Soils Magic: Bringing Civil Engineering to the K–12 Classroom

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Abstract: An investigation was conducted to assess the effectiveness of a series of kindergarten through 12th grade (K–12) educational outreach activities related to civil engineering. In particular, a program called *Soils Magic* that contains a series of simple geotechnical engineering experiments was delivered in various formats to K–12 students. This paper provides an overview of the *Soils Magic* program and provides further details of selected experiments from the program. This paper highlights the experiences of various civil engineering professors bringing the program to school children to promote the excitement and accessibility of the engineering profession. Suggestions are provided for conducting successful educational outreach programs. The effectiveness of the program was evaluated using survey responses of the program participants. The need for outreach activities that promote science and engineering in an entertaining manner was established using survey responses of K–12 students.

Introduction

Educational outreach programs have been shown to be effective in increasing kindergarten through 12th grade (K–12) students' interest in science and math (Fiegel and Elia 2000; Hanson et al. 2003). University education is becoming more important. The need to stay in school and attend college continues to gain in importance, for the individual and for a sustainable future. Engineers have an obligation to encourage the growth of the profession. This paper outlines a tool for encouraging growth of the profession, starting in public schools—*Soils Magic*.

United States engineering enrollments are increasing (*Engineering Trends* 2003), as are demands for engineers. However, BS civil engineering enrollments are down (ASCE 1998; Hirsh 2001) as much as 17% from 1996 to 2001 (*Engineering Trends* 2003). Environmental BS degrees are down 50% in the same period. Infrastructure rehabilitation and environmental protection demand more civil engineers. Globally, engineering education requirements are increasing (Lyons 2000; Kupferman 1998). It is particularly important to attract quality students to the profession.

While various professional organizations (American Society of Civil Engineers, American Society of Engineering Education, Women in Engineering Programs & Advocates Network, National Society of Professional Engineers, and others) encourage K–12 students to consider engineering as a college major, some of the most effective work is done at the grassroots level, in public schools, during Engineers Week, and through student chapters of professional organizations. The *Soils Magic* program has interested K–12 students in civil engineering. The magic show consists of some interesting and mysterious (but explainable) experiments. All of the experiments can be performed by an adult—and an engineering degree is not required.

This paper discusses the *Soils Magic* show, and relates some experiences useful to others involved in persuading K–12 students in continuing to college and pursuing civil engineering, or engineering in general as a career choice.

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Background

The prospect of engineering education can be somewhat intimidating to high school and other public school students. Moreover, engineering is often seen as drab and uninteresting. This image is somewhat deserved, due to poor promotion by practicing engineers. Much of engineering is exciting, interesting and, yes, hard work. More interest and education of K–12 students is needed to show them the excitement and benefits of engineering. Engineering educational outreach serves two purposes: encouragement to study and excel in math and science in public schools, and encouragement to study engineering in college.

Many have recognized the need to increase civil engineering enrollments, and the effects of low enrollments. Nehdi (2001) describes some of the issues causing lowered enrollments in civil engineering in the United States. These include perceived lack of fulfillment from the job, low pay, and perception that civil engineering is "low tech." Trial (2002) describes the effects of low civil engineering enrollments on the space program. Orbital structures, landers, and extraterrestrial surface explorers all require significant civil engineering. Trial (2002) predicts that the

space enterprise will suffer for 20 years from the current low enrollments.

Solutions to low enrollments have been suggested by Shoemaker and Elton (1989), Dennis (2000), Reuss and Vogel (1989) and actively pursued by, among others, the American Society of Civil Engineers (ASCE). These solutions often include K–12 outreach, and public relations. An outstanding recent example is the *Building Big* video series and book developed by the Corporation for Public Broadcasting and ASCE. Grigg (1998) advocates closer ties between educators and professional organizations. Ressler et al. (1997) developed a bridge design software package that is particularly suited to K–12 outreach activities for civil engineering. Fiegel and Elia (2000) suggest activities for K–12 geotechnical education. McCuen and Yohe (1997) recommend engineering in-service training for high school science teachers, noting science, not engineering, is introduced in high schools.

Soils Magic was originally developed to interest college students in geotechnical engineering, a subdiscipline of civil engineering. It was used in undergraduate soils laboratory classes. The experiments were chosen/developed to give unexpected results—hence the "magic." Later, the magic was modified to appeal to K–12 students. A book, *Soils Magic* (Elton 2001), was written on the subject. This book explains the inexpensive, simple experiments that often have delightful and startling results.

