2012

Engineering Education in the Science Classroom: A Case Study of One Teacher's Disparate Approach with Ability-Tracked Classrooms

Christine G. Schnittka

Follow this and additional works at: <https://docs.lib.purdue.edu/jpeer>

Recommended Citation

Schnittka, C. G. (2012). Engineering Education in the Science Classroom: A Case Study of One Teacher's Disparate Approach with Ability-Tracked Classrooms. *Journal of Pre-College Engineering Education Research (J-PEER)*, 2(1), Article 5.

<https://doi.org/10.5703/1288284314654>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

This is an Open Access journal. This means that it uses a funding model that does not charge readers or their institutions for access. Readers may freely read, download, copy, distribute, print, search, or link to the full texts of articles. This journal is covered under the [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Engineering Education in the Science Classroom: A Case Study of One Teacher's Disparate Approach with Ability-Trackd Classrooms

Abstract

Currently, unless a K-12 student elects to enroll in technology-focused schools or classes, exposure to engineering design and habits of mind is minimal. However, the *Framework for K-12 Science Education*, published by the National Research Council in 2011, includes engineering design as a new and major component of the science content to be taught by all K-12 teachers of science. This addition will likely require substantial teacher preparation in all the states that adopt the new standards that will be developed from the *Framework*. Engineering design will not be taught as just an elective to students who have prior interest in a career in engineering, but also as a habit of mind and a 21st century skill to *all* students in their regular classes. In this case study, one middle school science teacher taught an engineering design-based curriculum to two different classes of 8th grade students: a high-track and a low-track. The low-track class contained a substantial number of students with learning disabilities. Given the freedom to differentiate her teaching based on the needs of her students, the teacher provided a disparate learning environment for her lower-tracked students, and disparate learning outcomes were evident. This study is designed to begin the discussion about equity in engineering education at the K-12 level. Engineering design-based science instruction can level the playing field for students with learning differences if teachers are prepared for the challenge.

Keywords

engineering design, middle school, tracking, equity

Document Type

Research Article

Journal of Pre-College Engineering Education Research 2:1 (2012) 35–48
DOI: 10.5703/1288284314654

Engineering Education in the Science Classroom: A Case Study of One Teacher's Disparate Approach with Ability-Tracked Classrooms

Christine G. Schnittka

University of Kentucky

Abstract

Currently, unless a K-12 student elects to enroll in technology-focused schools or classes, exposure to engineering design and habits of mind is minimal. However, the *Framework for K-12 Science Education*, published by the National Research Council in 2011, includes engineering design as a new and major component of the science content to be taught by all K-12 teachers of science. This addition will likely require substantial teacher preparation in all the states that adopt the new standards that will be developed from the *Framework*. Engineering design will not be taught as just an elective to students who have prior interest in a career in engineering, but also as a habit of mind and a 21st century skill to *all* students in their regular classes. In this case study, one middle school science teacher taught an engineering design-based curriculum to two different classes of 8th grade students: a high-track and a low-track. The low-track class contained a substantial number of students with learning disabilities. Given the freedom to differentiate her teaching based on the needs of her students, the teacher provided a disparate learning environment for her lower-tracked students, and disparate learning outcomes were evident. This study is designed to begin the discussion about equity in engineering education at the K-12 level. Engineering design-based science instruction can level the playing field for students with learning differences if teachers are prepared for the challenge.

Keywords: engineering design, middle school, tracking, equity

Introduction

Engineering education and science education are about to undergo a merger in U.S. public schools. With the recent release of the National Research Council's (NRC, 2011), new *Framework* for K-12 Science Education, engineering education will be in the purview of science teachers across the nation. The NRC stresses in this framework that engineering will be a disciplinary area featured along with the natural sciences for *all* students. The framework is intended to be a guide for new state and national standards, new curriculum, new professional development, and the education of new teachers. The engineering elements embedded in the framework are especially important for science instruction at the K-8 level since engineering design principles and experiences are unlikely to appear in other disciplinary areas, "and thus are neglected if not included in science instruction" (NRC, 2011; p.1–4). Science and engineering disciplines are linked in so many ways, and while design can take place without a deep conceptual understanding of the science concepts at work behind the scenes, understanding the way the natural world works does indeed enhance and influence the way engineers solve problems and

invent solutions. Engineering education gives science something practical and tangible to grasp. Science education gives engineering the theories and laws of nature that promote functional, rather than merely aesthetic, designs.

