Effectiveness of an Engineering Curriculum Intervention for Elementary School: Moderating Roles of Student Background Characteristics

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ABSTRACT

We present main effects of treatment and moderating effects of student background on science and engineering outcomes for grades 3-5 children participating in an engineering intervention. Data is from a large-scale randomized-controlled trial of two matched pairs (intervention and comparison) of engineering units. The intervention curriculum utilizes methods of project-based learning with support to apply science concepts to engineering design, while the comparison curriculum relies primarily on direct instruction. Both groups were taught the same science content prior to treatment. Intervention students in one of two curriculum units showed greater improvement on science content outcomes, as compared to control. The white/minority science achievement gap shrank after the intervention. Results suggest that the project-based intervention improves science achievement, particularly for minorities.

PURPOSE

The purpose of this study is to assess the main effects of the Engineering is Elementary (EiE) intervention for elementary students using data from a large-scale randomized-controlled trial project and examine the moderating roles of student background characteristics in the association between the intervention and student learning of science and engineering.

EiE began development in 2003 to meet growing demand for children in the United States to learn basic principles and skills of engineering (International Technology Education Association, 2002; Massachusetts Department of Education, 2001; Rogers & Portsmore, 2004). Demand accelerated with interest from the National Research Council (Katehi, Pearson, & Feder, 2009), the incorporation of engineering learning goals into the Framework for K-12 Science Education (National Research Council [NRC], 2012) and the publication of the Next Generation Science Standards (NGSS Lead States, 2013). EiE currently reaches more than 2 million children in grades 1-5 annually. EiE units are designed to engage children in the process of engineering. Each unit begins with the presentation of a problem within a narrative context, engages children in further exploration of materials and methods for solving the problem, and challenges children to apply what they've learned both from materials exploration and from a particular field of science to solving the problem.

THEORETICAL FRAMEWORK

Social constructivism frames our understanding of how social activity in complex contexts drives learning. Through engaging with more competent others at a level just beyond what they can accomplish individually, students develop understanding and competence (Vygotsky, 1934/1987). By encouraging students to build on their prior experiences and reflect on new learning as they construct their understanding, a curriculum can positively affect student outcomes (Kolodner, Gray, & Fasse, 2003; Zubrowski, 2002). Supports to scaffold student learning are key to the success of instruction (Hmelo-Silver, Duncan, & Chinn, 2007). Students benefit from social and material support to answer open-ended questions, express their ideas, and reflect upon what they have learned (Quintana et al., 2004). Structuring problem-solving practices helps students progress at a level they couldn't accomplish independently, gaining experience they can draw on in similar situations (Hmelo-Silver et al., 2007; Kolodner et al., 2003).

Research about how education can increase equity in educational engagement and outcomes has also framed the development of EiE (Cunningham & Lachapelle, 2014). For example, each EiE unit begins with a story, because a narrative can help students to make connections across disciplines and the real world (Baker & Leary, 1995; Buxton, 2010; Klassen, 2007), because stories help children to learn and to enter into the culture of a new discipline (Martin & Brouwer, 1991; Wilson, 2002), and because a narrative can be a powerful way to engage children's interest and attitudes (Klassen, 2009; Koul & Dana, 1997; Stinner, 1996). EiE units present design challenges that are truly open-ended and invite learning from failure, with the aim of engaging diverse students: research has shown that open-ended questioning, problem-solving, and a classroom culture that rewards incremental improvement particularly benefit the achievement and interest of girls (Zohar, 2006) and minority students (Kahle, Meece, & Scantlebury, 2000). EiE units emphasize analysis, reflection, and sense-making in active learning, methods that also benefit these populations (Blanchard et al., 2010; Brotman & Moore, 2008; Cavallo & Laubach, 2001; Cuevas, Lee, Hart, & Deaktor, 2005; Kahle et al., 2000; Thadani, Cook, Griffis, Wise, & Blakey, 2010). Children work in teams to solve problems, because collaborative environments tend to be more engaging and validating of diverse learning styles and abilities than competitive environments, particularly for girls and underserved minorities who often find themselves left out or alienated by competitive hierarchies (Baker & Leary, 1995; Burke, 2007; Carlone, Haun-Frank, & Webb, 2011; Lee, 2003; Olitsky, Flohr, Gardner, & Billups, 2010).

In the current study, we examine the following research questions using the data from two of four EiE units that have been implemented for the project – electrical engineering units and environmental engineering units.

1. What effect does EiE have on children's learning of engineering and science content and processes compared to lessons that address similar learning objectives but do not include EiE's hypothesized "critical components" (Table 2)?
2. How do student background characteristics moderate the outcomes of implementation?

METHODS AND DATA SOURCES

The research described in this paper is part of an ongoing efficacy study, intended to test the causal effect of EiE on student achievement when EiE is implemented under ideal conditions (Towne, Wise, & Winters, 2005). In this case, ideal conditions were implemented as: (1) choosing from teachers who volunteered to participate, (2) providing all needed materials for implementation, and (3) providing extensive professional development. In addition, we monitored the innovation for fidelity, teachers were informed what fidelity to their assigned curriculum should look like, and we asked all teachers during professional development to adhere as closely to the intervention instructions and philosophy as possible to keep fidelity high (O'Donnell, 2008; Raudenbush, 2007).

We implemented the study as a random-assignment controlled test (RCT) because only RCT's and related designs are suitable for determining causality (Towne, et al., 2005). We randomized at the school level, not at the student level, so as not to introduce bias due to teacher and school differences or due to teacher interactions. We conducted a power analysis to determine the appropriate sample size for power to detect potentially small effect sizes (Raudenbush, 2007; Slavin, 2008).

To establish the validity of independent and dependent variables, we defined and monitored differences between EiE and the comparison curriculum, as well as fidelity criteria, to avoid Type III errors (Borman, 2002; O'Donnell, 2008; Raudenbush, 2007). We also took care that both EiE and the comparison curriculum addressed the same learning objectives that were measured by our instruments, so as not to inflate effect sizes due to over-alignment (Slavin, 2008).

In this paper, we focus specifically on main and moderation effects on student outcomes in engineering and science. We examine the moderating effects of student demographic characteristics on the outcomes. We are particularly interested in whether EiE affects outcomes for students belonging to demographic groups that are underrepresented in engineering as a field, including female, black, and Hispanic students.

Sample Selection and Randomization

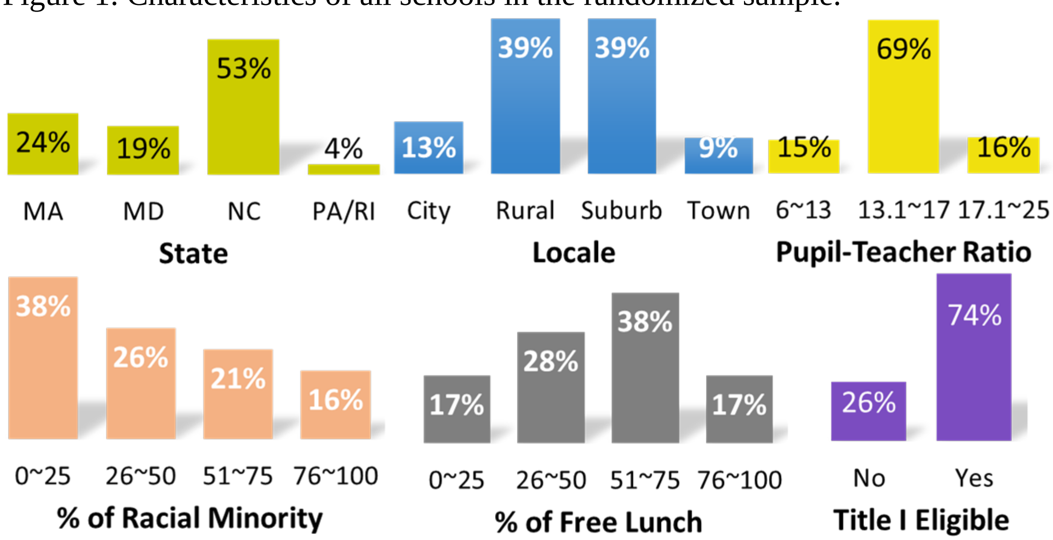
To recruit teachers, in January of 2013 we contacted administrators of schools and districts in Massachusetts, Maryland, and North Carolina, inviting them to encourage interested teachers to apply to an engineering education research study. We promised teachers free professional development, materials, and a stipend for implementing an assigned engineering unit and collecting data from their students. We encouraged teachers to apply as "school teams" of non-consecutive grades as our goal was to have two teachers from each school participate without repeating participation for students. We considered applications only from generalist or science specialist teachers of grades 3, 4, or 5 who were inexperienced with teaching engineering.

