learning, scientific inquiry, frequent feedback, and critical thinking exercises, was analyzed. The results of the pre- and post-course survey questions together with formative and summative assessments showed that our students' cognitive learning skills and interests in learning science were significantly improved.

### Keywords

critical thinking; deep learning, education, experiential learning, pedagogy, teaching

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### Cover Page Footnote

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Attracting and preparing more underrepresented minority students in Science, Technology, Engineering and Mathematics (STEM) is one of the challenges of the American 21<sup>st</sup> Century education goals to meet the country's projected growth in science and engineering employment (National Academies, 2011). In this goal, the number of STEM graduates needs to increase by 20 to 30 percent between 2006 and 2016 (Atkinson and Mayo, 2010). To meet this challenge, educators need to go beyond employing the traditional approach for teaching and learning as well as assessing success (Bain, 2004; Kuh, 2008; Wehling and Schneider). In the traditional methods so called lecture approaches, teachers serve as the primary source of knowledge while learners serve as passive receivers of large amounts of information (Bandura, 1989; Kramlinger & Huberty, 1990; Reeves, 1994).

The traditional way of gauging student's success typically based on access, retention, graduation and grade point average is no longer sufficient to measure success. This approach is often not performance-based, and does not measure what students will be able to do at the end of the course and beyond.

Whereas in non-traditional approaches typically comprising of lesser lecture format, teachers serve as facilitators, and students are in control of their learning (Duffy & Jonassen, 1992; Jonassen, 1998; Siemens, 2006). The literature includes several methods of non-traditional approaches towards educating students, but limited data are available that speak to the relevancy on attracting and preparing underrepresented minority students in STEM areas.

The effectiveness of a set of teaching and learning approaches in fostering significant learning in students, including underrepresented minority students in STEM sciences may depend on various factors, which can be discussed by grouping them into three categories. The first one is "misconception". Student's attitude towards sciences determines their interest in science. Many students develop negative attitudes towards sciences mainly due to some misconceptions. Some may think science is as collection of facts or "truths". Others consider science as a difficult subject and not relevant to their lives at the present time (Salta & Tzougraki, 2004). Some may even think

intelligence in science is fixed, and that they might need to be gifted to learn science. Students coming from introductory science courses often feel such misconceptions (NRC, 1997; Palmer, 1999; Mason, 1992). Misconception is generally the result of incorrect understanding of ideas, objects or events that are constructed based on a person's experience (Seligin, 2012). For example, a student may think he/she does not like life science because he/she is not good at it. Nevertheless, one cannot be good at a given discipline without practicing or gaining skills through trial and error. Many researchers also concluded that once a misconception has been formed due to previous bad experiences, it is extremely difficult to change such cognitive thoughts using traditional pedagogical approaches (Eggen & Kauchak 2004; Thomson & Logue, 2006).

The second understanding is that teaching and learning approaches play an important role in addressing science misconception and nurturing active learning (Fink, 2003; Bain, 2004). The lecture format invites students to listen and take notes as well as regurgitate information from notes. Such fact learning and memorization may not lead to learning that is transformative. In contrast, the transformative teaching integrates active learning approaches in which students learn more when they try to teach or assess others than when they listen solely to lectures (Felder & Brent, 2003; Mezirow, 1997; Taylor, 2000). Nevertheless, several studies indicate that active learning, direct participation or experiential learning beyond the walls of the classroom, whereby students wrestle with real-world problems provides ripe and salient opportunities to construct new knowledge, while gaining skills that promote social responsibility (Astin *et. al.*, 1999; Ehrlich, 2000; Kolb, 1984; Lombardi, 2007; Saltmarsh, 2005; Vogelgesang and Astin, 2000). More recently, the collaborative research of social scientists and neuroscientists related to active learning have led to new associations and discoveries in mapping cognitive development in the adult brain which provide direct evidence of how the brain retains information after active learning (Kanai & Rees, 2011; Lövdéna *et al.*, 2013).

The third and last factor that determines student interest in science is the content and design of the course materials. In

designing the introductory level science courses to address science misconception, Duff and associates (2004) indicated three main challenges: (1) the range of skills, knowledge, and attitudes to be developed in students, (2) the range of students' academic preparation, and (3) the range of learning styles or attitudes students may bring with them to classes. The introductory courses are intriguing when the content is important, relevant and current to the learner's real life experiences. The course must also engage students with challenging questions relevant to the society. For example, in an introductory environmental science course, one of the challenging questions would be why our society is facing more serious environmental challenges today compared to past given that the fluctuating energy prices and accelerating climate change is threatening the wellbeing of human kind and other life forms. Further, the course must invite students to explore other major environmental problems such as smog, hazardous waste sites, and ozone layer depletion while evaluating how one's daily activities can contribute to solving or exacerbating those critical environmental issues of the 21<sup>st</sup> Century.