Soils Magic in Public Schools

Experiences

Several faculty have used the *Soils Magic* in K–12 and other precollege programs. Their experiences have been very good. A few examples of faculty experiences are described below.

A number of geotechnical engineering activities were conducted over the duration of an after school educational outreach program related to civil engineering in Michigan (Hanson et al. 2003). This program was offered as an 8 week learning module at an inner-city middle school in Detroit. Various experiments and demonstrations were conducted with the students to teach them about the principles of civil engineering.

The experiments outlined in Elton (2001) provided dramatic and often surprising behavior for soils. The *Soils Magic* activities were very suitable to interaction with middle school students. Short attention spans of students were identified as a challenge in this after school program. The individual activities are generally short in duration and thus allow for capturing the attention of the students for the entire activity. Another benefit of the *Soils Magic* activities is that the students were allowed to participate in the program. Those activities in which the students were physically involved in the experiment preparation or assisted with the test procedures appeared to be the most effective for delivering the concepts at hand to the middle school students. Many of the activities involved inexpensive components and therefore, were easily modified to hands-on experiments by a large group of students (as opposed to a single demonstration to an entire group).

In one of the activities, the students were challenged to understand the concepts of "effective stress" (Terzaghi 1925) by observing how a rubber glove full of sand became rock hard when subjected to vacuum pressure (the so-called "iron glove" experiment). This was a particularly entertaining activity as each student had an opportunity to personally shake hands with the iron glove (Figs. 1 and 2). The concept of effective stress in soils was revisited using a demonstration of a bag of potato chips under loaded conditions (with pin holes introduced to the bag over time). In this case, the students enjoyed the "byproducts" of the experiment during a snack break. Some discussion in the class was developed to broaden the applicability of these simple demonstrations to real geotechnical engineering problems, such as retaining walls and building foundations. The students appeared to appreciate the importance of laboratory exercises and saw the connection between a laboratory experiment and a field application.

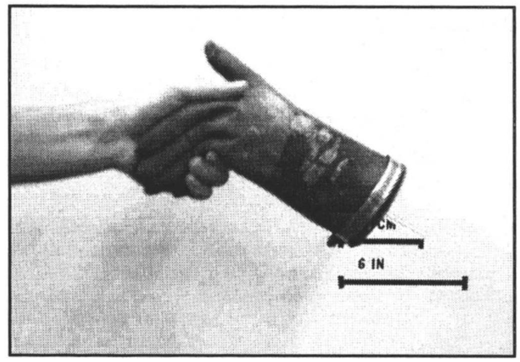

Fig. 1. Iron glove (before)

Other geotechnical activities included demonstrations of rock bolting and soil reinforcement mechanisms. Rock bolting was demonstrated by placing loose gravel in a bucket. After bolting, the bucket was inverted, but the gravel did not fall out. This behavior was achieved through the action of applied compressive forces through the rock mass with bolts. Although the mechanics were beyond the students' conceptual understanding, they enjoyed assisting in shoveling the gravel and tightening the bolts as well as hearing stories about tunneling for subways where this principle is used.

The effectiveness of reinforced soil was demonstrated by hiding paper disks within one pile of sand next to a "control" pile of sand. The students could not guess why the reinforced sand pile (which appeared identical to the control pile) was able to hold 20 times more weight before failing. The soil reinforcement demonstration was quite rapid because it had to be entirely set up ahead of time to maintain the element of surprise. This activity prefaced showing the students samples of geosynthetics and discussing a few aspects of ground modification engineering.

The middle school students' favorite geotechnical activity was related to the principle of dilatency (Figs. 3 and 4). Students made a water–corn starch mixture (termed "Ooblech") that maintained

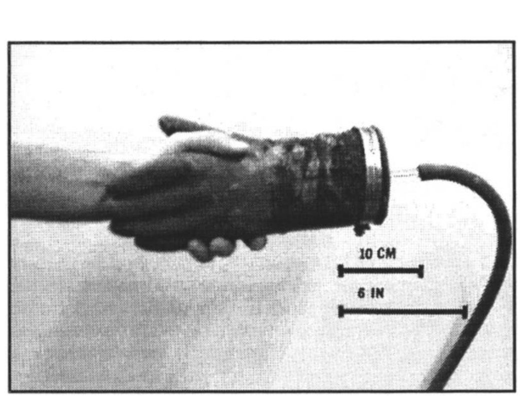

Fig. 2. Iron glove (after)

