Bringing Soil Mechanics to Elementary Schools

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1. Introduction

Studying math and science have commonly been perceived as an unpleasant experience for students at the primary and secondary education levels. Particularly, in the U.S., young students of all races and socioeconomic backgrounds are disinterested in the math and science disciplines[1] and schoolwork.[2] As a result, according to the 2011 Trends in International Mathematics and Science Study (TIMMS) survey results for the U.S. fourth graders, only 47% and 49% of students achieved the "high" international benchmarks in math and science, respectively.[3,4] The level of achievement decreases as students progress in the education system.[1] At the eighth-grade level only 30% of students achieved the high benchmark in math and 40% in science.[3,4] Most students are not drawn to solve a math or a physics exercise if they do not connect such problems with their daily life experiences or with improving life for themselves or for others.[1,5] For example, prior to being engaged in the activities described in this paper, only 50% of students at a Brooklyn elementary school passed standardized state exams of math in grades 3—5. It is evident that the schools in urban districts need to find ways to better engage students in their own learning. To make science and math subjects relevant to children, teachers and other professionals within the educational field must make the content a necessary tool that students will use to solve real-world problems that they care about.

It is also essential that students develop a positive disposition towards math and science in elementary school while they are still at a stage of being naturally eager to learn. Early development of interest and academic talent in science and math guarantees that students will perform better as they progress in the educational system. In fact, exposing elementary school students to engineering through simplified hands-on experiments is one of the better ways to improve their performance in math and science and excite them about pursuing technical careers.[6] In addition to exposing students to engineering, creating and applying imaginative approaches that employ technical concepts can ignite students' passion for learning and discovery. For example, by sharing the building blocks and societal benefits of his graduate research, the principal author of this paper has made elementary school students engaged in this effort keenly aware of his fascination for working in the field of soil mechanics. Similarly, one of the co-authors, who is an elementary school teacher, has shared his passion for technology by engaging students in the use of 3D modeling, 3D printing, and LEGO-based laboratory activities. The students have found the excitement of the graduate student and teacher for their chosen disciplines to be highly contagious.

Creation of partnerships involving colleges of engineering, industry, and elementary and secondary schools[1] can enable K-12 students to become aware of the limitless possibilities related to their future careers; especially when they receive challenging science, technology, engineering, and math (STEM) learning opportunities in elementary school grades while they are still of an impressionable age. For example, geotechnical engineering, which employs mathematics, solid mechanics, and fluid mechanics, can be adapted in the elementary school curriculum with some imagination and effort. In fact, some soil mechanics lessons are already introduced to elementary school students in several educational systems. Specifically, permeability of soils is part of the elementary school curriculum in countries such as Egypt, India, Iran, and U.S. By a judicious integration of engineering concepts and modern technology, students can be engaged in hands-on activities that are educational, interesting, and inspirational for them.

The technology component of the work presented here serves as an entry point for elementary school students to be introduced to engineering. It is widely observed that students are naturally drawn to iPads, LEGO robots, and even 3D printing. These tools, considered fun by students, can serve as hooks to engage them in learning. That is, the educators must leverage these *contemporary* manipulatives to engage students in the learning of the required standards-aligned curriculum. Unfortunately, technology has not changed the outcomes in the K-12 educational environment unlike it has in sectors such as business, transportation, communication, etc. To bring significant change in education through technology, classrooms need to evolve beyond the use of computers to create word documents, spreadsheets, power point presentations, or photo-collages. Students need to experience the use of computers as real-world problem-solving tools (e.g., program microcontrollers, design 3D objects, and create multimedia presentations). For example, as shown in this paper, soil mechanics can be used as a bridge between the required science and math content and the cool, “tech-toys.”

The main goal of this paper is to describe several soil mechanics-related activities conducted with elementary school students. The activities were designed and conducted by a graduate student (Fellow) and his partner teacher under a National Science Foundation (NSF) funded GK-12 Fellows grant. The Fellow exposed second, third, and fourth grade students to fundamental concepts of soil mechanics within the geotechnical engineering context as experienced by students in their own surroundings and environment. Applications of soil mechanics in construction were also presented. The activities presented in this paper include: (1) a soil permeability study where students learn that the flow rate of water in soils depends on soil composition and grain size; (2) shallow and deep foundations studies wherein students make their own soil profiles and test the bearing capacity of various foundation systems; and (3) an erosion in rivers study wherein students design and make buildings, and place them in the vicinity of a stream to predict their stability. All activities support the required science curriculum at the elementary school level. The Fellow and teacher conducted the lab experiments, challenged students, and helped them to understand their assignments.