Further, in designing relevant course content that foster active learning, the learner's academic background and interest must be taken into consideration. Many students come from different academic backgrounds with different attitudes towards sciences like chemistry and biology. When students do not feel confident in mastering the content of these hard sciences, they may try to develop superficial or strategic learning approach to just memorizing facts in order to meet the course requirement. For example, in an interdisciplinary environmental science course, a basic understanding of life science, chemistry, physics and math is required. Most underrepresented students may not necessarily have a strong foundation in all these core areas. As such, the course design must integrate skill-based, situated and authentic learning approaches (Herrington & Oliver 2000; Kim & Hannafin, 2008), which includes hands-on, experiential learning; service learning discovery/inquiry based learning, case-based or problem-based learning. Recent studies confirm that problem-based learning course design encourages students to adopt deep or active learning approaches, whereas lecture-based learning

course design encourages students to become passive learners (Chen & Hu, 2013).

In summary consideration of all three categories of factors, including students' misperceptions and attitude toward science and their previous experiences, teaching and learning approaches, and course design are crucial to create significant learning environments in STEM sciences. Such consideration significantly affects student perception as well as student motivation in underrepresented minority students approach to learn STEM disciplines. In this study, all three categories were considered.

### **Theoretical Framework of the Research**

Two concepts of learning theories are known: teacher-centered and student/learner-centered. The most common approach of a teacher-centered pedagogy is information transfer using lecture format. This is often considered a traditional approach in which students receive instruction passively and the teacher is in control of the content and delivery. Student learning emphasizes rote memorization. Examples of teacher-centered approaches include the ones that are based on objectivism (Reeves, 1994), instructivism (Reeves, 1994), behaviorism (Ertmer & Newby, 1993; Watson, 1913) and cognitivism (Bandura, 1989). It must be noted that behavioral-based active or experiential learning is not a teacher-centered approach if students are in charge of the design and delivery of their learning activities.

Cognitivism learning theory focuses on structured thought process, including how people think, understand and gain knowledge. In order to achieve the most efficient learning environment, it stands to reason that in a problem solving approach, information must be presented in an organized manner. In the case of addressing environmental problems, students must learn how to solve ill-defined and complex problems, which requires inquiry-based or learners-centered approaches. Examples of the learners-centered approaches include humanism (Rogers, 1969), constructivism (Piaget, 1953) and connectivism (Siemens, 2006). In these learner-centered approaches, students are responsible to develop their own new

knowledge, and the instructor serves as a facilitator (Duffy & Jonassen, 1992; Jonassen, 1998).

This study mainly focuses student centered learning theories, including cognitive constructivism and connectivism approaches. There are two constructivism theories: cognitive constructivism (Piaget, 1953) and social constructivism (Vygotsky, 1962; Powell & Kalina, 2009). Both approaches are inquiry-based approaches; the learners actively construct their own new knowledge based on prior knowledge or experience. The teacher is a facilitator, but students are in control of their own learning as well as approaches to solve ill-defined problems. This transformative learning approach invites learners to make their own new meaning by connecting the new theoretical concepts with prior experience through critical self-reflection.

In connectivism learning approach, learning occurs through recognizing the connection in learning as well as sharing knowledge. This learning theory argues that knowledge is distributed with a network and the learner must make connection to build knowledge (Siemens 2006). The connectivism learning theory depends on peer-based learning, which can be designed for both face-to-face and online learning communities.

Both cognitive constructivism and connectivism teaching strategies are recognized to have a great effect in self-regulated learning (Powell & Kallian, 2009). Self-regulated learning fosters student's curiosity to create new meaning from what they have learned. Significant or transformative learning requires curiosity, thinking and intention to construct new knowledge. According to the constructivist theory, knowing is an adaptive process, which organizes the individual's experiential world (Mayer, 1992; Hendry, 1996).

In general, effective teaching and learning method must create a constructivist and connectivist learning environments that create adaptive learners, because solving today's complex environmental issues requires adaptive expert. It is also recognized that effective implementation of constructivism and connectivism teaching strategies require technology (Karagiorgi & Symeou, 2005). Effective use of computer technology is required in the digital age for the preparation of underserved

students in sciences by creating conducive constructivism and connectivism learning environments.

The objective of this study was to analyze the effects of a set of teaching and learning approaches that foster significant learning in the introductory course of environmental sciences. The approaches included inquiry-based and problem-based active learning, integrated course design, nurturing curiosity at the beginning of the course, teaching scientific method, reflection, and peer-based learning.