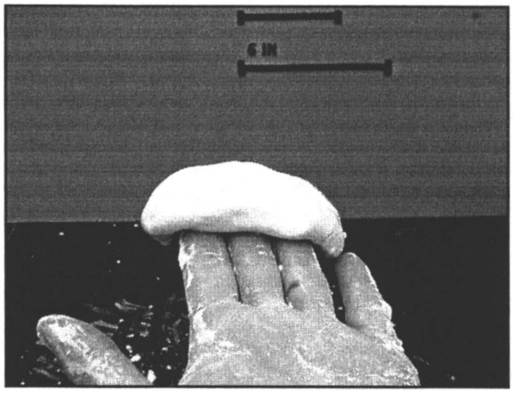

Fig. 3. Ooblech at rest

form as a ball as long as they kept moving it from hand to hand. However, if the action stopped, the substance became viscous and ran down their hands and arms. The students were quite taken by this phenomenon and many requested to take their samples home. The instructors were entertained at the prospective image of a sidewalk full of students having to continually move their samples from hand to hand as they walked home after school. We assured students that they could buy more of the magic powder (corn starch) at the grocery store.

Advice for Soils Magicians

These are great experiments, partly because of their inherent nature to attract attention and simplicity. A good presentation can greatly enhance their effectiveness. Some presentation suggestions follow.

Add Excitement

Maintaining student interest in educational outreach activities is challenging. A key benefit of the *Soils Magic* experiments is that they are simple to explain, rapid to conduct, and provide a connection to real engineering problems. Occasionally during long outreach sessions, instructors can use brief and dramatic demonstrations of science and engineering principles to change the pace of the session and regain attention of the class. The *Soils Magic* experiments were ideal for this sort of digression (one uses fire!). Some hands-on activity allows for refocus of the students' attention. Dramatic results lead to an interactive discussion. Finally, the application of the principle to real engineering projects provides additional lessons for the students.

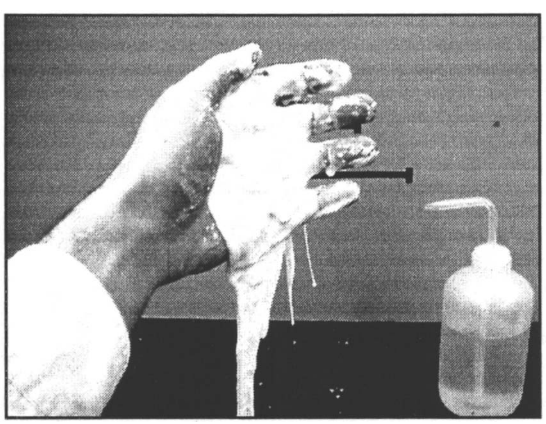

Fig. 4. Ooblech in motion

Add Entertainment

The *Soils Magic* program provides activities that contain high entertainment value and allow for flexibility in scheduling. Many of the experiments are short enough in duration that they can be included as individual activities for the students or broadened to promote group discussions. In general, the shorter duration activities were found to be most successful with the younger students. In addition, the younger students particularly enjoy competitive activities and recognition for their performance. Some of the principles of the *Soils Magic* program can be applied to competitive events. After demonstrating the effect of water on the behavior of cohesive and cohesionless soils, a group of middle school students competed to build the tallest soil structure using a given total mass of soil constituents (clays, sands, gravels, and water). The students were allowed to mix their own "building material" recipe. The excitement provided by the competitive aspect was evident.

Add Engineering Context

The *Soils Magic* program presents fun and interactive exercises for work in the classroom. By relating these simple classroom experiments and demonstrations to meaningful real-world projects, a context is provided for the K–12 students as to typical projects and problems that face today's engineers. Discussions that include large local construction projects are particularly captivating for the students. Highlighting local projects provides a direct link to the students' everyday lives and allows them to appreciate civil engineers' contributions to their lifestyle. Civil engineers struggle with projecting a positive image to today's youth. The combination of simple, fun, and memorable experiments of *Soils Magic*, together with discussion of sophisticated large-scale construction projects that are in some way related to the experiments, provides an opportunity to positively influence the perceived image of the civil engineering profession.