In this effort, robotic tools including LEGO NXT and 3D printers are utilized as technology platforms to actively engage students in sense-making, data collection, design of scaled-models of residential and commercial buildings, and developing a concrete conceptual understanding of the topics addressed. For example, for the soil permeability investigations, an experimental setup is devised that uses a LEGO NXT controller and an ultrasonic sensor to facilitate automated data collection. Moreover, when conducting the "river erosion model" studies, students take ownership of their learning since they: (1) propose designs for their buildings; (2) have their designs digitally fabricated; and (3) make decisions about the placement of their buildings on a riverbank, modeled on a table-top hydraulic bench using clay and sand. The river erosion model demonstrates water's ability to change the surface of the Earth and students can visualize the impact of erosion on their built environment. The setup can also enable students to investigate the ability of various types of foundations to withstand a flood event. Students find these experimental tools particularly attractive and inspirational, which makes the class more enjoyable. Hands-on activities motivate students to learn the required basic concepts of science, e.g., a unit on Earth materials. Furthermore, the automated data acquisition system provides an interactive learning environment that allows students to focus on the technical concepts rather than the drudgery of manual data collection.

Our classroom experiences demonstrate that students are motivated to study STEM disciplines through simplified geotechnical engineering exercises. Moreover, the use of LEGO NXT toolkit and 3D printers enhances student learning, reasoning, and analytical judgment. Specifically, to gauge students' knowledge gains, for the soil permeability activity, pre- and post-activity evaluations are conducted. The results of the evaluation reveal that through participation in the activities students (1) gained a reasonable understanding of engineering principles and (2) became motivated to study science and math. Finally, for the soil profiles, foundation, and erosion table activities, students are assessed through individual tag questions and description of phenomena and results.

2. Soil Mechanics in K-12 Education

Over the past decade, the engineering education literature has documented the introduction of soil mechanics concepts in elementary school classrooms to stimulate students' creativity and ingenuity. For example, Elton[7] presented classic soil mechanics to a general audience under the *Soils Magic* theme. Other examples of geotechnical engineering outreach include Fiegel et al.[8] in elementary schools, Elton et al.[9] in middle schools, and Fiegel[10] in high schools. Fiegel and DeNatale[11] and Hanson et al.[12] also presented case studies of outreach in undergraduate freshmen courses to stimulate students' interest to pursue careers in geotechnical engineering.

The implementation of soil mechanics activities in elementary school classrooms enables the introduction of basics of physics, mechanics, and math naturally, while allowing students to form a permanent association between science and math with real-world situations. In general, the implementation of such activities in K-12 environment comprises: (1) the recognition and formulation of a problem; (2) the design of a solution; (3) the creation and testing of such solution; (4) the optimization and re-design to reach an optimal solution; and (5) the formulation of solid arguments to justify the chosen solution. All of these tasks assist elementary school students in developing an appreciation for the profession of engineering, tools and techniques used by engineers, and their work environment. More importantly, these tasks can be used to apply students' curricular knowledge of science and math to real-world problems that capture their imagination and interest.

3. Soil Mechanics Activities

The soil mechanics activities, described in this paper, are conducted by following the steps of the *Engineering Design Process* (*EDP*), which was specifically designed for the K-12 audiences[13] and is shown in Figure 1. In actual practice, engineers do not necessarily follow a rigid step-by-step interpretation of the EDP. Nevertheless, having a formal framework is useful for elementary school students in their pursuit to *model* and perform as engineers. The EDP requires students to follow the following steps.

(1) **Ask:** students identify a problem and investigate what others have done.
(2) **Imagine:** students brainstorm possible solutions and choose the best one.
(3) **Plan:** students draw diagrams and make a list of materials needed.
(4) **Create:** students follow their plan and create a model that can be tested.
(5) **Improve:** students recognize what works and what does not, as well as come up with different options to improve their design.