In this study we considered two research questions and one hypothesis testing. *First*, can inquiry and problem-based learning foster significant learning in STEM specifically sciences? *Second*, can engaging students in various hands-on learning activities improve student learning goals including foundational knowledge, integration learning, application learning, human dimension, and learning how to learn? The hypothesis being tested is applying inquiry and problem-based learning can foster significant learning in sciences. The null hypothesis is there is no difference between pre- and post-course assessments in student learning goals.

## **Methodological Frames of the Research**

### **Study Design**

The change in students learning goals were assessed based on a newly developed environmental science course at the UDC, a Historical Black College and University located at the nation's capital Washington DC. The pre- and post-course assessment applied to the undergraduate class of mostly underrepresented minority students. Histogram analysis was applied for the normality test. The result of pre-course assessment is normally distributed, whereas the result of post-course survey questions is skewed to the right. Based on the pre-course data set, we applied two-tail student t-test to assess the effect of the set of teaching and learning approaches, such as course design, stimulate curiosity, scientific inquiry and problem-based, group project and frequent feedback, and teaching critical thinking. The method of course assessment and student success focused on formative and summative assessments, and students' self-

assessment using anonymous survey. In addition, we applied another set of survey questions that was designed to assess student's change in learning approach and their satisfaction with the course. Student's answers to the survey questions during the midterm formative assessment were compared with that of the final summative assessment.

### **Course design**

A skill-oriented introductory environmental science course in urban water quality management was designed for non-science majors and implemented at the UDC in spring semester 2013. We engaged students in various learning activities including, but not limited to (1) critical thinking, (2) problem solving, (3) data analysis and interpretation, (4) laboratory analysis, (5) scientific method, (6) writing technical report, and (7) oral presentation. The course content includes interaction of integrated urban wastewater system (storm water runoff, sewer system, wastewater treatment plant, and receiving waters), water quality assessment, best management practices, low impact development, sustainable living, and data mining. This course is relevant and timely for urban dwellers in the most densely populated older cities such as the Washington, DC.

Students were invited to learn the fact that urban water quality is one of the pressing environmental challenges facing the District of Columbia as well as other old cities worldwide. Currently, all main waterways of DC are impaired mainly by combined sewer overflows, urban stormwater discharges and leakage of aging wastewater system infrastructure. Consequently, many of our nation's water ways do not meet the designated water uses, which are swimmable and fishable water quality objectives. It has been reported that the cost to make improvements to abate urban water quality problems arising from stormwater discharges and combined sewer overflows in 32 states including the District of Columbia is estimated at \$44.7 billion (EPA, 2002). Further, Gallup poll depicts US worry more about water quality issues than global warming (Saad, 2011). To meet these environmental challenges, infusing such integrated skill-based introductory course in the undergraduate curriculum is essential.

Furthermore, even if we all know that water is the most important substance in our lives, many people take it for granted. This course was designed such that students acknowledge such beliefs and explore that everything human beings do is literally a function of water. It is, therefore, important to ensure that our usable water resources are sustainable because we do not have a replacement for it when it is gone or unusable. The course also provided insight to the illusion that water is free and abundant. Current research demonstrates that water is a finite natural resource and that water demands outstrip supply by 2030 (Watson, 2012). The challenge of water resources management in the 21<sup>st</sup> Century is the shift from supply management to demand management (Watson, 2012), and from quantity and quality related public health assessment to psychological distress in certain groups of the society (Wuticha & Ragsdaleb, 2008; Stevenson et al., 2012).

Finally, an urban water quality course was selected because the proposed course content was relevant to the daily activities of the learner and thus can foster significant learning in sciences in underrepresented minority students residing in an urban setting.

### **Stimulate curiosity**

Creating curiosity at the beginning of the course was a focus of this study. Several studies depicted that curiosity infuses students with the determination and need to figure out or learn about how things work and why they work a certain way (Bain, 2004; Wang, 2011). Creative mind-set is also the result of endless curiosity. On the 1<sup>st</sup> day of the class, our main goal was to stimulate excitement about learning environmental sciences specifically urban water quality, provide students a sense of classroom dynamics, and establish course expectations. This was done using the so called "invitational syllabus" or "promising syllabus" (Bain, 2004). In this unique syllabus approach, students were invited to address an ill-defined problem that was relevant to their daily life activities and how the course would help them get prepared to address such a big problem that is not limited to the course itself. Students were also invited to discuss

careers in sciences as a means to stimulate their interests. To further encourage students to make explicit connections between the course content and their lives, we applied inquiry and problem-based learning approaches.