Furthermore, engineering design activities are natural for children. From the youngest years of life, children build, tear down, and re-shape their worlds regardless of their academic prowess. Design is a natural human process, and engineering design-based instruction can level the playing field for students with learning differences. With its emphasis on creativity, design, and non-verbal representations of ideas, engineering can be an equalizer for students if their teachers are prepared for the challenge. Teacher education programs have traditionally done little to prepare future science teachers for working with students with learning, physical, or emotional difficulties (Norman et al., 1998). The science class has so much potential for providing a least restrictive environment for students with disabilities, as science classes are conducive to collaborative work groups and a variety of modalities for presenting content (Cawley et al., 2002). However, this potential is not often reached as learning-disabled students are marginalized in science (Carlisle & Chang, 1986). Special education teachers are often not trained in science teaching (Patton et al., 1990), and general education teachers are often not trained sufficiently in special education (NSF, 1997). Additionally, when middle school science students are tracked by ability levels and placed in different leveled classes, students with disabilities are often placed in lower level classes, and multiple studies indicate that students in these classes learn less than their comparable peers in mixed-level classes (Hoffer, 1992). This is the milieu into which engineering design education will be introduced.

Ability tracking in middle school is contentious. While teachers may prefer tracked classes because they are able to teach homogeneous groups, especially high achieving ones, tracking has been shown in numerous studies to benefit higher-ability students and harm lower-ability ones (Hoffer, 1992; Slavin, 1993). Tracking promotes lower expectations from teachers and students alike, and results in lower achievement levels among comparably able students (Gamoran, 1987). The new framework for K-12 science education is not designed solely to educate future scientists and engineers but to ensure that:

by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives (NRC, 2011; p.ES-1).

Ability tracking in science at the middle school level has the potential to limit the degree to which students with

learning differences will engage in rich, meaningful engineering design experiences.

Self-efficacy (Bandura, 1977) is a psychological construct that connects how confident a person is in his abilities with his actual motivation to succeed and performance accomplishments. Teacher self-efficacy, the perception teachers have about the degree of influence they have on their students' achievement, is an issue that comes into play when accommodating special needs students, or students who typically do not excel academically. Teachers with low self-efficacy spend less time on academics in class, are more prone to give up on students who are not quickly excelling, and blame those students for their failures (Gibson & Dembo, 1984). A teacher's self-efficacy is also influenced by the types of students he or she has. Teachers typically have lower self-efficacy with lower-ability students, and more self-efficacy with higher-ability students. This in turn influences how well different groups of students learn (Gusky, 1987).

When general education teachers are prepared to make accommodations for their special needs students, they often fail to do so, whether in tracked classes or heterogeneous ones (Baker & Zigmond, 1990; Schumm & Vaughn, 1991). Bottge (2001) developed a teaching model based on learning theories that suggests how to effectively teach students with lower achievement levels. The model involves teaching skills explicitly, providing motivating tasks and meaningful projects, and having students work on authentic problems in collaborative, supportive groups. In this way, students can understand the concepts but also make links between their learning in school and their home experiences. Students at lower ability levels need to be exposed to enriched curricula in order to show achievement gains (Ireson & Hallam, 1999).

Research in the area of special education has provided many suggestions for ways general education teachers can make adaptations for the special education students in their classrooms. For a variety of reasons- confidence, knowledge and skills, this research does not always make its way into practice (Schumm et al., 1994). Brown et al. (1991) reviewed the literature and listed the 10 most commonly recommended adaptations for special education students in the regular classroom. They included curriculum modification, peer tutoring, and cooperative learning. However when they studied teachers in practice, they found that these techniques were infrequently used. When these adaptations are used, there is quite a bit left to interpretation by the teacher about how best to use them.