Through the Fellow-teacher collaboration in four classrooms of second, third, and fourth grades, 60 students were introduced to the field of soil mechanics and conducted the aforementioned three activities. Each activity required 90 to 135 minutes, divided into two or three 45-minute class periods, on consecutive weeks. During the first period corresponding to each activity, essential concepts related to the activity are introduced. Next, the students are challenged to identify the problem (*ask*), *imagine* possible solutions, and make a *plan* to implement the solution. In the second and third periods, the students implement the plan (*create*) and seek to *improve* upon their initial solutions.

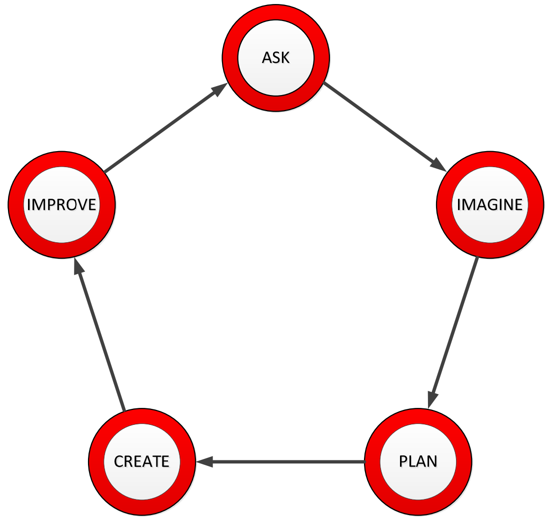

Figure 1: Engineering design process (EDP) adopted in elementary schools[13]

To identify and imagine solutions for the problem, the Fellow begins by introducing the basis of the problem and its implications within the context of real-world geotechnical engineering practice. This permits the elementary school students to gain confidence and familiarity with the subject matter. Next, the students are divided into groups of four-to-five each (except in the erosion table activity which requires individual work). Since these activities by their nature are interactive, each student is assigned a specific task, such as setting up the experiment, controlling the pace of the experiment, recording data, or performing calculations.

To assess the educational benefit of the activities in the students, different assessments are conducted after the completion of each activity. For example, in the soil permeability activity, pre- and post-activity assessments, with identical questions, are conducted immediately before and after the activity, respectively. In the soil profiles and foundation activities individual qualitative and oral assessments are conducted. Finally, in the erosion table activity, a questionnaire is completed by the students referring to the initial and final scenarios. The evaluation questions test the subject matter proficiency using typical, exam-like questions.

3.1. Soil Permeability Activity

The soil permeability topic is part of the water cycle unit, typically included in elementary education. The soil permeability activity supports the "Elementary Science, Core Curriculum in K-4" learning standard for New York City by demonstrating that water runs at different flow rate across different soils. The learning goals of this activity include that the students can: (1) compare the grain size of different soils; (2) relate the effect of pores size to permeability of the soil media; and (3) recognize the importance of soil permeability in civil engineering. To follow the EDP in this lesson, the Fellow begins by sharing with the students several examples of landslides and failures in retaining walls and earth dams (*Ask*). The students are challenged to identify various factors that influence the aforementioned failures in civil engineering structures (*Imagine*). A discussion ensues concerning the role of soil permeability in civil engineering, thus introducing the students to the underground water behavior and complications arising from it (*Plan*). Next, the Fellow highlights salient points, e.g., (1) the implementation of accurate drainage systems to relieve water pressure, such that the students are able to suggest feasible solutions to avert these failures, and (2) the elaboration of appropriate structure design that, together with the drainage evaluation, permits the students to recognize how engineers choose optimal solutions (*Create*). The discussion ends when the students demonstrate an awareness of the need to *a priori* measure the soil permeability, treat the construction bed to produce desirable soil permeability, and use soil permeability information to design a failure-proof structure (*Improve*).

The lesson is followed by the introduction and explanation of a soil permeability test apparatus. Under an NSF funded summer research program for teachers, the partner teacher had designed a special transparent permeameter for this activity. Several permeameters containing gravel, sand, and play marbles are setup in the classroom to illustrate the effect of grain size on the flow rate of water (Figure 2). The entire class identifies the type of soils to be tested. Before the students begin to perform the tests, they are challenged to predict which soil samples yield the highest and lowest permeability, thus providing further support for the *imagine* step of the EDP. Moreover, every student is asked to sketch three different testing scenarios consisting of three permeameters, with each containing a different soil sample; thus providing further support for the *plan* step of the EDP. Next, the permeameters are saturated which allows the students to visualize the flow of water in soils and revise their initial predictions. A falling head test follows in which the rate of discharge is measured using (1) a clock and a ruler and (2) an ultrasonic sensor whose measurement is displayed using the LCD screen of a LEGO NXT controller. Collecting the data using two methods allows the Fellow-teacher team to discuss with the students the accuracy of two measurement methods and the role of error in everyday measurements. These tasks further support the *create* step of the EDP and permit the students to analyze the pros and cons of using a computerized data acquisition device. After completing the first round of tests, the students notice that testing only once may result in measurement uncertainties. Thus, some students repeat the test a second time, which further supports the *improve* step of the EDP.