Working with K–12 Teachers

These experiments naturally appeal to teachers because they are simple to conduct, and have little chance of failure. Teacher involvement begins with a review of the most interesting experiments—reinforced sand experiment, thixotropy, dilation tube, bucket of bolts, portable liquefaction tank, and the iron glove experiment. The low cost and short setup time is attractive. An overview of *Soils Magic* experiments is presented in Table 1. The preparation level noted in Table 1 provides a ranking for the relative difficulty of setting up the experiment (1 is easiest, 5 is most difficult).

Arranging for Visit

Schools interested in having K–12 activities related to civil engineering are encouraged to contact their local university ASCE student chapters. It is feasible that the equipment to perform many of the activities outlined in *Soils Magic* would be available to the college students. Many ASCE student chapters are actively involved in K–12 outreach education. Alternatively, the activities of the *Soils Magic* program are so clearly presented by Elton (2001) that any adult could easily perform most of the experiments. In

Table 1. Overview of *Soils Magic* Experiments

Experiment	Soil mechanics principle	Duration of activity (min)	Preparation level	Special notes
Reinforced sand experiment	Planar reinforcement	5	2	Simple setup and dramatic results.
Magic cube	Planar reinforcement	10	5	Large-scale, extra preparation required.
Thixotropy	Clay sensitivity/ thixotropy	5	2	Soaking overnight required.
Ooblech	Dilation during shearing	10	1	Perfect for individual hands-on activity for young participants.
Dilation experiment	Dilation during shearing	5	2	Some hardware required.
Bucket of bolts	Rock bolting reinforcement	10	3	Heavy to transport.
Soil turns to a fluid[a]	Liquefaction	10	4	Need access to plumbing.
Iron glove	Shear strength as a function of effective stress	5	3	Good for interaction with audience, especially young participants.
Saltwater clay	Pore fluid/clay interaction	10	1	Good to encourage volunteer from audience.
Nonsticky clay	Pore fluid/clay interaction	10	1	Dramatic results with flame.
Soil is swell	Swelling soils	60[b]	2	Easy set-up, need to wait for reaction upon hydration.
Bentonite and sand wall	Drilling mud for slurry walls	10	2	Takes some practice.
Water does flow uphill	Soil capillarity	10	3	Some waiting time required.
Water does not flow in straight lines	Flownet demonstration	60[b]	5	Significant set-up required including large apparatus and plumbing, good for university setting.
Broomstick and sand experiment	Dilation during shearing and interface shear strength	5	2	Difficult to achieve intended result.
Retaining wall simulator	Active and passive lateral earth pressures	5	5	Significant apparatus required, yet simple operation once built. Good for university setting.
Beach sand demonstrations	Soil capillarity, shear strength, compaction, densification, effective stress	5 min to 2 weeks	1	Access to beach required; lounge chair and sunglasses recommended for higher-level analyses.
Magical soil compaction	Densification of sands	5	1	Very simple setup.
Clay desiccation	Capillary stresses	5	2	Drying time required before presentation.
Clay electrocution	Electro-osmosis	45[b]	4	Waiting time required for process to occur. Good for university setting.
Stressed out coffee	Effective stress	5	1	Virtually no equipment required.
Foam peanuts/potato chips	Effective stress	5	1	Very simple.
Fiber reinforced soil	Discrete fiber reinforcement	5	3	Extensive soil mixing, large quantity to transport.
Borehole breakout	Stress conditions in boreholes and tunnels	5	1	Simple and excellent demonstration of principle.
Electrophoresis of clay	Electrically polar nature of clay particles	30[b]	4	Not dramatic, although good to show concept. Good for university setting.

[a]Portable version of liquefaction tank available, which simplifies scale of preparation.

[b]Longer duration experiments can be initiated at the beginning of a magic show and revisited later.

most cases, the equipment required to perform the experiments is available at a hardware store. The kit of hardware for performing the experiments is also available at ⟨www.soilsmagic.com⟩.