Of the 613 applications we received, we either accepted or placed on a wait list 359 teachers from 231 schools, with 131 of the schools from North Carolina, and the remainder split between Massachusetts (52 schools) and Maryland (48 schools). We looked at each group of teachers from a school as a potential team in determining which teachers and schools to accept. First, we excluded all teams from schools that had previously implemented EiE or other engineering units that involve implementation of an engineering design process, such as those from NASA's Beginning Engineering, Science and Technology (BEST) curriculum. Then, we looked at the composition of each team. For each school, we could accept either a team of teachers all from the same grade, or a team of third and fifth grade teachers. We could not accept teachers of consecutive grades, because we wanted all students in our 2-year study to be new to engineering. In deciding whether to reject the fourth-grade teachers or the third- and fifth-grade teachers from a school, we considered the number of teachers (prioritizing larger teams) and the science units they planned to teach (prioritizing those who would teach the less common of the four required science areas). From the pool remaining, we chose all eligible teams from Massachusetts and Maryland (as the number of applicants in each of these states was low). We then prioritized larger teams from North Carolina for acceptance. The remaining eligible school teams (all from North Carolina) were placed on a waitlist.

The accepted schools were randomized at the state level, with the waitlist randomized separately. Schools were assigned alternately to intervention and comparison groups in order of their random assignment. We randomized our sample at the school level to avoid cross-contamination of samples within schools. Teachers were assigned to one of the four units according to what science they taught. We then contacted teacher teams with news of their acceptance, waitlist, or rejection status by email. Any teacher team that did not reply with confirmation of their participation was replaced from the waitlist by a school from the appropriate treatment group.

We performed an analysis of the equivalence of the two samples (intervention and comparison) at the school and classroom levels at the start of the study to determine the effectiveness of randomization. In the case of categorical variables we performed a chi-squared analysis to determine significance between samples. We observed a number of different variables, racial makeup, locale of school, pupil-teacher ratio, percentage of students eligible for the National School Lunch program, and percentage of schools eligible for Title I funding. Analyses showed no significant difference between the two samples, indicating that they are indeed equivalent. Demographic characteristics of the full sample are presented in Figure 1.

Figure 1: Characteristics of all schools in the randomized sample.



Intervention versus Comparison Curriculum.

The project focused on implementing and evaluating 4 select EiE units (out of 20 available): electrical, environmental, geotechnical, and package engineering. We chose to implement four units rather than all 20 available to maximize power to conduct the analysis of each unit, and to make the teacher training and materials distribution feasible.

In each unit, students were guided to apply knowledge of relevant science content, i.e., ecosystems for environmental engineering, landforms and erosion for geotechnical engineering, electricity for electrical engineering, and plants for package engineering. The same engineering content was delivered in a matching comparison curriculum unit, which we called "Engineering for Children" (E4C) but with more traditional pedagogy and curricular materials. E4C units were adapted from engineering activities freely available on the internet. Engineering and science content for each matched pair of units assessed is presented in Table 1.

Table 1: Science and engineering content tested for each unit.

Engineering Field	**Science & Engineering Content Tested**
Electrical Engineering	• Forms and transformations of energy • Electrical conductors and insulators • Analyzing series and parallel circuits
Environmental Engineering	• Reading food webs • Analyzing changes to food webs • Pollution and how it moves through the environment
Geotechnical Engineering	• Landforms and erosion • What is a model? • Foundations of structures
Package Engineering	• Structures of plants and their functions • Plant survival needs • Package design to meet the needs of product & consumer

The E4C units are intended to match engineering content and process learning objectives with the chosen EiE units but to differ from those units, inasmuch as possible, in the critical components of the EiE curriculum. EiE's critical components are congruent with the definitions of both inquiry learning and project-based learning. We developed a rubric to measure the presence of critical components in curriculum materials; this rubric was employed by an independent researcher to independently verify that the critical components are strongly represented in EiE, while they are only weakly represented in the comparison curriculum units. For the few cases where a lesson scored low on the rubric for the EiE curriculum, or high for the E4C curriculum, we modified the curriculum materials. The target rubric definitions for each critical component, as manifest in each treatment, are presented in Table 2.

Table 2: Critical components of EiE as compared to E4C.

EiE	E4C
Engineering content is introduced in a narrative context, designed to appeal to children from diverse backgrounds.	Engineering content is introduced in traditional textbook style. No context is provided for why to do the challenge.
Students learn about and are provided support to use an engineering design process.	Students are not explicitly taught an engineering design process.
Engineering challenges specify a problem with constraints on and requirements for the solution requiring trade-offs.	Constraints and requirements for successful solution of the engineering challenge are not given. Trade-offs are not required.
Students are given support to use math and science to design solutions.	Math and science are not explicitly featured nor is their use supported.
Students analyze data and use failure constructively as they design iteratively.	Students are not supported to analyze data or reflect on failures. Designs are not improved.
Students are supported to work collaboratively and negotiate.	Students may work together in teams but are not given support to do so.
Creativity, brainstorming, and the development and consideration of a multiplicity of ideas are all supported.	The design challenge is open-ended but development of multiple design ideas is not discussed or supported in the curriculum.
Teacher guide supports engaging prior knowledge, prompting reflection, and modeling engineering thinking and practices.	Teacher guide focuses on how to explain content to students and the specifics of running the activity.

Teacher Preparation and Participation

All teachers in the study participated in 3-day professional development workshops held during the summer of 2013. Separate workshops for intervention and comparison curricula were held in each state: Massachusetts, Maryland, and North Carolina. The same pair of teacher educators, both well-versed in the design of the project, participated in the design and ran all workshops with the support of the research staff and oversight of our external formative evaluator.

We designed each workshop to adhere to the pedagogical philosophy that underpinned the curriculum being taught. Therefore, workshop presenters used a social constructivist pedagogical style during the workshops for teachers assigned to the EiE treatment: asking open-ended questions designed to support students to reflect and make connections on their own, modeling engineering practices and thinking, and engaging teachers in thinking metacognitively about how they should interact with students in order to get them engaged in engineering practices. In contrast, the workshops for E4C teachers used direct instruction, explanations of content, and prepared expository content in the form of videos and handouts. Our external formative evaluator reviewed the video of all workshops to confirm that the presenters adhered to the format and content specified for each treatment's workshops, and teacher reactions and participation reflected the intended experience for each treatment (Shaw, 2015).

Seventy-nine percent of teachers from each treatment participated in a second one-day workshop in the Spring of 2014, after the first year of implementation. These workshops were designed to address common questions from the first year, and to emphasize the importance of fidelity. The workshop for EiE focused on mentoring teachers to ask open-ended questions that support students to reflect or brainstorm. The workshop for E4C focused on how to facilitate student readings and student design presentations.

We assigned each teacher one engineering unit to learn and teach to at least one of their classes each year of the study. Approximately one quarter of participating teachers were assigned to teach each engineering topic; approximately half of those teaching each engineering topic had been assigned to each of the teaching conditions. These numbers are not exact—because the landforms and erosion science topic was less commonly taught, and teachers addressing ecosystems with their classes more common, the geotechnical engineering units (matched to landforms) had the fewest teachers implementing, while the environmental engineering units (matched to ecosystems) had the largest number of teachers.

Teachers were also invited to volunteer to implement a Civil Engineering unit in addition to their assigned unit. As most of the teachers expressed interest, we randomly assigned those interested so that half of each treatment sample includes the second "dose" of engineering. The content of the civil engineering unit was not assessed; however teachers were required to implement it between pre- and post-assessment data collection.

Teachers' participation during the school year included three phases:

1. Collect pre-assessment and demographic data
2. Complete all related instruction (related science, the optional Civil Engineering unit, and the assigned Electrical OR Environmental Engineering unit)
3. Collect post-assessments and attitudes survey

Each teacher implemented their assigned engineering unit for two consecutive years, as mentioned earlier. Half of teachers also implemented the Civil Engineering unit matching their treatment condition with each of their classes. All teachers were required to implement the science content related to their assigned unit, using a curriculum of their choice. Both the optional unit and required science were to be completed before the assigned engineering unit.

Instruments

Engineering instruments suitable for elementary school students are only beginning to be published. Therefore, we have invested in the development of our own instruments and development process. This process begins with (1) the specification of learning objectives to be tested; (2) development of a large set of candidate questions for each learning objective; (3) analysis of questions to ensure they do not violate basic principles of item development as specified by Taylor and Smith (2009); (4) validity testing of revised items using a talk-aloud protocol for cognitive interviews with the target population of students; (5) revision and further validity testing as necessary; (6) reliability testing, IRT analysis, determining items to be dropped using PCA, finalizing of scales, and further revision as necessary. In-depth description of our instrument development process can be found in Lachapelle & Cunningham (2010).

Data analyzed for this paper is from two of the four pairs of EiE and E4C units: those addressing electrical engineering and environmental engineering. Each unit was assessed with three item scales covering two science and one engineering learning objective, as described in Table 1. The psychometric and descriptive characteristics for each of these scales, including Cronbach's alpha and number of items comprising the scale, as well as the posttest score descriptives for the sample used to develop the scales (N, mean, and standard deviation) are given in Table 3. For this paper, we analyze both the engineering and science assessments for each pair of units.