The learning outcomes of this activity include that the students are able to: (1) compare different porous soils in grain size; (2) discuss the effect of pores or voids in the permeability of the soil media; and (3) recognize the importance of soil permeability analysis in civil engineering projects. To assess the benefit of the activity, identical evaluation questionnaires are administered immediately before and after the activity. The students are asked to identify soil samples with the largest grains, more voids, and the one where the water runs faster. Similarly, they are asked to predict the soil that yields maximum permeability. Finally, since sensors are used to improve measurement accuracy, the students are asked to comment on the suitability of using the ultrasonic sensor in a permeater test apparatus.

The evaluation results indicate that the students increased conceptual understanding of soil permeability and were enthusiastic about the use of LEGO-based test apparatus (Figure 3). Furthermore, the activity allowed the students to apply their knowledge of math to a real-world problem. This is important for (1) students' learning, (2) developing an affinity to STEM subjects, and (3) establishing a permanent connection between STEM studies and engineering at a young age.

Figure 2: Elementary school teacher and students conducting a falling head permeability test using a LEGO-based laboratory apparatus

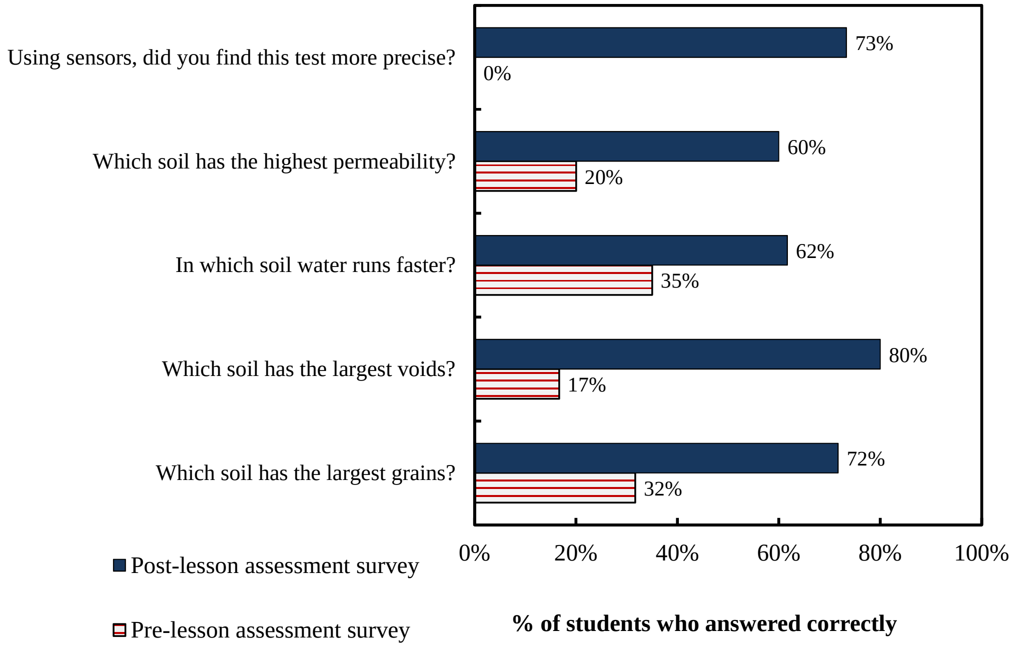

Figure 3: Assessment of soil permeability activity using exam-like content questions

Finally, to measure the effectiveness this activity on improving the students' grasp and understanding of the concepts of soil permeability, a *t*-test for paired samples is performed. This evaluation utilizes each student's average scores on pre- and post-assessment content questions. The *t*-test on this set of data (Table I) reveals improvement that is statistically significant. The *t*-value was calculated to be 11.12, which is higher than the *t*-value at p=0.0001, corresponding to a confidence level of 99.99%. Thus, the *t*-test rejects the null hypothesis that there was no change in the students' performance using a 0.01% significance level, i.e., the students' average performance from pre- to post-test increased significantly and we can state with a confidence level of 99.99% that the activities of this lesson played a significant role in this gain.