The National Research Council's framework for science teaching (NRC, 2011) includes what students should know about science and engineering. They state emphatically that engineering is integral to K-12 science instruction. The NRC stresses that the essential elements of engineering should be taught to all students. In particular, design is the approach used by engineers to solve problems. With the lack of

research on how science teachers effectively scaffold instruction for special needs students, and the initiation of new standards with include engineering, more research is necessary to determine how science teachers should incorporate engineering design education so that it is not just for the highest performing students, but for all students.

Theoretical Framework

The key features of this study are: problem solving through design, working within social groups, creating artifacts, and scaffolding by a more knowledgeable person—the classroom teacher (Krajcik & Czerniak, 2007). These features fit well within the theoretical framework of social constructivism, which guided the data collection and the data analysis. Social constructivist perspectives emphasize that the student plays an active, rather than passive, role in learning. Teachers find out what students know, what they are thinking, and scaffold understanding as the mind of the learner constructs knowledge through discourse and concrete sense-making activities (Bleicher & Lindgren, 2005; Palinscar, 1998; Tobin & Tippins, 1993; Vygotsky, 1978). The social exchange of ideas between peers and between students and teacher is a key element in the social constructivist classroom. The role of the teacher was vital to the success of this intervention, as students were not expected to construct scientific understandings alone, but with the help of the teacher, socially mediated through discourse with peers.

Purpose

The purpose of this study is to determine how one teacher made curricular adaptations and differentiated between her standard and advanced-level classes when given the same engineering design-based science curricula to teach.

By matching teaching practices to the student achievement in science concepts and design tasks embedded in the curriculum, this study attempts to shed light on teaching engineering design in science classrooms for equitable learning. The major research questions were:

1. How did the teacher modify the curriculum for her upper and lower-level science classes?
2. How did the teacher's instructional practices differ between the upper and lower-level classes?
3. What were the learning outcomes in the two classes?
4. What inferences can be drawn about the relationship between learning outcomes and teaching strategies?

Methods

This case study examined one teacher and two of her eighth grade classes in a suburban public school in a Mid-Atlantic state at the beginning of the school year. Students

participated in an engineering design-based science curriculum called *Save the Penguins* in order to learn about heat transfer, the environment, and engineering (Schnittka, Bell & Richards, 2010). *Save the Penguins* was initially conceived at the University of Virginia by engineering students and the Virginia Middle School Engineering Education Initiative, but has been modified significantly by the author for various studies (Schnittka & Bell, 2011; Schnittka et al., 2010; Motto et al., 2011). The curriculum was ideal for special needs students according to Bottge's (2001) recommendations in that it was motivating, explicit, authentic and meaningful, and collaborative.

Students worked in groups of four, and were required to test materials, then design, build, and test a device designed to keep a penguin shaped ice cube from melting in a test oven. The curriculum was set in a broader context of how global warming is affecting penguin habitats and food resources, and students made the connection between what we do to insulate our buildings here at home and energy efficiency, energy use, greenhouse gas emissions, and global warming. One teacher taught two levels of students—advanced and standard. The standard-level class had a significant number of students with learning, behavioral, and physical disabilities. The teacher was instructed to use the same curriculum with both classes, but was expected to adapt the curriculum to the special needs of her students. A special-education collaborative teacher was present in the standard-level classroom, but his role was peripheral, primarily providing an extra set of hands, watching over the class, and walking around. In addition to teacher interviews, all classes were observed and qualitative field notes were taken by the author. Each class was also videotaped and transcribed word-for-word with frequent time stamps for further analysis. Analytic induction was used for data analysis, as preliminary codes collapsed into themes (Erickson, 1986). Pre and posttests were administered to each student, and select students were interviewed at the completion of the unit. Penguin houses created by teams were also analyzed for their effectiveness and creativity.