Feedback from Teachers

Soils Magic has occasionally been held in science rooms at middle schools. Based on the laboratory equipment that was available in some of the science rooms, it was apparent that the science and engineering related activities that were presented related to the *Soils Magic* program were substantially more interactive, hands-on, and entertaining than the conventional materials presented in most classes. Therefore, the students were able to see that science and engineering can be fun. The program provided image enhancement to engineering, and the civil engineering profession in particular. The students left this program with a better understanding of what civil engineers do for society and how the principles of science and engineering can be applied to simple problems. The excitement in the classroom was evident by ob-

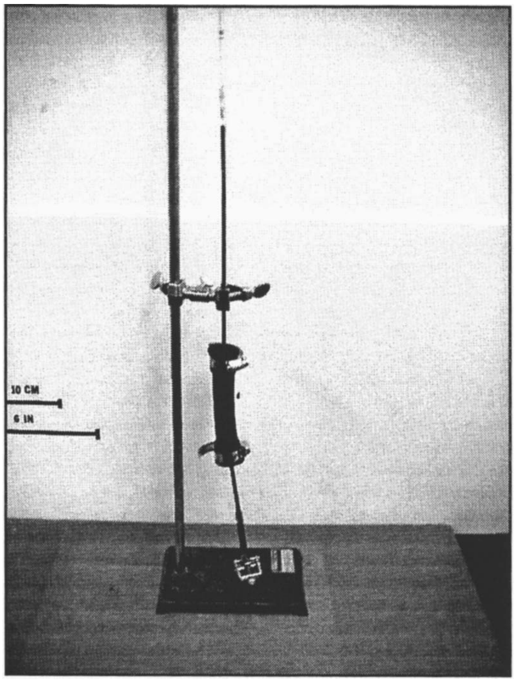

Fig. 5. Dilation tube, before

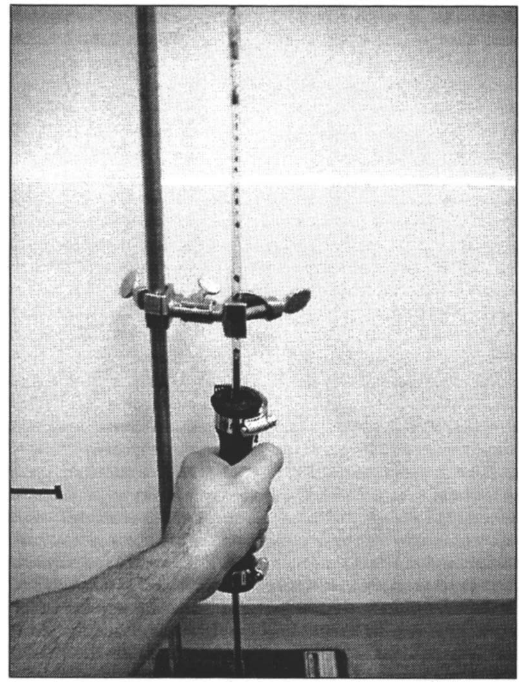

Fig. 6. Dilation tube, after

serving the number of questions, eagerness to participate, and the enthusiasm and competition to play with the magic equipment afterwards.

Many teachers were thrilled, and anxious for a repeat performance at a later date. Some asked for experiment instructions. The emphasis on simplicity and inexpensiveness was particularly appealing to them. Occasionally, other teachers at the same school requested demonstrations for classes that did not participate the first time. Public service organizations (Girl Scouts, church groups, and others) have received the experiments very well, often recommending other groups.

Sample Experiment

In order to get a feel for how these experiments can be made entertaining, the following soil dilatency experiment is presented as a case study. This experiment is an exciting and particularly mysterious experiment (Figs. 5 and 6), which lends itself to "magic." The tube is prepared in advance by packing very clean sand tightly in a piece of bicycle inner tube. The ends are sealed with one-hole rubber stoppers. The top stopper has a clear plastic standpipe. The lower stopper is used to introduce colored water. The water is inserted in the bottom of the tube, forcing air out the top, until the water is halfway up the standpipe. Once the lower tube is pinched off with a hose clamp, the experiment is ready. To conduct the experiment, the dilation tube is held vertically on a ring stand. The instructor (magician) explains that the flexible rubber tube holds soils and colored water. After explaining that the experiment may produce magic results, a student participant is invited to act as the sorcerer's apprentice. Students are told that their colleague will soon be invited to squeeze the rubber tube. The students are to imagine which direction the water will go in the tube. Most, of course, will assume the water will go up, like squeezing toothpaste. A magic spell is then cast on the tube (e.g., "Here's an experiment you can take downtown, abracadabra! make the water go down!"). The apprentice then squeezes the tube and the water level plummets out of sight!

The principle is explained easily using a ping-pong ball model (Figs. 7 and 8). The balls are sheared (equivalent to squeezing the tube) and the space between the balls increases, allowing the water to drop down and fill the newly created void spaces.