Table I: Results of a dependent *t*-test for paired samples. Values calculated using students' average scores on pre- and post-assessment content questions.

n	Mean Difference	Standard Dev.	*t* calculated	*p* value
60	42.5	29.58	11.12	< 0.0001

3.2. Soil Profiles and Foundations

The main motivation for bringing the soil profiles and foundation activity to the elementary school students is to illustrate how structures such as bridges, ports, and buildings are supported by the underlying soil. The learning goals of this activity are that the students identify that: (1) foundation systems are important to assure stability of structures; (2) in areas where difficult soils such as soft clays are present, foundation systems are needed to permit building development; and (3) deep and shallow foundations are different since deep foundations can sustain larger loads than shallow foundations. To follow the EDP in this lesson, the Fellow begins with a discussion about why buildings need support to stay standing up (*Ask*). Through this activity, the students learn (1) the function of a foundation system and (2) the difference between shallow and deep foundations (*Imagine*). This activity also aims to teach the students the concept of bearing capacity. The first part of this activity introduces the students to natural soil profiles. A brief introduction to rock formations and their weathering into soils is presented. Since this activity follows the permeability activity, the students are already familiar with the role of grain size in affecting soil properties. Various types of soils are defined according to their grain size (*Plan*). The students are divided in groups of four to five and tasked with making their own soil profile model, see Figure 4, (*Create*). Pictures of various natural soil profiles are shown to encourage the students to come up with reasonable ideas. The students fill transparent acrylic cubes (of 0.15m sides) with their choice of a layered system made of any of the following materials: gravel, play dough, natural sand, colored sand, and transparent Aquabeads, which is a transparent, water-absorbing, polymer gel, soil surrogate that is a typically used for modeling flow and contamination problems.[14]

Figure 4: Students making their own soil profile with natural sand (left) and transparent soils (right)

Next, the Fellow introduces to the students the concept of foundations (Figure 5) using models made of LEGO pieces representing shallow and deep foundations embedded in transparent soils.[14] The EDP plays an important role in this lesson when the students come to the realization that all man-made structures, such as homes, buildings, towers, schools, stores, bridges, etc., are supported by foundations and that some of them collapse because of the lack of proper soil investigation and/or knowledge of soil behavior. This further supports the *ask* step of the EDP and allows the students to understand that geotechnical engineers must be careful in their investigations and know in detail the properties of soil layers of a specific site to design suitable foundations.

Figure 5: Graduate Fellow teaching the differences between shallow and deep foundations using sand and transparent soils (left) and a physical model of a pile driven into a multi-layer soil profile (right)

Within the lesson's framework the Fellow, teacher, and students have room to discuss situations that necessitate shallow versus deep foundations. The students are encouraged to brainstorm ideas related to foundation systems for both large permanent structures and light construction, thus providing further support for the *imagine* step of the EDP. Later, each student is asked to draw their soil profile, dimension it, and label it. Moreover, the students are asked to sketch houses and buildings along with their selected foundation systems. These tasks further support the *plan* step of the EDP. Once the students have captured their plan on paper, groups of students construct their own buildings using LEGO pieces, thus providing further support for the *create* step of the EDP. Shallow foundations are simply made of long flat pieces placed under the structure. Deep foundations are made using multiple small pieces stacked under each other. Later, the Fellow explains the importance of using physical modeling in geotechnical engineering education. Once the building units are completed, the students are asked to carefully place them on top of (shallow) or in (deep) soil profiles. The models are loaded and the students observe that models with deep foundations can carry more load than those with shallow foundations, before failure. The students also observe soil settlement as the buildings are loaded. This leads to a discussion on bearing capacity followed by the Fellow showing pictures of real bearing capacity failures originally published by Tschebotarioff.[15] The Fellow shows the modes of bearing capacity failure and demonstrates general, local, and punching shear in the models made by the students (Figure 6). The activity ends with a discussion of total collapse versus failure to meet serviceability requirements. These tasks motivate the students to consider the *improve* step of the EDP.