Participants

The standard-level class consisted of 23 students: 13 boys and 10 girls. One student was African American, one was Indian American, and one was Asian American; the rest were Caucasian. The advanced-level class also consisted of 23 students: 12 boys and 11 girls. Two were African American, one was Indian American, and two were Asian American; the rest were Caucasian. During their 7th grade year students were tested by the state in math and language arts. The classes were quite different in terms of standardized test scores in mathematics and language arts, but similar in terms of gender and ethnicity characteristics. Less than half the students in the standard-level class

passed their 7th grade state math assessment while almost all of the 23 students in the advanced-level class passed. They were also quite different in terms of specific disabilities. Thirteen of the 23 students in the standard-level class were identified as needing special education services due to learning disabilities, hearing impairments, autism, ADHD, and other psychological issues. However, to an outside observer, these two classes would look very similar. They were each full of excited, chatty, engaged, and eager learners. Behavior issues were similar and mild in both classes- what was typically seen in 8th grade classrooms in the county. The advanced-level students were more complaint when asked to complete seat work, but when both groups were engaged in engineering design activities the degree of enthusiasm and engagement was indistinguishable between the classes.

The teacher in this study was a Caucasian female in her late 20s with 4 years of teaching experience, and experience as a science department chair. She was enthusiastic, experienced in cooperative learning, dedicated to motivating her students, and had experience using engineering design to facilitate science teaching. Since this study took place within the first few weeks of the academic school year, the teacher had not yet had much time getting to know these particular students, but she did use the *Save the Penguins* curriculum the previous year and was well prepared to teach it.

Site

This study took place at a well-regarded middle school in the suburbs of a small city (approximately 100,000 residents) in a Mid-Atlantic state. The school, Montebello Middle School¹, had 747 students at the time of this study: 89% Caucasian, 4% African-American, 3% Hispanic, and 3% Asian-American. Only 11% of students qualified for free or reduced lunch, whereas county-wide 24.5% of students qualified for free or reduced lunch. This particular school was considered to be the most affluent middle school in the county.

Curriculum

The *Save the Penguins* curriculum (Schnittka, 2009) is a 6–7 day unit requiring approximately 60 minutes of class time per day. It consists of the following key elements:

- (1) pre-tests on science concepts and engineering conceptions;
- (2) an introduction to the role engineers play in our society focusing on how they solve problems critical to our health and welfare;

- (3) an introduction to penguins in the Southern Hemisphere and how they are being affected by warmer temperatures;
- (4) a discussion about how humans contribute to global climate change, and how engineers try to design building materials that reduce energy usage. This reduction in energy usage reduces the demand on fossil-fuel power plants and reduces the amount of greenhouse gases deposited into the atmosphere;
- (5) targeted demonstrations that explicitly teach concepts of heat transfer and how they relate to building materials students may have seen in their homes. Explicit discussions about conduction, convection, and radiation ensue;
- (6) testing of different building materials under heat lamps with thermometers and timers. Materials include felt, foam, foil, aluminized Mylar, cotton, wood, paper, and bubble wrap;
- (7) discussions about the results of these material tests- knowledge is shared amongst all groups in the class;
- (8) storyboard construction which encourages design analysis, materials testing analysis, demonstration analysis, and other science or engineering-related ideas;
- (9) construction of penguin dwellings from provided materials;
- (10) testing of dwellings in an oven heated by four 150W shop lights;
- (11) discussion of results- knowledge is shared amongst all groups in the class;
- (12) re-design of dwellings, and final testing in oven;
- (13) posttests on science concepts and engineering conceptions.

Following the social constructivist philosophy, students construct their understandings after misconceptions are elucidated and targeted. They engage in concrete, sense-making inquiry activities about heat transfer, and engineering design activities which make abstract concepts more concrete. They participate in interpretive discussions related to the content, and tie the content into issues relevant to their lives.

Data Collection and Analysis

While the focus of this research was on teacher behaviors and attitudes, data sources other than classroom observation and video transcripts were used to examine how differentiation was implemented by the teacher and received by students. These other data sources included formal exit interviews with a random subset of students in each class, formal and informal interviews with the teacher, pre and posttest scores, homework assignments and unit test grades, and results of the design activity.