### **Scientific Inquiry and Problem-Based Learning**

In this study, we taught scientific inquiry through problem-based learning approaches, which include analytical lab analysis to nurture student's positive attitude toward science. In the beginning of the course, many students from non-science majors did not have a sound understanding of the relevance of scientific method in the area of their majors. To address this deficit, active learning by hands-on approaches was employed.

Prior to learning new theoretical concepts, students were invited to make their hypothesis, collect data, analyze results, and make conclusion about their hypothesis. Students were expected to write lab reports following all hands-on lab exercises. This engaged and experiential approach demanded that students utilize reflection and meaning-making as they went about discovery. When students did not receive lectures on this particular problem, some may feel challenged to solve the problem and interpret their results. The main purpose of this type of inquiry and problem-based learning approach was to encourage students to fill in their mental and cognitive gaps by using literature review, peer-to-peer learning, consulting books or online publications, and reflecting on what things mean. Further, it encourages students to develop holistic learning approaches, such as constructivism or connectivism.

### **Group project and frequent feedback**

Following the lab project and a series of computer labs on data analysis, we divided students into groups of two to four to conduct a group project that encompassed hypothesis testing, sample collection and analysis, literature review, data analysis and interpretation, conclusion extracting, writing technical reports, and PowerPoint presentations. We encouraged students to conduct comparative analysis of real situations. They collected and analyzed water samples from their home or nearby water sources for a set of water quality parameters and provided

justification of their findings based on existing published works. In addition, students were asked to test very simple but important hypothesis, e.g. tap water has more orthophosphate than Rock Creek water found in Washington DC.

Subsequently, students were invited to discover the sources of orthophosphate and write a complete report and receive just in time frequent feedback on their report, but received a grade on the final version the report. We allowed three targeted feedbacks communications before grading. The purposes of three targeted feedback communications allowed students opportunities to reflect and make sense of learning opportunities. At the end of the course, students created and shared a PowerPoint presentation on their findings, which simulates conference style professional presentation. At the end each student was required to assess their peer's presentations as well as receive feedback.

### **Teaching critical thinking**

Critical thinking is one of several learning and innovation skills crucial for preparing students for the 21<sup>st</sup> century workforce. The way students think affects the way students learn, and their problem-solving skills. Problem solving skills are part of critical thinking. In this study, our teaching method incorporated learning activities with an emphasis on students' critical thinking skills. According to Kennedy et al. (1991), critical thinking is represented by skills of analyzing arguments, making inferences using inductive or deductive reasoning, judging or evaluating, and applying or making decisions or solving problems. This implies that teaching critical thinking means teaching mainly higher order thinking which includes analyzing, evaluating and applying.

There are several ways of nurturing critical thinking in students. In this study we applied the Socratic method, critical thinking questions, and hands-on experience. The Socratic teaching method focusing on higher order or critical thinking skills during all class discussions was emphasized. Both before and after class discussions, we encouraged students to analyze, evaluate and apply their knowledge based concept questions or critical thinking questions. Each class discussion started with

concept questions instead of traditional approach of listing course content. We assume that starting a class discussion with concept questions created curiosity and encouraged students to think critically. At the end of each class discussion, students received additional open ended concept questions, also termed as critical thinking questions, to continuously engage them in higher order thinking. According to Lynch et al. (2001), students need to give up their old ways and adopt new ways of thinking about the world in order to develop critical thinking skills. In contrast, such a shift in students thinking is not easy to stimulate using the traditional education approach as the main emphasis is lecturing and note taking. Further, we engaged students in hands-on learning experience. When students start with hands-on activities without prior knowledge of theoretical concepts, they will have more questions than otherwise, and this approach stimulates critical thinking and self-regulated learning.

### **Assessment**

Based on the six learning goals indicated in Fink (2003), we assessed the effectiveness of the proposed teaching and learning strategies in fostering significant learning in the 16 students enrolled in the urban water quality management course. The six learning goals include foundational knowledge, application, integration, human dimension, caring, and learning how to learn. We assessed these learning goals using pre- and post-course survey questions, initial and final progress test survey questions, writing lab reports, group project, PowerPoint presentation, practical, and written examinations. In addition, we applied another set of survey questions for the qualitative and quantitative assessment of student's satisfaction as well as change in their learning approach, attitude to scientific inquiry, and progress in personal development in critical thinking, and problem solving skills. All tests and assessment was based on open ended questions and hands-on analytical and computer lab exercises. The significance difference of the pre- and post-survey questions was analyzed using student t-test.