Table 3: Characteristics of unit-specific engineering & science assessment scales.

Unit	Domain Code	Scale Name	Item *N*	α	Posttest Score Descriptives					
					EiE			E4C		
					N	M	SD	N	M	SD
Electrical Engineering	ACe	Circuits	10	0.60	485	5.69	2.23	698	6.49	2.26
	ACs	Energy	6	0.74	475	3.91	1.79	703	4.38	1.81
		Electricity	6	0.77	475	3.79	1.79	703	4.11	1.71
Environmental Engineering	COe	Pollution	7	0.66	853	3.64	1.66	954	6.47	1.70
	COs	Read foodwebs	7	0.69	816	6.03	1.19	842	5.75	1.43
		Analyze foodwebs	6	0.78	816	4.75	1.63	842	4.44	1.76

Note: 'e' and 's' subscripts in the domain code denote "engineering" and "science," respectively.

For the electrical engineering units, the engineering learning objectives include that students can demonstrate (1) an understanding of electrical engineering and the role of electrical engineers in designing and improving electrical technologies; (2) that they can read and create schematic diagrams to represent and create electrical circuits; (3) that they can identify technologies using electricity and explain how those technologies transform electricity into other forms of energy; and (4) that they can communicate their ideas through drawings, justify design decisions, and understand testing as an important step in engineering design. Additionally, the EiE Electrical Engineering unit is designed such that students are supported to apply the following learning objectives previously addressed in their science curriculum: (1) they can identify different forms of energy and (2) they can identify insulators and conductors of electricity. The electrical engineering instruments are available in Appendix A.

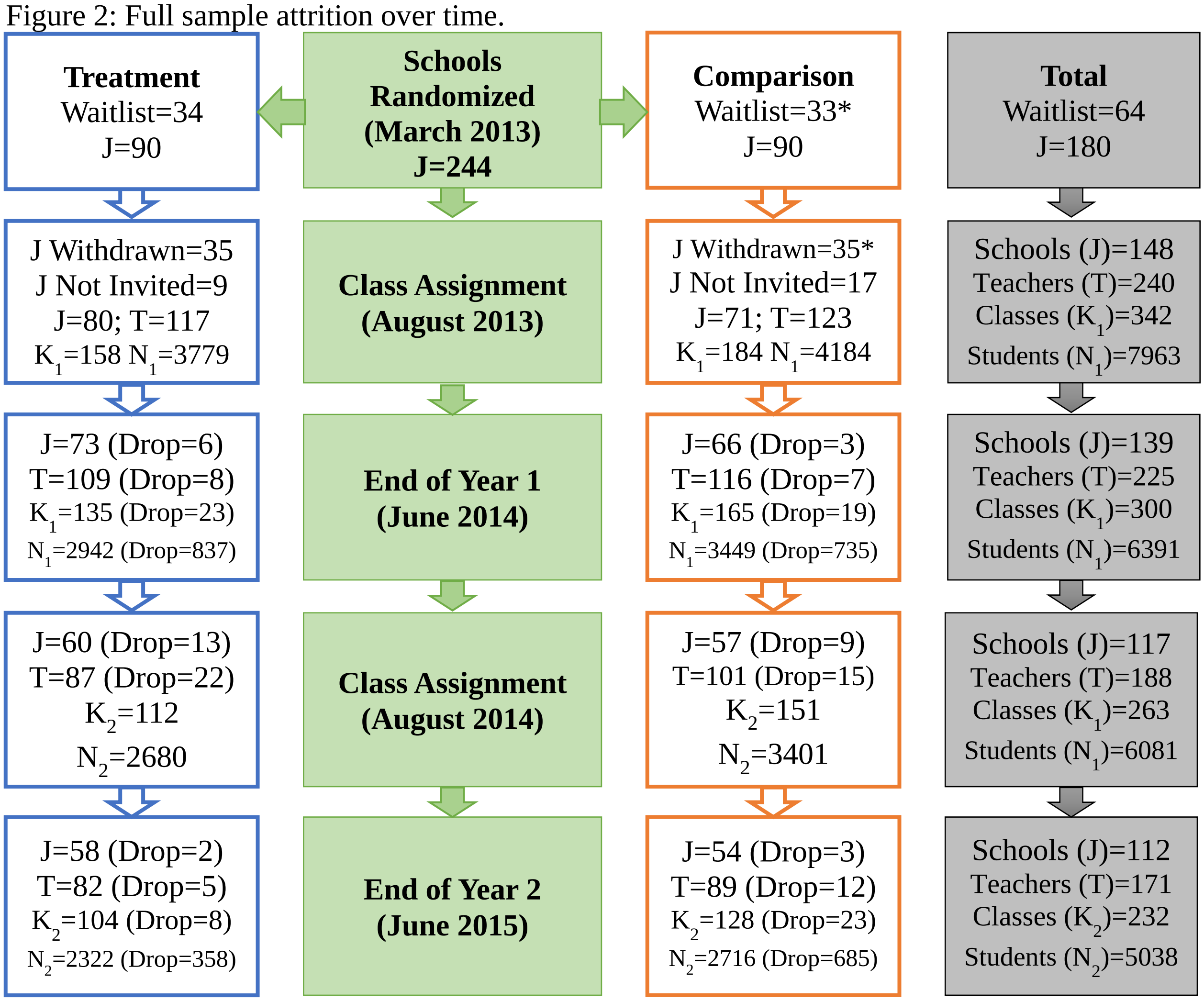
The engineering learning objectives for the environmental engineering units include that students can demonstrate (1) an understanding of environmental engineering and the role of environmental engineers in cleaning up pollution; (2) an understanding of the nature of pollution and different ways that pollution can spread, particularly via rain and the action of water moving above and underground; and (3) that they can communicate their ideas through drawings, justify design decisions, and understand testing as an important step in engineering design. In addition, the EiE Environmental Engineering unit is designed to reinforce the following learning objectives that should have been previously addressed in science: that students can demonstrate

(1) an ability to read food web and food chain diagrams; (2) an understanding of the major components of ecosystems (producers, consumers, decomposers, and the physical environment) and how they are interdependent; and (3) an understanding of how a change in one part of an ecosystem can be related to other changes. The engineering assessment includes 7 questions, and the science assessment includes 13 questions addressing the three learning objectives listed above (interpretation of food webs, components of ecosystems, and the implications of changes in ecosystems). The environmental engineering instruments are available in Appendix B.

Analytic Sample

We began the study in August of 2013 with 240 teachers in 148 schools with 342 classrooms and 7963 students (see Figure 2). Schools were distributed between the two treatments, while teachers (and their classes) were assigned to implement one of four engineering units within their treatment. Attrition was counted at four time points (Figure 2). Reasons for drops included teacher drops from the study, unusable student or class data during the data cleaning process, and student drops from the study (due to absences or moves).

Figure 2: Full sample attrition over time.



*Includes 3 schools randomized in error

For the current paper, we use the data from two pairs of E4 units: electrical and environmental engineering. Table 4 shows the initial and final samples (after attrition) for each pair of units. Demographic makeup of the samples is shown in Table 5. Student-level demographics used in this analysis included race/ethnicity, gender, and whether the student was an English learner (EL). At the class level, we modeled grade, year of implementation (first or second), and whether the class implemented the optional civil engineering unit. At the school level, we added treatment and state—Massachusetts (MA), Maryland (MD), or North Carolina (NC).

Table 4. Initial and final analytic sample sizes for each unit.

Unit Sample	Schools			Classrooms			Students		
	Total	EiE	E4C	Total	EiE	E4C	Total	EiE	E4C
Electrical Initial	39	18	21	144	61	83	3304	1491	1813
Electrical Final	36	16	20	122	48	74	2451	1034	1417
Environmtl Initial	54	29	25	204	98	106	4790	2334	2456
Environmtl Final	53	28	25	179	85	94	3717	1792	1925

Table 5. Demographics for final analytic samples.

Unit Sample	Electrical Engineering			Environmental Eng.		
	Total	EiE	E4C	Total	EiE	E4C
White	1337	530	807	2333	1181	1152
Black	476	235	241	552	184	368
Hispanic	204	96	108	372	182	190
Asian	150	54	96	156	94	62
Other	263	108	155	265	129	136
Male	1202	509	693	1916	950	966
Female	1234	516	718	1776	829	947
EL	84	32	52	166	92	74
Grade 3	8	3	5	30	13	17
Grade 4	87	40	47	32	17	15
Grade 5	27	5	22	117	55	62
Year 1	67	24	43	94	45	49
Year 2	55	24	31	85	40	45
Civil Unit	66	30	36	92	50	42
State-MA	12	5	7	9	5	4
State-MD	4	1	3	13	7	6
State-NC	19	10	9	31	16	15

Analytic Methods

We first examined the main effect of the intervention on each student achievement outcome and then proceeded to examine the moderating roles of student background characteristics in the association between intervention status and academic assessment outcomes. We used 3-level hierarchical linear modeling (Raudenbush & Bryk, 2002) to take into account the nested structure of the data (students nested within classrooms and classrooms nested within schools). We adjusted for a set of student-, classroom-, and school-level covariates. Student-level covariates included student gender, racial/ethnic background, free or reduced lunch eligibility status, limited English proficiency status, and pretest scores. Classroom-level covariates included grade level indicators (Grade 3 and Grade 4, with Grade 5 as a reference category), whether an extra engineering unit was implemented, and cohort. School-level covariates included a set of dummies indicating state (Maryland and North Carolina, with Massachusetts as a reference category) as well as the intervention status, our predictor of major interest.