Students are, of course, invited to use the two experiments themselves to reinforce that there is no real magic—it's civil engineering. A discussion of the results of the experiment and of applications related to the principles of the demonstration follows the experiment. For the dilation experiment, examples of civil engineering applications include the development of pore-water pressures under loading conditions for foundation design. The

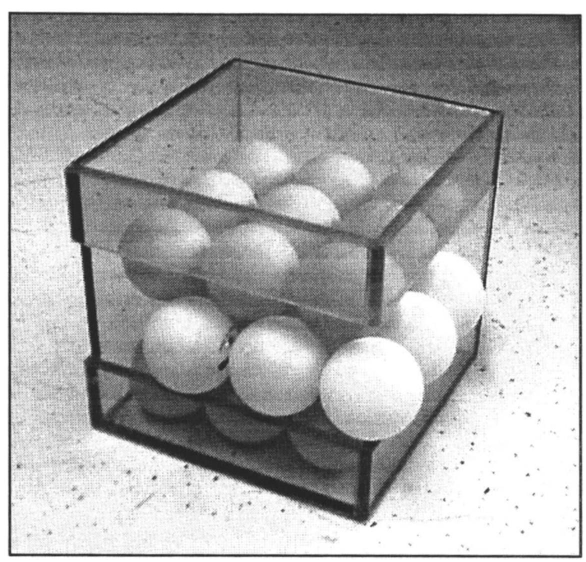

Fig. 7. Dense packing

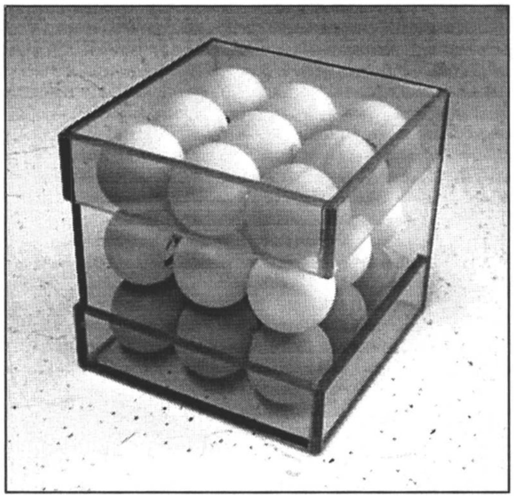

Fig. 8. Loose packing

students are able to see a connection between the physics of a simple classroom demonstration to a high-level design consideration for civil engineers.

Assessment of Effectiveness of Program

The feedback from K–12 students and teachers related to *Soils Magic* has been favorable. To better quantify the effectiveness of the program, a survey was developed and distributed to a large group of program participants (approximately 100 elementary school students). The survey was tailored to the age group and provided assessment related to the students' interpretations of the *Soils Magic* experiments, their demographic backgrounds, their intentions for pursuing engineering in the future, as well as whether this program influenced their impressions of the engineering profession.

Statistical analyses were conducted that ranked student responses. Correlations were drawn between their assessment of the program and both their demographics as well as their scholarly plans for the future. The sample consisted of 102 students. Of these students 55 (53.9%) were boys and 47 (46.1%) were girls. Racially, 48 (47.5%) were white, 36 (35.6%) were African–American, and 18 (15.9%) were of other racial origin. Overall, the students reported that 32.4% of their fathers had completed college, whereas 41.2% of their mothers had completed college.

A descriptive summary (means and standard deviations) for the attitude items from the *Soils Magic* assessment survey is reported in Table 2. Therefore, the items appearing at the top of the list were received most positively by the sample of students while those at the bottom were less favorable. Four items had an average response at or above 3.75 (on a four-point scale). These were: I like field trips, *Soils Magic* was fun, *Soils Magic* was interesting, and I would like to do more engineering experiments. The item that received the lowest average response (2.08) pertained to copying from the blackboard.

The 13 items pertaining to attitudes toward the *Soils Magic* experiment and learning methods were examined to determine the extent to which they were reliable (consistent) with each other. Cronbach's alpha (Cronbach 1951) was used as an index of internal consistency for this analysis. This measure yields a value with an upper bound of 1. The estimate for the 13 items from the *Soils Magic* survey was 0.6610, providing moderate support for the scale's reliability. In addition, the items pertaining to high school curriculum plans were summed to form a total score (total number of technical courses they are interested in taking). The total score yielded a reliability estimate of 0.7288, supporting the internal consistency of the scale.