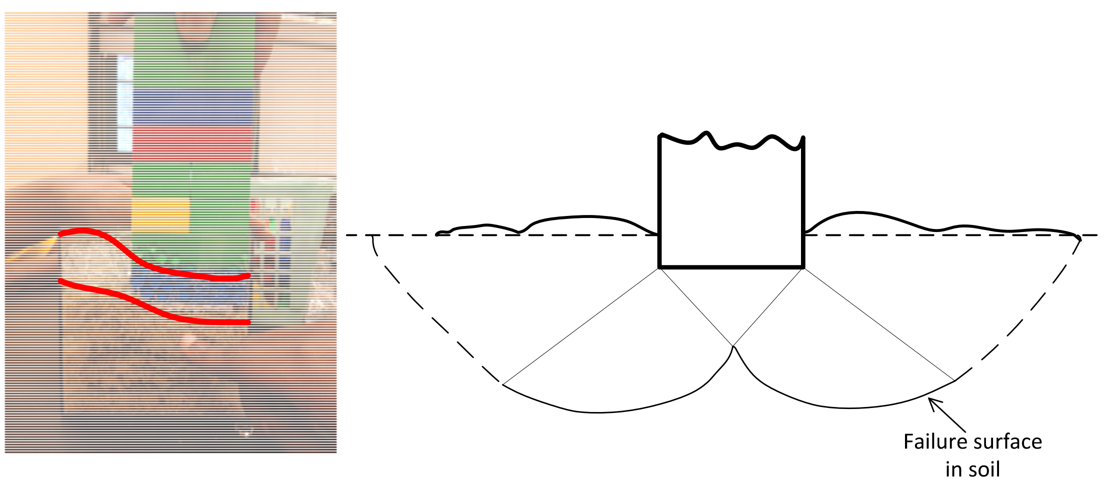

Figure 6: Model of bearing capacity failure made by a second grade student who is pointing the identified failure surface (left) and graphical representation of a bearing capacity failure learned by students (right)

The learning outcomes of this activity include that the students are able to: (1) identify and describe different layers in soil profiles; (2) differentiate and describe the size and shape of different kinds of soils; and (3) differentiate between shallow and deep foundations. After the activity, the Fellow and partner teacher probe the students to assess their knowledge, using questions such as: *What happens to the soil when its resistance is exceeded*? The students typically answer that the soil beneath the footing is pushed to the side and bulges up, or that the soil to the side of the foundation moves because the soil underneath pushes it. Another question is: *If a skyscraper was to be built by using a deep foundation, how deep would the foundation need to be*? An outstanding answer from a fourth grader was that the deep foundation would need to be located at the deepest place, or where the soil was the strongest.

Wartman[16] concluded that the use of small physical models helps undergraduate students understand classic theories of soil mechanics. Similarly, this activity demonstrates that physical models are helpful in elementary schools and that elementary school students can understand fundamental geotechnical engineering concepts through the use of physical models. The students developed a meta-cognitive approach to learning by being both hands-on and minds-on.[5] Moreover, physical models allowed engaging the students in small teams to conduct learning activities according to their different learning styles.