To assess the main effect of the intervention, we estimated random intercept models, treating all level-1 and level-2 slopes as fixed. In level 1, each student assessment outcome was modeled as a function of the intercept, student-level predictors, and a random student-level error. In level 2, the intercept from the level-1 model was modeled as a function of the intercept for each school, classroom-level covariates, and a random classroom-level error. The level-3 model used the intercept from the level-2 model as a dependent variable and examined the effect of the intervention controlling for two dummy indicators of school location. To examine the moderating effects of student-level demographic characteristics, we added cross-level interaction terms, for example, gender-by-intervention, to the main outcome models by allowing each level-1 slope to vary across schools. We used the MPlus software package (Muthén & Muthén, 2015) for all analyses. We handled missing data using multiple imputation.

RESULTS

The results of main effect analyses (Table 6) showed significant and positive effects of the curriculum intervention on both science outcomes for the environmental engineering unit: Reading Food Webs (b = 0.316; p = .002) and Analyzing Food Webs (b = 0.289; p = .084). We did not find significant main effects of the intervention for any science or engineering assessment outcomes for the electrical engineering unit. Although the electrical engineering results were not statistically significant, there was a tendency for the treatment group to show higher posttest scores in all but one domain of the engineering and science assessment instruments (i.e., ACe).

Table 6. Impact of EiE Intervention on Engineering & Science Achievement

Unit	Code	Scale	Estimate	SE	*p*-value
Electrical Engineering	ACe	Circuits	-0.074	0.232	0.749
	ACs	Energy	0.068	0.157	0.662
		Electricity	0.053	0.169	0.756
Environmental Engineering	COe	Pollution	0.089	0.117	0.447
	COs	Read Food Webs	0.316	0.102	0.002
		Analyze Food Webs	0.289	0.108	0.007

We also found significant moderating effects of student racial/ethnic background and pretest scores. While the main effect of the intervention (EiE) was not statistically significant, the interaction between race/ethnicity and intervention status was statistically significant for one of the science outcomes in the electrical engineering unit, i.e., ACs-Energy. As shown in Figure 3, the intervention effectively increased the assessment outcome in ACs-energy for racial/ethnic minority students, but not for white students. We also found significant moderating effects of student race/ethnicity on both science assessment outcomes in the environmental engineering unit. As presented in Figure 4, the intervention significantly increased student ability to read food webs for students of both racial/ethnic groupings, but the effect of the intervention was stronger for minority students compared to white students. For student ability to analyze food webs, the interaction effect was even stronger. As shown in Figure 5, the intervention increased the outcome for both groups, but it was more effective in improving ability to analyze food webs among minority students, compared to white students. While minority students' performance was less than that of white students in the control group, they outperformed white students in the treatment group.

In addition to student race/ethnicity, the results also show a significant moderating effect of pretest scores in the association between the intervention status and one of the science assessment outcomes in the unit of environment of engineering, i.e., reading food webs. As displayed in Figure 6, students in the treatment group generally performed better than those in the control group, but the gap between the treatment and control groups was greater for those with lower pretest scores. This result suggests that the intervention was more effective for low-performing students.

Figure 3: Significant moderating effect of race/ethnicity for ACs-Energy.

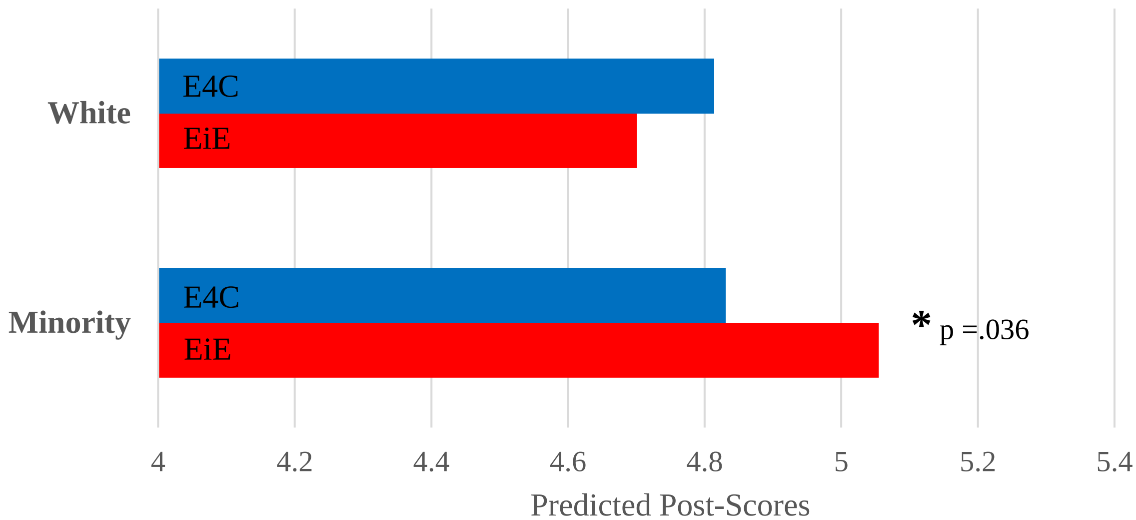


Figure 4: Significant moderating effect of race/ethnicity for COs-Read Food Webs.

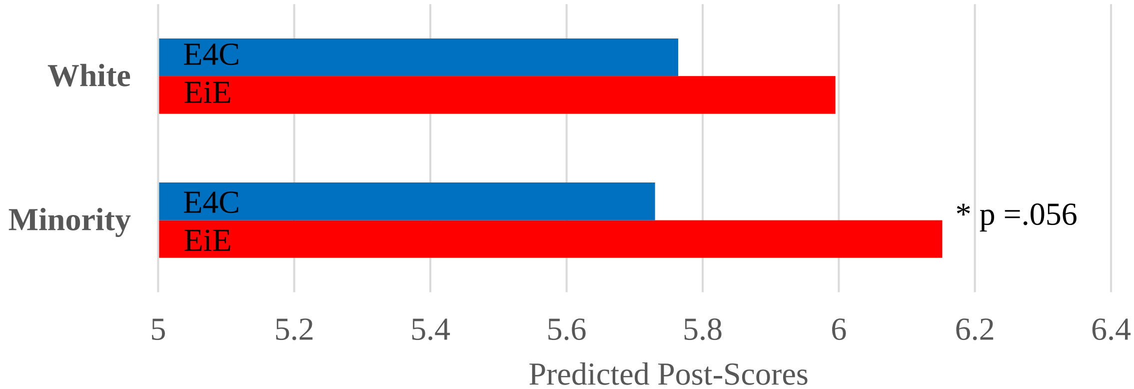


Figure 5: Significant moderating effect of race/ethnicity for COs-Analyze Food Webs.