Table 2. Comparison of Boys and Girls Regarding, *Solis Magic* Attitudes

Topic	Gender	Sample size	Mean	Standard deviation
Soils Magic was fun	Girl	47	3.87	0.397
	Boy	55	3.82	0.389
I learned something	Girl	47	3.77	0.598
	Boy	55	3.58	0.567
Soils Magic made me more interested in science	Girl	47	3.21	0.832
	Boy	55	3.25	0.947
Soils Magic was interesting.	Girl	47	3.83	0.481
	Boy	55	3.75	0.517
I know more now about soils	Girl	47	3.28	0.994
	Boy	55	2.98	1.009
I know more now about earthquakes	Girl	46	3.43	0.807
	Boy	55	3.13	1.001
Soils Magic made me want to go to college	Girl	47	3.57	0.773
	Boy	55	3.42	0.832
I know more now about civil engineering	Girl	46	3.13	1.258
	Boy	55	2.93	1.168
I would like too do more engineering experiments	Girl	47	3.79	0.690
	Boy	55	3.71	0.712
I like doing the experiment myself	Girl	47	3.55	0.653
	Boy	55	3.25	0.821
I like watching a live experiment	Girl	47	3.60	0.712
	Boy	55	3.67	0.721
I like copying from the blackboard	Girl	47	2.02	1.053
	Boy	55	2.13	1.090
I like field trips	Girl	47	3.98	0.146
	Boy	55	3.95	0.299

Group comparisons were made for the variables of gender and ethnicity regarding *Soils Magic* attitudes. Comparisons between boys and girls are summarized in Table 2. Overall, girls had higher means on ten of the 13 items. One item on which they had a lower mean was "copying from the blackboard." To determine whether the responses were statistically different, independent *t*-tests (Lomax 2001) were used. While there was no overall statistical difference between boys and girls, girls did respond significantly more positively to the item: "I like doing the experiment myself."

Another group comparison was made between African–American and White students. Overall, African–American students had higher means on ten of the 13 items, including "copying from the blackboard." The results from the independent *t*-tests (Lomax 2001) failed to yield any statistically significant differences between the two groups. These results are presented in Table 3. An overall summary of the survey results is presented in Fig. 9.

Each of the 13 attitude items was correlated to the total number of technical courses students planned to take in high school. Students responded on the survey to which courses they are interested in taking in high school including math, engineering, science, and computer classes. The relationships between attitude items and scholarly plans were assessed using Pearson product–moment correlation coefficients (Lomax 2001), summarized in

Table 3. Comparison of African–American and White Students Regarding *Soils Magic* Attitudes

Topic	Ethnicity	Sample size	Mean	Standard deviation
I like field trips	African–American	36	4.00	0.000
I like field trips	White	48	3.96	0.202
Soils Magic was fun	African–American	36	3.92	0.280
I would like to do more engineering experiments	African–American	36	3.83	0.697
Soils Magic was interesting	White	48	3.79	0.504
Soils Magic was fun	White	48	3.77	0.472
Soils Magic was interesting	African–American	36	3.75	0.500
I like watching a live experiment	African–American	36	3.69	0.577
Soils Magic made me want to go to college	African–American	36	3.64	0.723
I learned something	African–American	36	3.64	0.639
I learned something	White	48	3.60	0.610
I would like to do more engineering experiments	White	48	3.60	0.792
I like watching a live experiment	White	48	3.48	0.875
I like doing the experiment myself	African–American	36	3.39	0.803
Soils Magic made me more interested in science	African–American	36	3.36	0.867
I know more now about earthquakes	African–American	36	3.33	1.014
I like doing the experiment myself	White	48	3.33	0.781
Soils Magic made me want to go to college	White	48	3.31	0.903
I know more now about soils	White	48	3.21	1.010
I know more now about civil engineering	White	48	3.19	1.123
I know more now about earthquakes	White	47	3.17	0.916
I know more now about soils	African–American	36	3.00	1.095
I know more now about civil engineering	African–American	35	3.00	1.260
Soils Magic made me more interested in science	White	48	2.98	0.887
I like copying from the blackboard	African–American	36	2.33	1.069
I like copying from the blackboard	White	48	1.94	1.080

Table 4. Four items correlated positively with high school plans with correlation coefficients ranging from 0.214 to 0.330. These items were: *Soils Magic* was fun (0.330), *Soils Magic* was interesting (0.250), I would like to do more engineering experiments (0.265), and I like field trips (0.214). The higher Pearson product–moment correlation coefficients (for both I would like to do more engineering experiments and *Soils Magic* was fun) represent significant correlation at the 0.01 level (2 tailed), whereas the correlation coefficients for *Soils Magic* was interesting and I like field trips represent significant correlation at the 0.05 level (2 tailed).