3.3. Erosion Table Activity

An erosion table (Figure 7) was designed and built for a second grade classroom in support of the water cycle unit of New York City learning standards. The learning goals of this activity are that the students recognize: (1) the effect on stability of running water through soils and (2) that the magnitude of erosion depends, among other factors, on the amount of rainfall. The table is made from a hydraulic bench that pumps water in a $1.2\times0.6\times0.1$ m^3 sand bed, which represents a snaking river, and permits simulating erosion due to water flow in a stream/river. The relationship between water velocity and soil erosion is investigated. First, to follow the EDP in this lesson, the Fellow begins the introduction to the erosion table activity by showing pictures of natural disasters when erosion in rivers devastates structures (*Ask*). The Fellow discusses why soils erode when they are in contact with water and the importance of preventing the phenomena for safety of riverside buildings and bridges. Since the main problem is identified as the combination of the impact energy delivered by the water and the presence of weak soils in the affected area, the students become animated to provide ideas on how to mitigate these types of failures (*Imagine*). Second, each student is inspired to *plan* and *create* their own building model for testing on the erosion table. Specifically, the use of a web-based 3D modeling software (http://www.3dtin.com) allows each student to express his or her imagination in creating a custom building design and take ownership of the experiment. That is, the students feel ownership over their model homes, which makes them much more invested in the flood event outcome. Third, the teacher produces a scaled model of each student's building using a consumer desktop 3D printer, which had been donated to the class by a 3D printer manufacturer. Fourth, each student selects and places his or her building along the riverbank in a location that provides a nice water view but that they believe is safe from erosion. Fifth, a camera is setup to capture time-lapse photographs of the status of the built environment on the erosion table. When the recorded time-lapse images are played for only a few minutes, an observer can visualize the results of various flood events that may have actually taken several tens of minutes. Sixth, the hydraulic bench pump is operated at a small flow rate that results in a laminar flow. Some of the buildings collapse due to soil erosion but most survive. Seventh, the flow rate is incrementally increased simulating large storms and turbulent flow. This permits the students to observe the increase in the rate of erosion with the increase in flow rate, which results in the failure of many buildings. Since the students act individually in the design and placement of their buildings, they develop a stronger affinity to their designed building and its location. The students are asked to position their buildings in areas where they believe no damage occurs, thus, they pay special attention when flow rate is increased. Next, the students, Fellow, and several teachers engage in a riveting discussion of the dangers of natural disasters, occurrence rates of hurricanes, building codes, the importance of deep versus shallow foundations, the role of sinuosity in erosion, and the rates of erosion of various soils. The students also recognize the importance of attempting to develop construction projects in areas where natural disasters are less impacting than others (*Improve*). Finally, the Fellow uses this activity to illustrate how natural disasters, such as landslides and floods are serious events that have to be designed for by experienced geotechnical professionals. The Fellow stresses the importance of math and science as a foundation for the modern built environment.

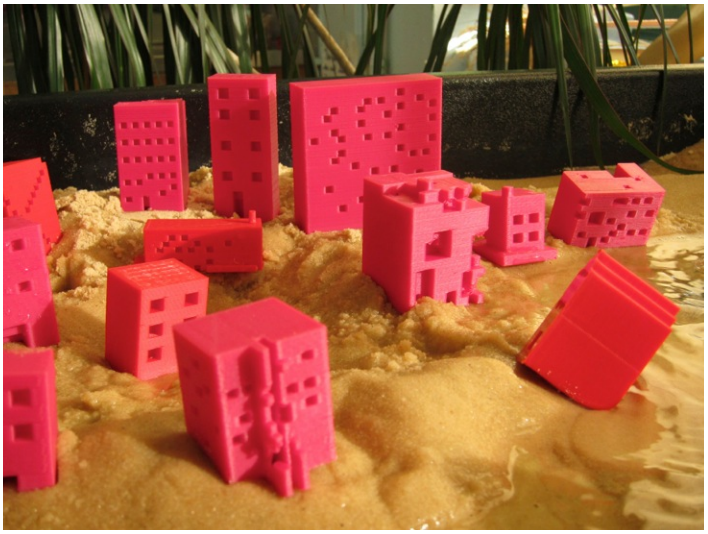

Figure 7: Students observing erosion table during activity (left) and close-up view of the riverbank and building units that students designed, built using a 3D printer, and placed besides the riverbank (right)

The learning outcomes of this activity include that the students: (1) experience that change from laminar to turbulent water flow increases the risk of building collapse; (2) identify that the placement of buildings nearby rivers and water bodies is detrimental to structural stability; and (3) explain that the engineering malpractice may result in disasters that not only affect building integrity but may also threaten people's lives (Figure 8) The pre- and post-activity questionnaires reveal that the activity made the classroom lesson real (Figure 8). This activity also sensitized the students to the importance of preserving natural resources, taking care of water bodies, respecting riverbanks, and avoiding construction in risky areas. Furthermore, the students concluded that employing common sense when placing buildings nearby rivers, especially where loose sand is present, is a noteworthy lesson for urban development. Finally, the use of the 3D printer afforded the students an opportunity to express their creativity and increased engagement and ownership of the experiment.