## Results and Discussion

Based on qualitative and quantitative data, we analyzed the effectiveness of the proposed teaching and learning approaches in fostering significant learning. The result of pre- and post-course survey questions received from 13 out of 16 students enrolled in the course is given in Table 1. The result of student t-test statistical analysis shows that the proposed teaching and learning approach had significantly improved students' learning goals ( $P < 0.05$ ), which means we accept the hypothesis being tested that experiential learning foster significant learning in minority students enrolled in STEM sciences. Figure 1 illustrates the gap between pre- and post-course results.

Table 1. The result of pre-course and post-course survey questions: agreed or strongly agreed

	Learning Goals	Pre-course (%)	Post-course (%)
<b>I</b>	<b>Examples of Foundational Knowledge Goal</b>		
1	I can define water quality standard and water quality criteria	23	100
2	I can define integrated urban wastewater system	31	100
3	I can describe correctly interaction of urban wastewater systems	15	100
4	I can apply data mining concepts to analyze or predict urban water quality trends	8	92
5	I can apply most basic analytical technologies, but not the advanced one	23	92
6	I can identify the difference between water quality standard and water quality criteria	23	100
7	I can use scientific inquiry to collect, analyze, and discuss information related to practice and policies that impact the environment	46	100
8	I can analyze best management practices that improves urban water quality	39	100
8	I can analyze best management practices that improves urban water quality	39	100
9	I can describe the problem of combined sewer overflows and solutions	8	100
10	I can describe the difference between point and non-point source pollutions	8	92

<b>II</b>	<b>Application Goal</b>		
11	I can apply basic biological processes in treating wastewater	8	92
12	I can use data mining concept to analyze urban water quality issues	16	92
13	I can identify storm water management solutions to address water quality issues	15	100
<b>III</b>	<b>Integration Goal</b>		
14	I can describe the interaction of urban waste water management	0	92
15	I have basic understanding of system approach in addressing social, economic and environment to address water quality issues in DC	23	100
<b>IV</b>	<b>Human dimension goal</b>		
16	If given opportunity, I would like to work as a water quality expert to clean the water ways of DC	39	39
17	Sustainable living means for me not getting rich	23	32
18	For me, learning about water quality management is much more important than learning to manage water quality challenges in DC	8	38
19	I have invaluable perspective on how to apply my knowledge to help others in addressing water quality issues in DC and beyond	23	84
<b>V</b>	<b>Caring Goals</b>		
20	I want to live sustainable living to save the earth planet	92	100
21	It is my responsibility to help the next generations meet their need	92	100
22	I have been interested in becoming water quality expert to address water quality issues	38	23
<b>VI</b>	<b>Learning how- to- learn Goals</b>		
23	I can learn a body of content without learning the concept, and I can learn a concept without learning how to use in thinking something through.	8	39
24	I feel learning more when all my questions get answered instead of having more new questions to think through	38	46
25	When I start a homework problem, I am more likely to try to start working on the solution immediately instead of fully understand the problem first	54	31
26	When I have read the course materials and memorized facts, I assume I have learned something	46	38

The result shows that most students agreed the proposed teaching approach significantly improved their learning goals in foundational knowledge, application, integration, and human dimension.

If we examine student’s feedback for one of the survey questions pertaining to foundation knowledge goals in the application of scientific inquiry (Figure 2), 46% of students agreed that they know how to use scientific method in the pre-course survey. Later in the post-course assessment, 100% of students agreed that they know how to use scientific method,

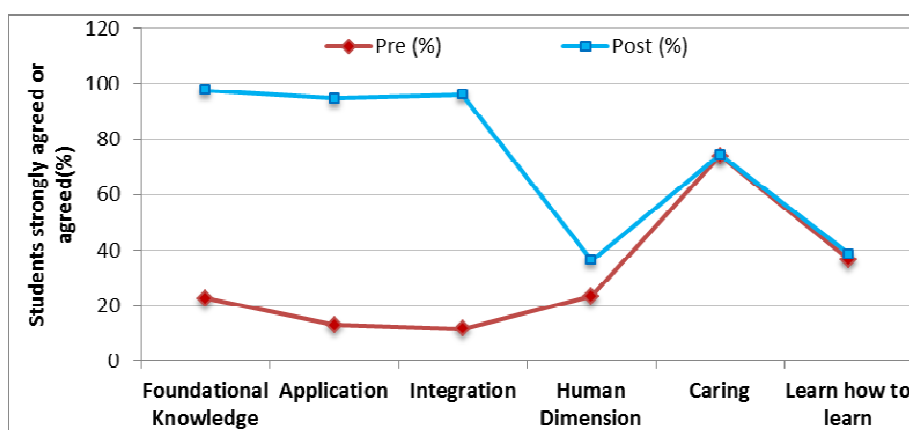


Figure 1. Pre- and post-course survey questions result (average of each perceived learning goal)