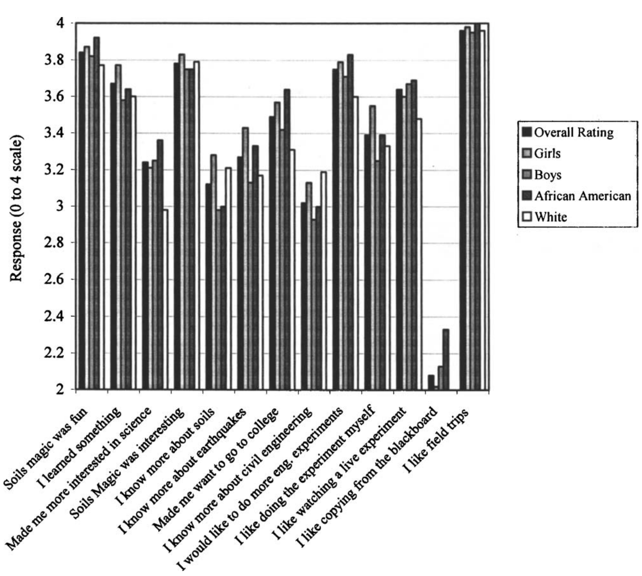

Fig. 9. Summary of survey results

Conclusions

The *Soils Magic* program developed by Elton (2001) has proven to be effective at demonstrating the principles of soil mechanics.

Table 4. Correlations between *Soils Magic* Attitudes and High School Course Plans

Topic	HSTOTAL (number of courses student plan to take)
Soils Magic was fun	0.330[a]
I learned something	0.127
Soils Magic made me more interested in science	0.095
Soils Magic was interesting	0.250[b]
I know more now about soils	0.161
I know more now about earthquakes	−0.066
Soils Magic made me want to go to college	0.088
I know more now about civil engineering	−0.118
I would like to do more engineering experiments	0.265[a]
I like doing the experiment myself	0.189
I like watching a live experiment	0.107
I like copying from the blackboard	0.040
I like field trips	0.214[b]

[a]Correlation is significant at the 0.01 level (2 tailed).

[b]Correlation is significant at the 0.05 level (2 tailed).

Although originally developed for college students, the program has been used successfully for elementary, middle, and high school students. The activities provide exciting and often surprising results that capture the attention of the students. The program has been used in educational outreach activities to introduce the civil engineering profession. Students appreciate the simplicity of the experiments and the relation to real engineering problems. Hands-on activities were especially successful for younger students.

A survey was conducted of a large group of students that participated in *Soils Magic*. Overall, highly favorable responses to their experiences were documented, including high levels of learning from the experience. The benefits of participating in an interactive technical outreach program were evident in the student survey responses. It appears that technically inclined students (those with intentions of pursuing technical coursework in high school) were particularly attracted to participating in the program and received the greatest benefit from the activities (by analyzing Pearson product–moment correlation coefficients for the survey data).

Approximately 80% of students responded that they would "very much" like to do more engineering experiments. In an era when interest in pursuing science and engineering is at relatively low levels for American students, it is encouraging to see that grade-school students have a strong interest in participating in experiments. Documentation of this response supports adapting elementary and middle school curricula to include hands-on experiments and technical content at an early age. The relatively favorable responses to the survey by both girls (in comparison to boys) and by African–Americans (in comparison to Whites) suggests that interactive outreach programs such as *Soils Magic* may provide increased interest by these underrepresented groups in pursuing engineering education.

In the larger context, *Soils Magic*, and similar engineering outreach programs, help students relate education to life, and gain an enhanced appreciation of engineering, whether they enter the field or not. *Soils Magic* provides a highly adaptable program for use in engineering educational outreach. The activities can be tailored to suit both a wide variety of audiences and a wide variety of schedules.

"Abra-kadabra, Zing-zanger-zill. If Soils Magic won't turn kids on to Civil Engineering, Nothing will."

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