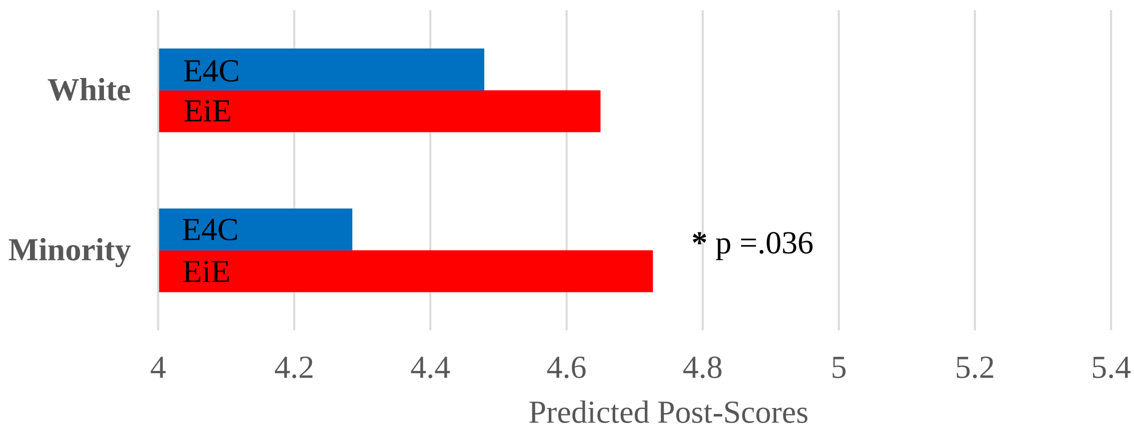
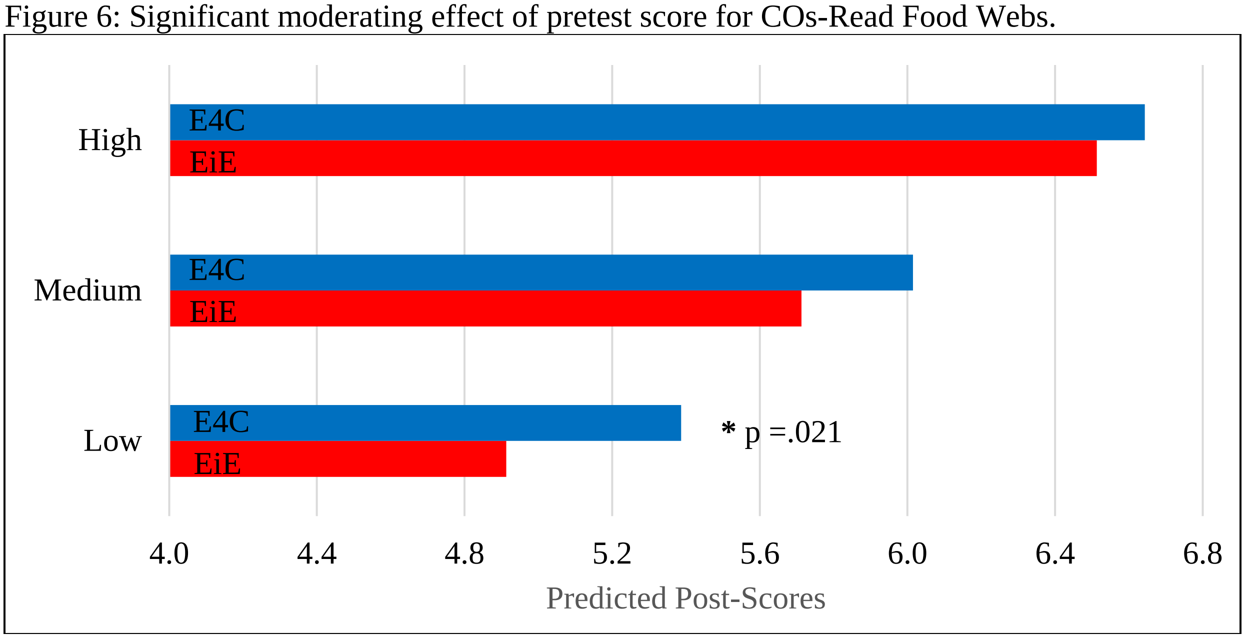


Figure 6: Significant moderating effect of pretest score for COs-Read Food Webs.



DISCUSSION

In the proposed study, our goal is to assess the main effect of the intervention and the moderating roles of student characteristics. Our current analyses provide some evidence for the efficacy of the EiE intervention for improving student learning of science concepts. Given the relatively short period of the curriculum implementation, only about 8-10 instructional hours in total, we consider these findings promising. It appears that an engineering intervention that incorporates support and opportunities to apply science learning to an engineering design challenge can improve students' learning of the targeted science concepts.

Furthermore, we found that the intervention curriculum was particularly effective for improving achievement outcomes for disadvantaged students, i.e., racial/ethnic minority students and initially low-performing students. These findings suggest that the EiE intervention could contribute to reducing science achievement gaps between advantaged and disadvantaged students by presenting design challenges that engage students from diverse backgrounds in the application of science to a contextualized engineering problem.

NEXT STEPS

Our next steps for the analysis include (1) modeling the main and moderating effects of the other two unit pairs, geotechnical engineering and package engineering; (2) modeling the mediating effects of implementation fidelity; and (3) creating a set of models of standardized engineering and science scores from all unit pairs.

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Electrical Engineering Assessment

Marking Instructions	
• Use a No. 2 pencil or a blue or black ink pen only. • Do not use pens with ink that soaks through the paper. • Make solid marks that fill the response completely. • Make no stray marks on this form.	CORRECT: ● INCORRECT:

Name:______________________________________ Date:________________

For each question below, fill in the bubble for the **BEST** answer.

1. The figures below show a light bulb connected to a battery in two different ways. When the switch in Figure 1 is closed, the bulb will light. What will happen when the switch is closed in Figure 2?

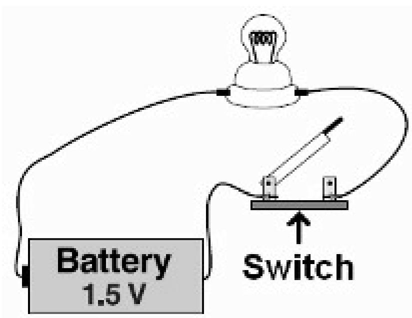


Figure 1

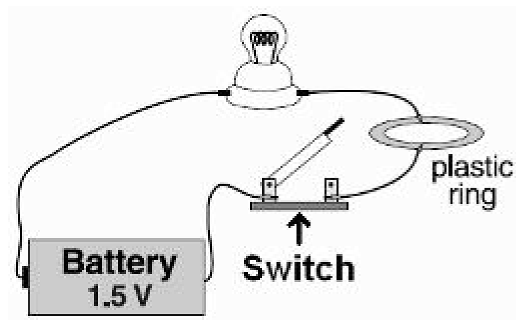


Figure 2

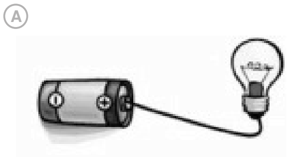
Ⓐ The bulb will light just as it did in Figure 1.

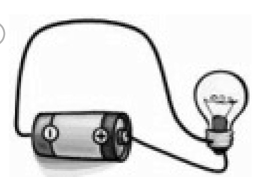
Ⓑ The bulb will be brighter than it was in Figure 1.

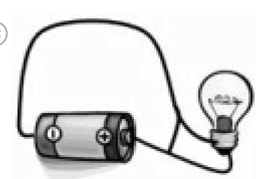
Ⓒ The bulb will light, but it will be less bright than it was in Figure 1.

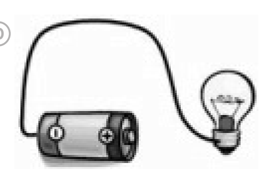
Ⓓ The bulb will not light at all.

2. Which picture shows a circuit that will cause the bulb to light up?

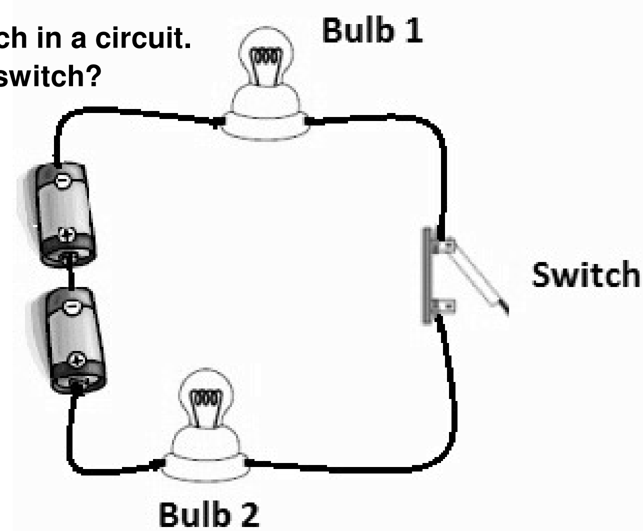
Ⓐ


Ⓑ


Ⓒ


Ⓓ


3. **The picture to the right shows two bulbs and a switch in a circuit. Which of the bulbs can be turned on and off by the switch?**



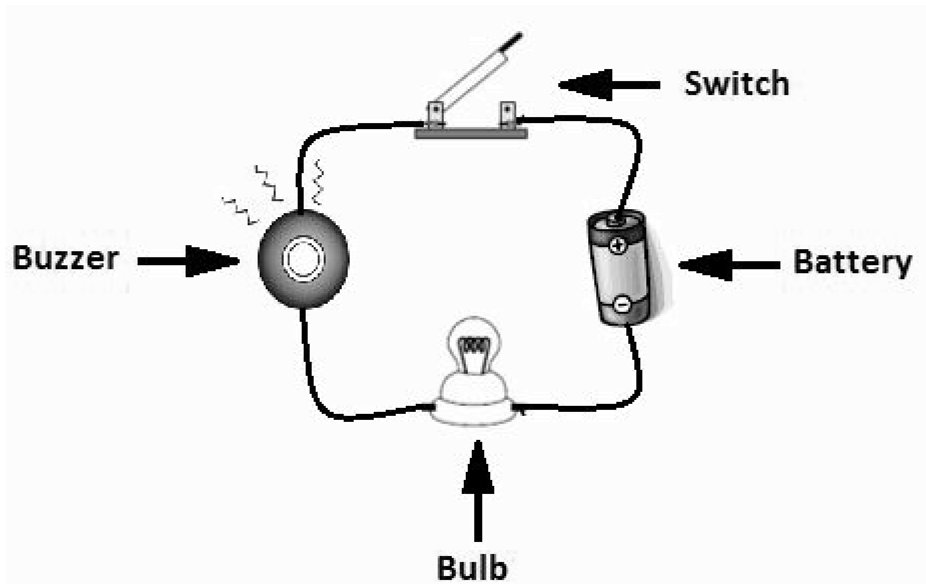
Ⓐ bulb 1

Ⓑ bulb 2

Ⓒ both bulbs

Ⓓ neither bulb

4. **Which set of parts could you replace with wire in the circuit below? You should still have a safe and complete circuit.**