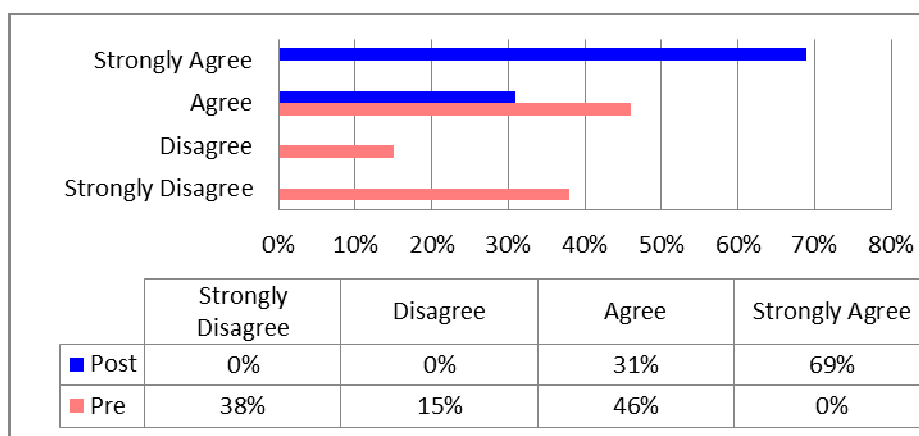


Figure 2. Foundation goal: I can use scientific method to collect, analyze and discuss information related to practices and policies that impact the environment.

collect, analyze and discuss information related to practices and policies that impact the environment. This shows that all students perceived they can apply scientific method to the real world.

In application goals (Figure 3), 84% of students agreed that they want to apply what they have learned during this study in order to help others to meet their need in terms of water quality and quantity.

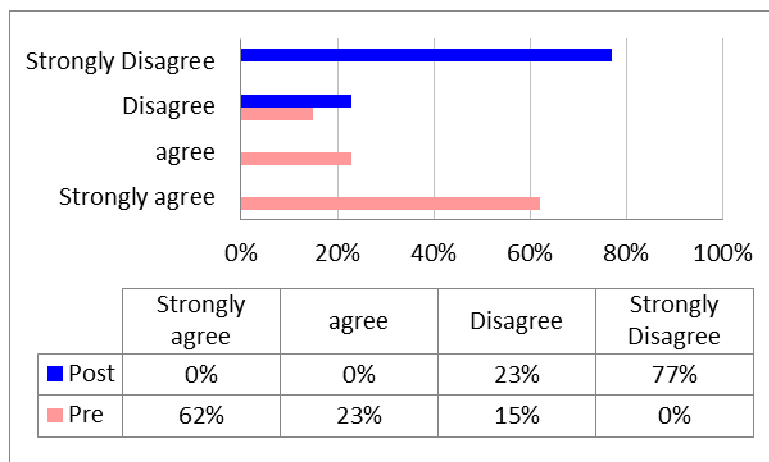


Figure 3. Application goal: Question 13 - I can identify storm water management solutions to address water quality issues

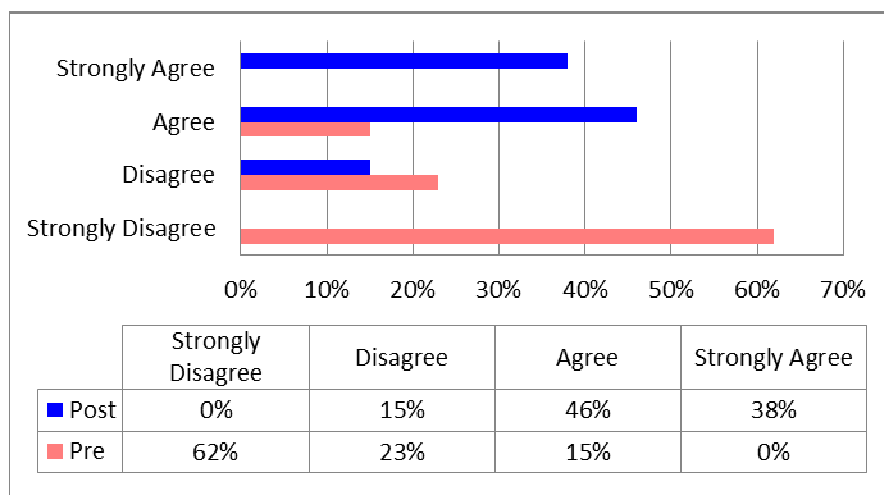


Figure 4. Human Dimension Goal: Question number 19-I have invaluable perspective on how to apply my knowledge to help others in addressing water quality issues in DC and beyond

The result of survey questions pertaining to “caring” and “learning how to learn” goals is also intriguing. In terms of “caring goals”, student’s feedback to questions 20 and 21 depicts that most students (about 92%) agreed that they care about sustainable living and saving earth planet for the next generation to meet their needs. In terms of “learning how to learning goals”, there is no clear difference between pre- and post-course assessment (Figure 1). As illustrated in Table 1, the responses to “caring goals” are (in general) consistent and higher than the ones to “learning how to learn goals.” except question 22. This is consistent with the recent change in US curriculum, where students start learning about environmental stewardship at an early stage of their elementary or middle school years.