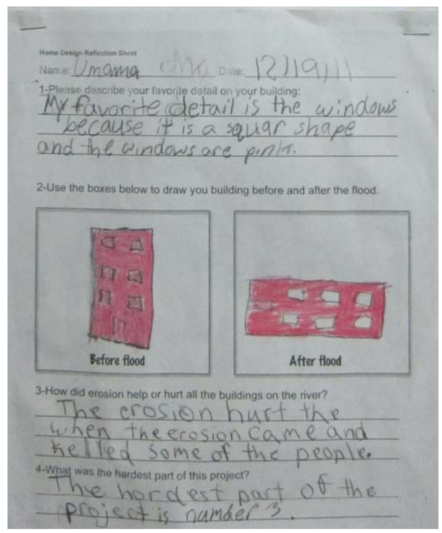

Figure 8: Typical student assessment of erosion activity for students who presented their building designs and entries before and after flooding phenomena

4. Overall Impact of Activities

Evidence such as instructors' interaction with the students, class observations, and assessment results suggest that the students liked the geotechnical activities and that these activities helped them to apply their science and math skills. Bloom[17] identified a number of skill thresholds that describe human learning, commonly known as *Bloom's Taxonomy*. Dewoolkar et al.[18] suggest that elementary school students can only achieve three fundamental levels of learning thresholds from Bloom's taxonomy, namely: (1) cognition or knowledge of a problem, (2) having positive disposition towards the subject matter, and (3) mental ability to solve the problem in question. Nevertheless, through this geotechnical engineering education module, the students were observed to be engaged in the higher levels of learning identified in Bloom's taxonomy, including (4) analysis, (5) synthesis, and (6) evaluation.

It is difficult to assess the long-term impact of the geotechnical engineering activities on student achievement since many of the main objectives need much time to determine their effect. However, most students were motivated at the opportunity of acting as geotechnical engineers. Moreover, many students affirmed that soil mechanics lessons were their favorite aspect of the science course. The classroom teacher believed that concepts learned in soil mechanics were more memorable to the students than those encountered in a traditional class. Finally, we believe that the opportunity for elementary school students to interact closely with goal-oriented role models, who are studying engineering, will help them to develop academic goals for themselves.

5. Reflections, Sustainability, and Conclusions

The observations on student engagement from the Fellow and classroom teacher are largely positive for both science and math lessons. The students were reported to be eager to participate in the lesson and actively encourage other classmates to join. They attentively listened to the lesson descriptions and completed the tasks assigned to them. As all activities were conducted using small groups or individually, informed discussions often emerged where the students tried to predict test results or debated conflicting observations. The students without prior experience with LEGO Mindstorms kits and 3D printing were able to quickly learn to operate the LEGO-based laboratory apparatus and the 3D design software, respectively, and teach the same to the other students. The Fellow also reported that some students were uninterested in completing the pre- and post-evaluation surveys with similar questions.

Promoting learning through hands-on activities, such as the ones described in this paper, is valuable for two reasons. First, it allows students to connect their science and math studies to real-life applications. Second, it permits each student to access the material according to his/her own learning style. To build on the success of these lessons, in future lessons, the authors will explore the use of load sensors to read and store real-time measurements such as stress values using the LEGO NXT controller. The main idea will be to develop and assess student learning using simplified soil stress-strain responses and analysis. This will result in the inclusion of a basic geotechnical unit, as a customized module, within the science curriculum in the elementary school.

Although the developed activities took advantage of LEGO-based and other electronic devices to increase students' interest, they can be replicated and integrated within the STEM curriculum without using sophisticated tools. Each activity can be implemented using low-cost, affordable materials. For example, in the soil permeability activity, teachers do not have to build the type of permeameters developed by the authors; instead plastic soda bottles can be employed. In the erosion table activity, the lack of a hydraulic bench is not an impediment for demonstrating erosion in rivers since foil pans can be utilized as riverbeds. Moreover, if there is no easy access to 3-D printers, LEGO pieces, popsicle sticks, or other suitable material can be employed to make buildings and foundations. The activities may be replicated in a typical classroom by teachers, who may neither be geotechnical engineering experts nor LEGO NXT programmers, by using our lessons and resources posted on Teachengineering.org website of the National Science Digital Library. Specifically, lessons related to activities presented in this paper and already published on Teachengineering.org include: (1) How fast does water travel through soils?[19] and (2) Building our bridge to fun.[20] Several other related activity lessons are currently being reviewed for publication on Teachengineering.org, including (1) The stress that you apply, (2) Erosion table, and (3) Retain or not retain.

In conclusion, introducing elementary school students to real engineering activities inspires their creativity at an early age. Hands-on engineering activities stimulate positive feelings towards engineering, since novel tools and techniques are used to deliver curricular content aligned with standards. Likewise, exposure to what engineers do, allows students to aspire to become engineers while they are at an impressionable age.

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