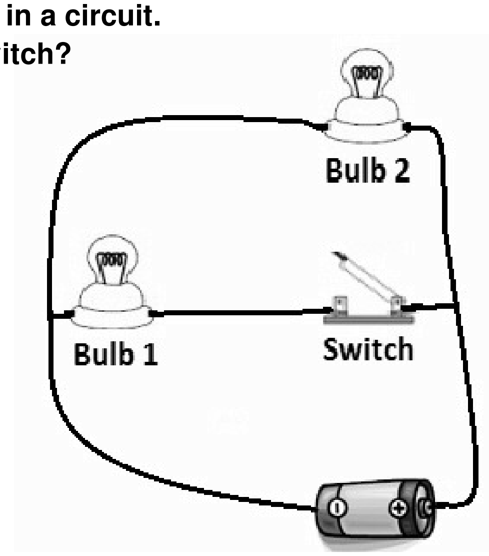
Ⓐ battery and bulb

Ⓑ battery and buzzer

Ⓒ switch and bulb

Ⓓ switch, bulb, and buzzer

5. **The picture to the right shows two bulbs and a switch in a circuit. Which of the bulbs can be turned on and off by the switch?**



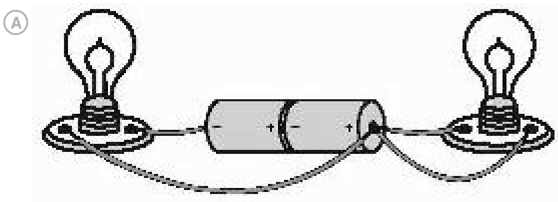
Ⓐ bulb 1

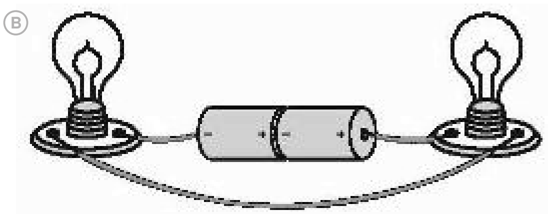
Ⓑ bulb 2

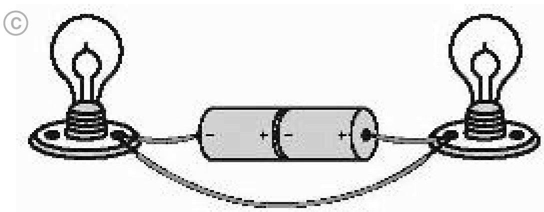
Ⓒ both bulbs

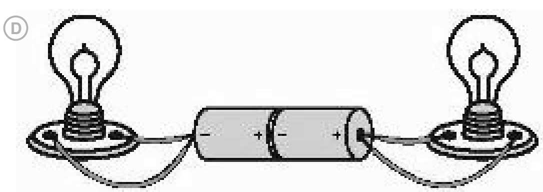
Ⓓ neither bulb

6. **In which circuit below will both bulbs light?**

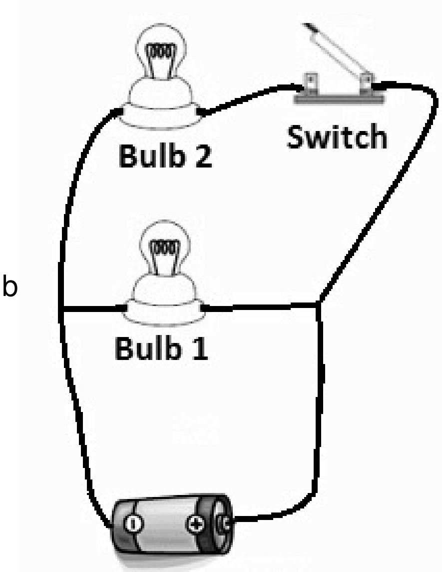
Ⓐ


Ⓑ


Ⓒ


Ⓓ


7. **The picture below shows two bulbs and a switch in a circuit. Which of the bulbs can be turned on and off by the switch?**



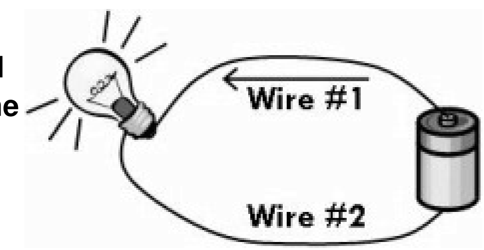
Ⓐ bulb 1

Ⓑ bulb 2

Ⓒ both bulbs

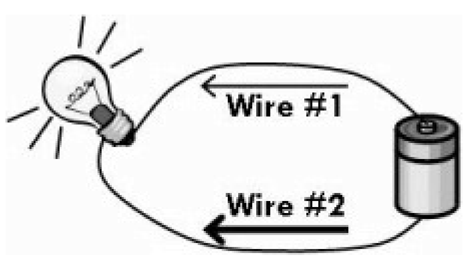
Ⓓ neither bulb

8. **The picture to the right shows a glowing light bulb connected to a battery using wires. An electric current is flowing from the battery, through Wire #1, to the bulb.**

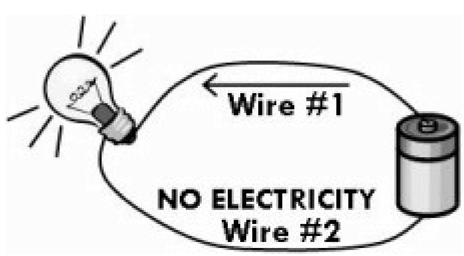


What is happening in Wire #2?

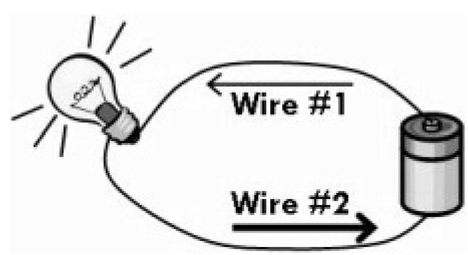
Ⓐ The electricity flows through Wire #2 from the battery to the bulb.



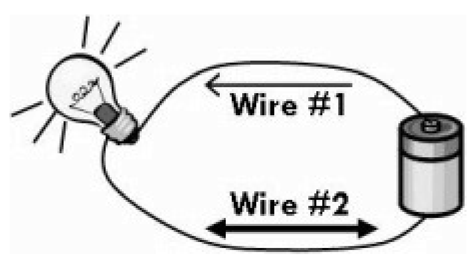
Ⓑ No electricity flows in Wire #2, it is all used up by the bulb.



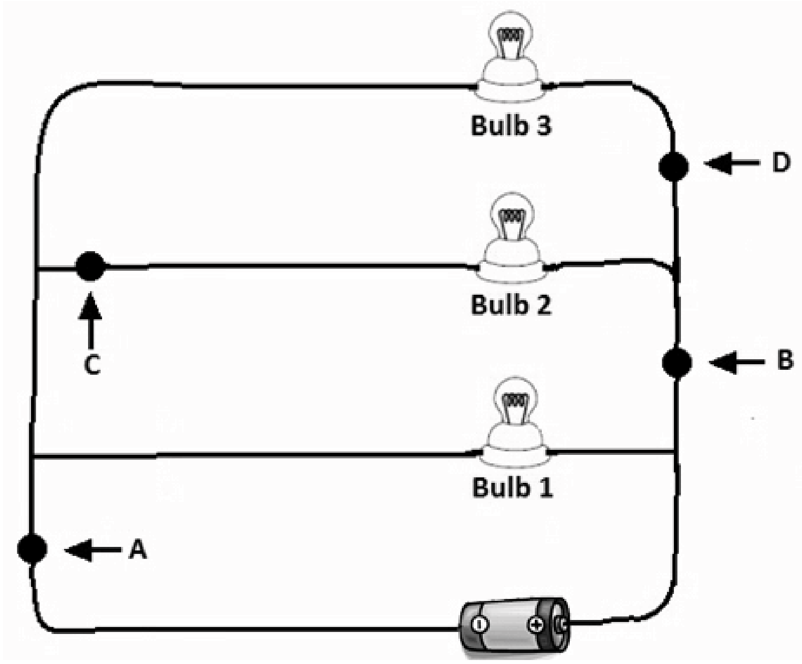
Ⓒ The electricity flows through Wire #2 away from the bulb to the battery.



Ⓓ Electricity flows both ways through Wire #2, from the battery to the bulb and back again.



The picture below shows three light bulbs in a circuit. Use the picture to answer questions 9 and 10.