Finally, in “caring and learning how to learn goals”, the difference is low between pre- and post-course assessment as compared to foundational goals (Figure 1). Question 22 was designed to assess if students have interest to become water quality experts. In the pre- course assessment some students thought they have, but after post course assessment less students have interest to become water quality expert which might be due to self-realization.

For further validation of student’s satisfaction, we administered additional survey questions near the beginning and end of the semester as progress test to measure the change in student human dimension and cognitive learning goals. These additional tests complement pre- and post-course survey. Figure 5 is consistent with Figure 1, where 100% of student agreed or strongly agreed that they understood the concept and will apply it to solve problems. In other words the application goals of this course are met. Figure 6 shows that in the final test, most students agreed that it is easier for them to learn concept than to memorize facts.

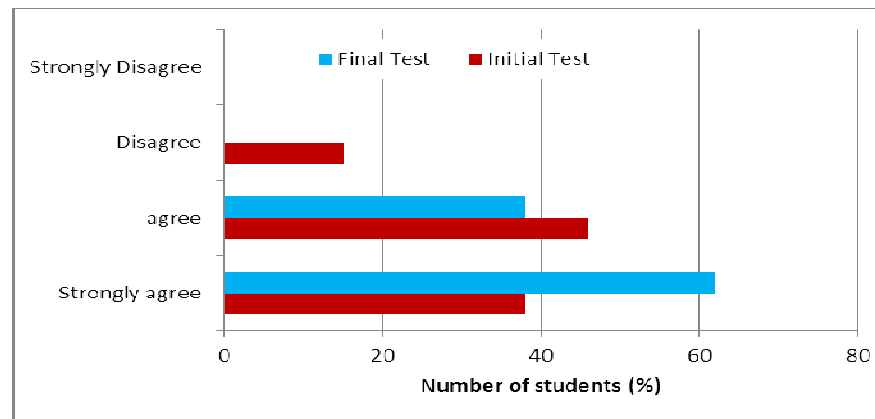


Figure 5. I clearly understand the scientific method and will apply it to solve problems and make decision

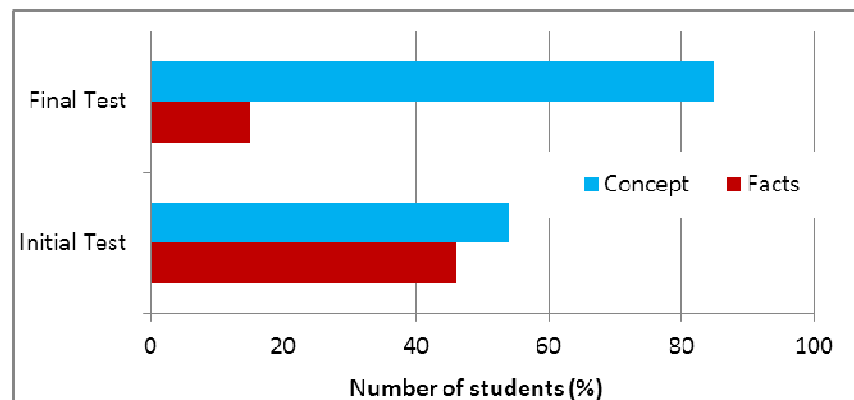


Figure 6: Shift of learning approach: I find it easier to learn facts or concept

To test the overall assessment of student satisfaction both near the beginning (Figure 7-A) and end (Figure 7-B) of the course, we asked students if the course was life changing. Based on the final survey questions, the result shows that 85% of students agreed or strongly agreed that this course was life changing (Figure 7), which depicts that most students were satisfied.

Students' academic performance in terms of grade and thinking was also monitored based on formal tests. We administered four tests during and end of the semester. Student's records show a continuous improvement (Figure 8). Of course, the letter grade A or B itself is not enough to confirm what students' be able to after the completion of the course and

beyond. Nevertheless, the result is consistent with the result of post-course survey assessment (Figure 1).