¹ All person names and place names are pseudonyms.

Observations

Classroom observations began a week before implementation of the unit in order to familiarize students with the presence of an observer and the presence of a video camera in the back of the room. A total of 18 classroom observations of 83 minutes each were made in both classes. Qualitative field notes were taken by hand and subsequently typed, and then video transcriptions were added to supplement the field notes. Observations, especially conversations between the teacher and her students, were the primary source of data for characterizing how the teacher differentiated between her two leveled classes.

Pre- and Posttest

All participants were administered two pre and posttests, the 12-item multiple choice Heat Transfer Evaluation (HTE) and the 11-item Likert scale Attitudes Toward Engineering Survey (ATES). Both the HTE and the ATES were assessed for face, content, and construct validity by a panel of experts in the fields of science education and engineering. The coefficient of reliability for the HTE calculated through a test-retest assessment was determined through linear regression to be 0.71. The coefficient of reliability for the ATES was determined to be 0.82. More details about these instruments- their development and assessments of validity and reliability- can be found in Schnittka & Bell (2011).

Results

Teacher interviews

The teacher in this study was comfortable using design as a teaching tool in her science classroom. She had used several design activities in the past including roller coasters, musical instruments, structures, and insulating containers. In her entrance interview she expressed an enthusiasm for using design in the classroom. She said, "When you're designing something, you're thinking about it, you're being creative, you brainstorm. Usually when you're designing you're usually designing with other people or you're bouncing your ideas off..." However, when asked if she could think of any drawbacks to using engineering design, she said that the biggest drawback was with the lower-track students, that they are intimidated by design and need a "jumpstart to help them kind of get into that frame of mind." She felt like lower-track students have a harder time with engineering design because they are not used to it and lack ability.

Not everyone can be creative or think and build. It's hard for them. They're used to the traditional, 'I'm going to do this, I'm going to learn these definitions, I'm going to

take this test, I'm going to memorize it and I'm going to be done'. When you ask them to step outside and have to create and have to think about it and apply it, you know, it's hard for some kids. (Entrance interview)

The teacher was pleased with how innovative the designs were in her standard-level class when compared with the advanced-level class designs.

I am a little surprised! I'm very happy. This class (the standard-level class) had some great, innovative designs. Again, they kind of surprised me! I was a little taken aback on the advance kids and how kind of uncreative they were. They didn't seem as... it seemed very generic, theirs seemed very much similar... (Interview on 6th day of unit)

She admitted that she was afraid that the students in the standard-level class would perform poorly on the HTE post test and unit test. She felt as if they were poor test takers with poor memories. Her expectations for them were low before they took the posttest.

That's another thing that scares me about this standard (level class). I could actually write the answers on the board and they still won't get the answers on the test right. You know what I mean? Where they understand the concepts when you sit and talk with them one-on-one, they get it-they understand it, but when it comes to the test, I mean I could be reading off the answers and some of them would not get the answers correct. You know what I'm saying? So that's the only thing that scares me a little bit about the testing with them. Where the advanced kids, they'll do just fine. They'll remember. (Interview on 6th day of unit)

She believed overall that her students met her objectives, but that some of her students could not learn despite her best efforts. She said in the exit interview: "Are there kids that still get it confused and get misconceptions? Yes. I don't think I would be able to change that within a year of teaching heat constantly every day."

When she learned that students in her standard-level class did not do as well as students in the advanced-level class on the HTE posttest, she blamed it on immaturity or test-taking skills.

I hate to say it, you know even if they did see the demo and they understood, 'okay, this is one of the ways that heat transfers', but then they see that same question on a test, it doesn't register in their head. They don't make the connection. It's not that they don't get it, it's almost a maturity thing or they just don't know how to take tests. Unfortunately. (Exit interview)

However, she was pleasantly surprised by how well the standard-level students were engaged in the project and stayed committed to the work. Their work ethic exceeded her expectations.