9. Where should you put a switch so that bulb 2 and bulb 3 can be switched on and off, but bulb 1 will stay on all the time?

Ⓐ location A   Ⓒ location C

Ⓑ location B   Ⓓ location D

10. Where should you put a switch so that bulb 2 can be turned on and off, but bulb 1 and bulb 3 will remain on all the time?

Ⓐ location A   Ⓒ location C

Ⓑ location B   Ⓓ location D

Question 3 from MCAS 2007 STE Assessment- Gr 5.
Question 4 from MCAS 2003 Science and Technology/Engineering (STE) Assessment - Grade 5. Question 9 from MCAS 2010 STE Assessment- Gr 5.
Massachusetts Department of Elementary and Secondary Education, Boston.

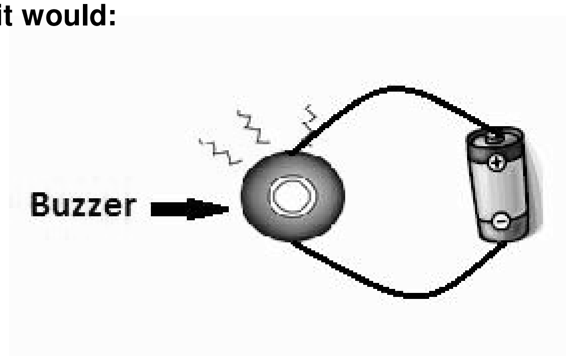
Electricity Assessment

Marking Instructions	
• Use a No. 2 pencil or a blue or black ink pen only. • Do not use pens with ink that soaks through the paper. • Make solid marks that fill the response completely. • Make no stray marks on this form.	**CORRECT:** ● **INCORRECT:**

Name:______________________________ Date:______________

For each question below, fill in the bubble for the **BEST** answer.

1. The picture below shows a circuit with a battery connected to a buzzer with wires. The circuit is making a noise. Energy flowing through the circuit would:



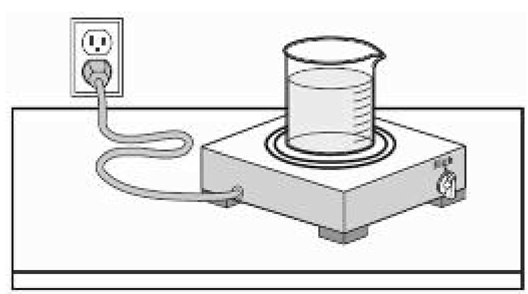
Ⓐ use up all the sound energy.

Ⓑ change from light energy into sound energy.

Ⓒ change from sound energy into electrical energy.

Ⓓ change from electrical energy into sound energy.

The picture below shows a glass of water being heated on a hot plate. Energy is changing from one form to another. Use this information to answer questions 2 and 3.



2. At first, the energy is in what form?

Ⓐ plug
Ⓒ cold
Ⓑ heat
Ⓓ electricity

3. What form does the energy change into?

Ⓐ heat
Ⓒ electricity
Ⓑ water
Ⓓ hot plate

4. What is the name for any material that electricity can easily flow through?

Ⓐ a wire
Ⓑ a current
Ⓒ an insulator
Ⓓ a conductor

5. Any material that electricity can <u>NOT</u> easily flow through is called:

Ⓐ rubber
Ⓑ a switch
Ⓒ an insulator
Ⓓ a conductor

6. Which of the following is an electrical conductor?

Ⓐ cloth
Ⓑ glass
Ⓒ copper
Ⓓ all of these

When a light bulb is turned on, energy changes from one form to another.

7. At first, the energy is in what form?

Ⓐ plug
Ⓑ light
Ⓒ darkness
Ⓓ electricity

8. What form does the energy change into?

Ⓐ light
Ⓑ lamp
Ⓒ light bulb
Ⓓ electricity

9. Electricity:

Ⓐ is used up by a battery.
Ⓑ can move through an open switch.
Ⓒ can move through a closed circuit.
Ⓓ all of the above.

10. When an electric fan is running, <u>MOST</u> of the incoming electricity changes into which kind of energy?

Ⓐ heat energy
Ⓑ light energy
Ⓒ mechanical energy
Ⓓ sound energy

11. Which of the following is an electrical insulator?

Ⓐ cloth
Ⓑ glass
Ⓒ rubber
Ⓓ all of the above

12. Electricity can easily flow through:

Ⓐ an insulator.
Ⓑ an open switch.
Ⓒ a closed switch.
Ⓓ a schematic diagram.

Questions 2 & 3 from MCAS 2008 Science and Technology/Engineering (STE) Assessment - Grade 5.
Question 4 from MCAS 2009 STE Assessment- Grade 5. Questions 8 & 9 from MCAS 2005 STE Assessment- Grade 5.
Massachusetts Department of Elementary and Secondary Education, Boston.

Environmental Engineering Assessment

E4

Name: ______________________________

Date: ______________________________

Marking Instructions
• Use a No. 2 pencil or a blue or black pen.
CORRECT: ●
INCORRECT: ✓ ⊠ ◒ ◔

1. Chemicals spill onto the ground near a lake and sink into the dirt. The chemicals do not fall into the lake. Could chemicals get into the lake water anyway? Choose the BEST answer.

Ⓐ No, because chemicals didn't fall in the lake.

Ⓑ No, because the chemicals will sink down into the dirt, not sideways into the lake.

Ⓒ Yes, because animals can move the chemicals into the water.

Ⓓ Yes, because water moving under the ground can move the chemicals into the lake.

2. A truck crashes and spills oil into a pond. Could plants growing in the soil near the pond get sick from the pollution?

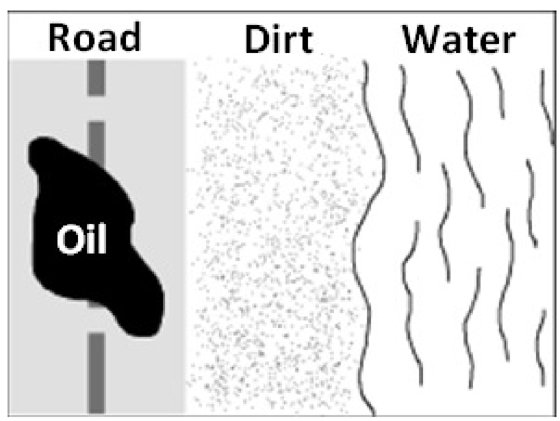
Ⓐ No, plants don't get sick from pollution.

Ⓑ No, pollution can't move from water to soil.

Ⓒ Yes, water can move pollution through the soil and hurt the plants.

Ⓓ Yes, but only if the water from the pond splashes onto the plants.

3. Oil spilled on a road as shown in the diagram. Will the oil reach the water?



Ⓐ No, the oil will stay on the road.

Ⓑ No, the dirt will soak up the oil and hold it.

Ⓒ Yes, the oil will slide over the dirt.

Ⓓ Yes, the rain will move the oil through the dirt and into the water.

4. Dangerous chemicals spill into a garden. Is it a good idea to pour water on the area?

Ⓐ No, because the water will spread the chemicals to more places.

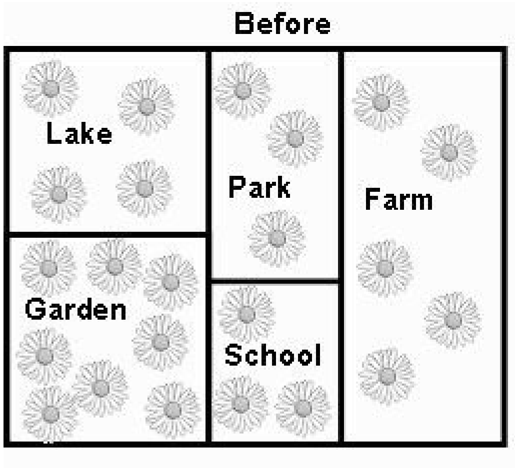
Ⓑ No, because the water will go into the plants before it touches the chemicals.

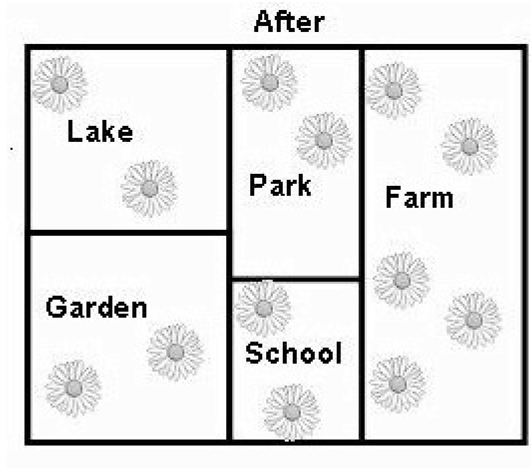
Ⓒ Yes, because the water will collect the chemicals in one area.

Ⓓ Yes, because the water will clean the chemicals out of the garden.

A harmful chemical that kills flowers was spilled somewhere in a town. The maps below show the numbers of flowers in different parts of the town before and after the spill.