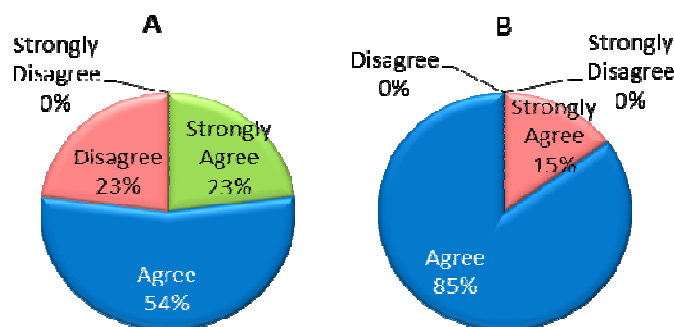


Figure 7. This course is one of the life changing courses I have ever taken as it makes me think how to apply knowledge than learning facts; A-Initial assessment; B-final assessment

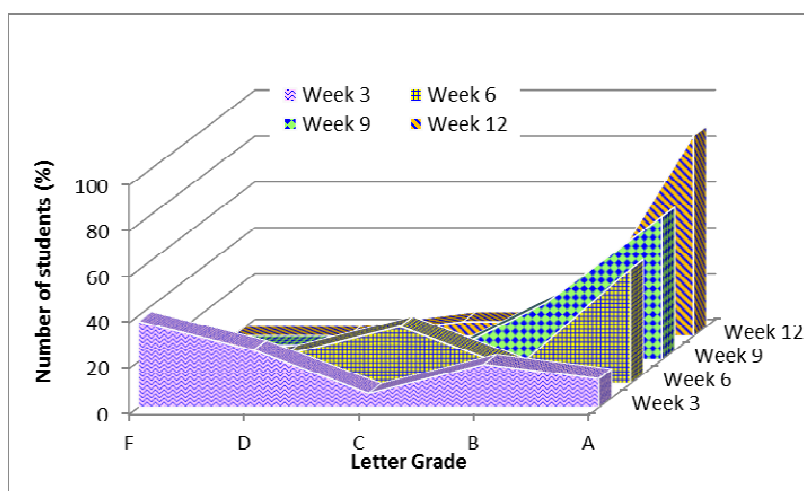


Figure 8. Summative assessment grade (A > 90%; B = 80 -89%; C= 70-80, D= 60-70, F <59)

We also observed a continuous improvement of student thinking levels throughout the semester as they received frequent open ended questions and just in time frequent feedback.

## **Conclusions**

In order to assess the effectiveness of non-traditional teaching and learning method, the proposed study designed and implemented an experiential teaching and learning for a science course. This study demonstrated the relevance of experiential learning to address the significant issue of how to foster significant learning in all students including underrepresented minority students in STEM sciences. The results addressed the two research questions as well as the hypothesis being tested. The result depicts that the constructivism learning theories plus hands-on activities, scientific inquiry, group project, teaching critical thinking, frequent feedback has significantly improved student's learning in foundational, application, and integration goals. It was also observed that students take a deep approach when the course content invites them to solve ill-defined problems that are relevant and necessary, and intriguing to their daily experience. Based on the pre- and post-course assessment as well as formative and summative assessment, we can draw the following specific conclusions:

- Appropriate course design with inquiry and problem-based teaching improved student's cognitive learning skills.
- Applying student-centered learning theories such as constructivism and connectivism fosters transformative and significant learning.
- Engaging students in hands-on and inquiry-based problem-solving activities is very effective in attracting and preparing underrepresented minority students in sciences and technologies.
- Teaching critical thinking through hands-on activities helps students change their learning approach, from memorizing facts to exploring concepts.
- Engaging students in hands-on lab project right at the beginning of the course helps students to bridge academic theory and real-world practice. In this experiential learning approach, students learn the theoretical concept by contemplating and reflecting on their experiences.

In general, to foster significant and transformational learning in sciences in both mainstream and underrepresented minority students, the course content needs to be relevant to the bigger purpose than the course itself; students need to be encouraged to adopt active learning approach; have a sense of confidence that they can learn the new skill but feel free to try and fail and receive frequent feedback. The constructivist and connectivist teachers need to focus more on concept questions that are ill defined, but intriguing and relevant to learner's daily lives to nurture the 21<sup>st</sup> Century skills such as ingenuity, team work, critical thinking, and problem solving skills.

There were a few limitations associated with this study. One limitation was that there was no larger sample pool and nor control sample. To overcome this limitation, we conducted pre- and post-course assessment based on all students enrolled in the proposed course (n=16). Significant student learning gains, both observed and perceived, were assessed based on comparing the mean difference assuming normal distribution. Further analysis on a larger sample size to compare the traditional lecture-based learning approach with the proposed student-centered approach will help us determine the significance of these initial findings.

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