Use this information to answer questions 5 - 6.





5. Did the chemical kill the flowers in places where it was not spilled?

Ⓐ No, the chemical cannot move.

Ⓑ No, the chemical cannot move that far.

Ⓒ Yes, people must have moved the chemical.

Ⓓ Yes, chemicals can move through the ground.

6. The chemical was spilled last year. Do people at the farm need to worry about the chemical killing their flowers in the future?

Ⓐ No, the chemical is done moving.

Ⓑ No, the chemical can't move from the place it was spilled.

Ⓒ Yes, water can move the chemical through the ground.

Ⓓ Yes, but only if animals walk through the chemical and move it.

---

7. A tank outside of a factory leaks pollution into the soil. Could the pollution spread to areas that are a mile away from the factory?

Ⓐ No, because pollution can't spread that far through the ground.

Ⓑ Yes, because factories are very big.

Ⓒ Yes, because water can spread pollution through the ground.

Ⓓ Yes, but it only spreads if people or animals walk on the polluted dirt and move it.

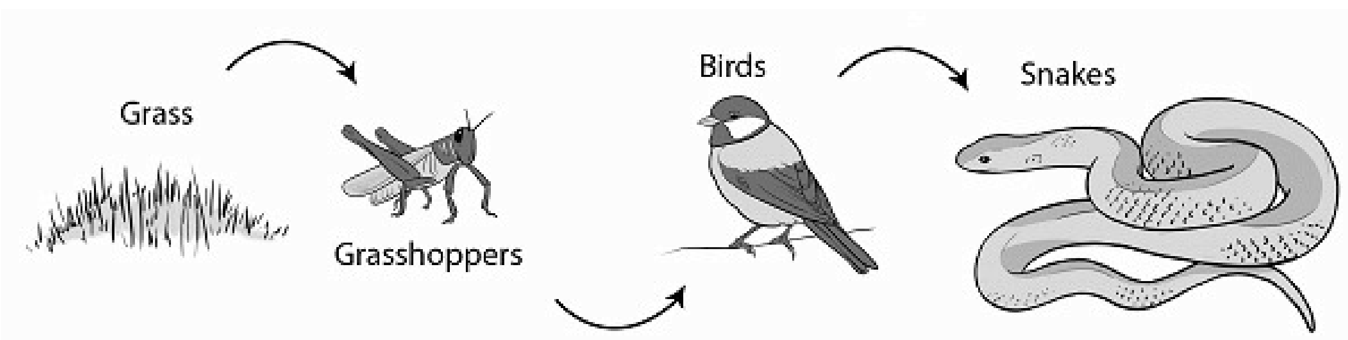
Ecosystems Assessment

Marking Instructions	
• Use a No. 2 pencil or a blue or black ink pen only. • Do not use pens with ink that soaks through the paper. • Make solid marks that fill the response completely.	CORRECT: ● INCORRECT:

Name:____________________ Date:____________

For each question below, fill in the bubble for the **BEST** answer.

1. The diagram below shows a food chain. Which of the following is a producer?



Ⓐ grass Ⓑ grasshoppers Ⓒ birds Ⓓ snakes

2. Which of the following events involves a consumer and a producer in a food chain?

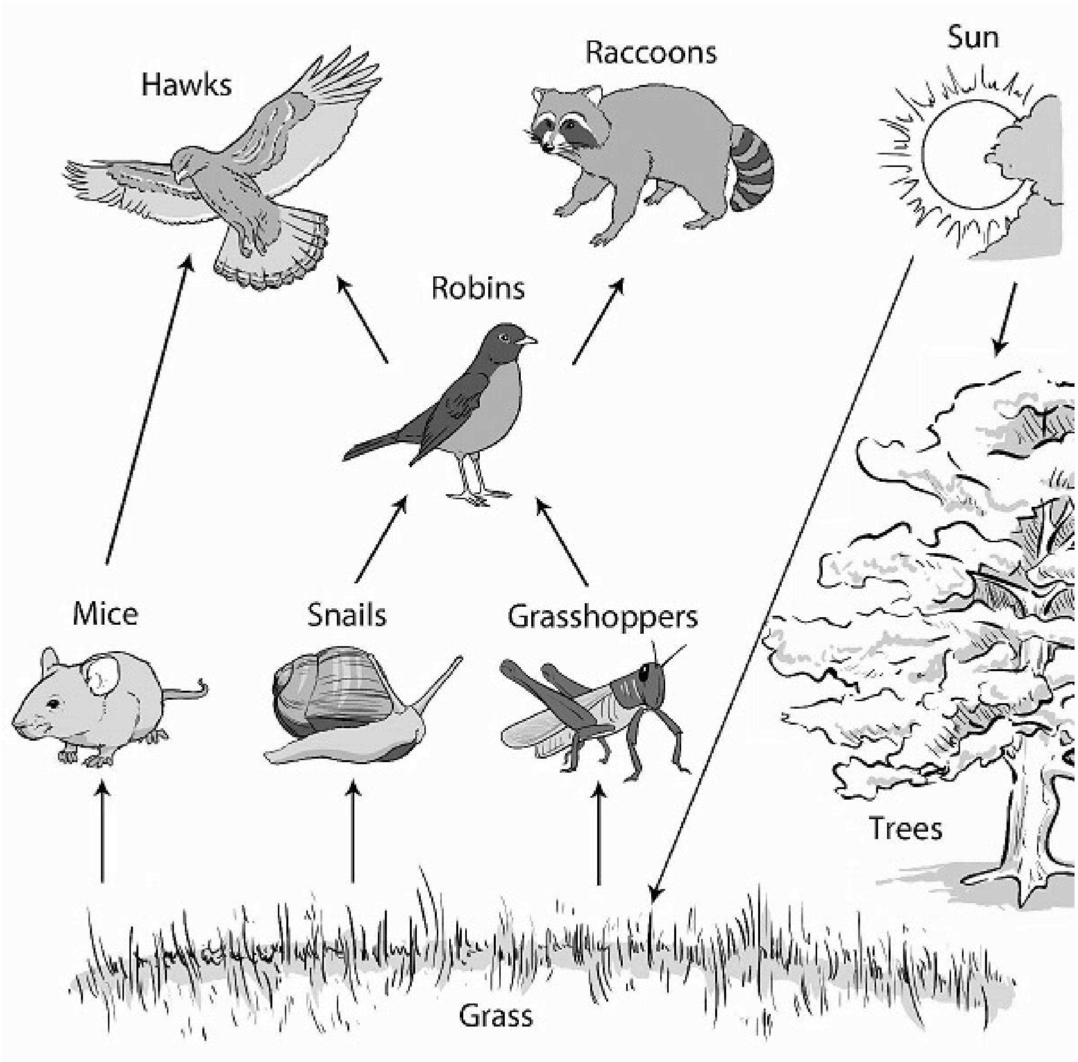
Ⓐ a deer eats a leaf

Ⓑ a snake eats a rat

Ⓒ a cat eats a mouse

Ⓓ a hawk eats a mouse

The diagram below shows part of a food web for a meadow ecosystem.
Use it to answer questions 3 - 7.



3. What does the arrow from the grasshopper to the robin in the food web diagram mean?

Ⓐ that robins get energy from grasshoppers

Ⓑ that grasshoppers get energy from robins

Ⓒ that grasshoppers and robins live next to one another

Ⓓ that robins are more important than grasshoppers in the ecosystem

4. Which of the following lists all of the consumers in this food web diagram?

Ⓐ grass and trees

Ⓑ hawks, robins, and raccoons

Ⓒ mice, snails, and grasshoppers

Ⓓ mice, snails, grasshoppers, hawks, robins, and raccoons

Use the diagram on the previous page to answer questions 5 - 7.

5. Which of the following is NOT a food chain found in this food web diagram?

Ⓐ grass-mice-hawks

Ⓑ grass-mice-raccoons

Ⓒ snails-robins-raccoons

Ⓓ grass-grasshoppers-robins-hawks

6. If the grass in the meadow stopped growing, what would probably happen in the meadow ecosystem? Please answer questions *a* through *e*.

a. There would be...	① fewer	② the same number of	③ more	**...snails.**
b. There would be...	① fewer	② the same number of	③ more	**...robins.**
c. There would be...	① fewer	② the same number of	③ more	**...hawks.**
d. There would be...	① fewer	② the same number of	③ more	**...raccoons.**
e. There would be...	① fewer	② the same number of	③ more	**...grasshoppers.**

7. If a disease caused most of the robins to die, what would probably happen in the meadow ecosystem? Please answer questions *a* through *c*.

a. There would be...	① fewer	② the same number of	③ more	**...snails.**
b. There would be...	① fewer	② the same number of	③ more	**...raccoons.**
c. There would be...	① fewer	② the same number of	③ more	**...grasshoppers.**

Question 1 from MCAS 2006 Science and Technology/Engineering Assessment- Grade 5.
Question 2 from MCAS 2008 Science and Technology/Engineering Assessment- Grade 5.
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