Maybe it took them (students in the standard-level class) a little bit longer to get going-but once they got going and once they kind of bought in and saw that this is their project, I think they all worked really well, to tell you the truth. I was pretty impressed with that. I thought at first it would be a disaster. (Exit interview)

She expressed the idea that advanced-level students do not need as much external motivation to work hard, implying that standard-level students need more external motivation, but also implying that standard-level students require more active teaching than advanced-level students.

They (students in the advanced-level class) just have an intrinsic motivation that they are just going to do well. I could have them sitting in the chair writing notes every single day and they would still do it and they would still do well.

The teacher remained committed to active teaching methods for all her students, not so much for the sake of content, but for other skills such as problem solving and life skills.

They're out of their seats and they are doing things like in the real world, you know. We don't all sit behind desks all day, very rarely. And it's fun for them, and they learn. They learn better than just sitting there sometimes getting it just regurgitated back to them. And it may not mean necessarily that they're learning more about the content, but they're learning just more how to work with each other, what works, what doesn't, when they come to a problem, how do we get around that problem, it's more almost life skill learning. But they get that content in there as well. (Exit interview)

She believed all her students had fun, and that through the fun experiences they would remember this unit more than one with less engaging activities. She admitted that doing engineering design in the classroom was time consuming as a teacher, involving more preparation time and energy, but that it was "worth it because you're going to get them hooked in."

Results from pre- and posttest

Due to absences, only 20 of the 23 students in the standard-level class took both the HTE and ATE pre-tests and posttests. The pre-test mean for the HTE was 3.0 out of 12 points and the posttest mean was 5.65 out of 12 points

for these paired sets. This represents an average gain of 2.65 points. The pre-test mean for the ATE was 3.44 on a Likert scale of 1 to 5 with 5 representing a positive attitude toward engineering. The posttest mean was 3.39, which means that there was a negative change in engineering attitudes of 0.05 points.

All of the 23 students in the advanced-level class took both the HTE pre-test and posttest. The pre-test mean was 4.10 out of 12 points and the posttest mean was 8.22 out of 12 points. This represents a gain of 4.12 points. The pre-test mean for the ATE was 3.63 on a Likert scale of 1 to 5 with 5 representing a positive attitude toward engineering. The posttest mean was 3.89, which means that there was a positive change in engineering attitudes of 0.26 points.

The achievement gap in terms of conceptual understandings of heat transfer was 1.1 points before the unit began and 2.57 points after the unit. See Figure 1. Instead of engineering design being a vehicle to narrow the achievement gap in science between these two levels of classes, it widened it. While students in the advanced-level class reported more positive attitudes toward engineering after the unit, students in the standard-level class reported more negative attitudes toward engineering.

Comparison of class time

The same amount of class time was dedicated to this unit in both classes, 398 minutes spread out over 7 class periods. Additional time in class was dedicated to a guest speaker from the guidance department, a unit test, review for the unit test, and other non-unit activities. See Table 1 for a breakdown of time spent in the unit into categories.

In some cases, the same amount of time was spent in each class on a particular topic or activity. In other cases, more or less time was spent in one class or another. Where the same amount of time was spent, differences in how that time was used were examined. When different amounts of time were spent on the same component of the curriculum, reasons for that were also examined. See Figures 2 and 3.

While a similar amount of time was spent on science discussions in both classes, those discussions had different characteristics. Overall, there was much more teacher talk and less student talk in the standard-level class. In the advanced-level class, students were asked with each topic to think about the topic, discuss it in their 4-person group table, and then a teacher questioning and student answering session occurred. However, in the standard-level class, table group discussions were not encouraged during science discussions. Occasionally the teacher would ask students to think about something, but that was quickly followed with teacher questioning and student answering. The following examples of paired exchanges at the same juncture in the curriculum are typical (Table 2).

Teacher questioning patterns were different too. More open-ended questions were asked of students in the

Figure 1. Pre- and posttest scores on the heat transfer evaluation.

advanced-level class, and students demonstrated sufficient background knowledge to answer these kinds of questions. Students in the standard-level class were primarily asked simple, step-by-step questions, or simple yes/no questions. The following examples of paired exchanges at the same juncture in the curriculum are typical (Table 3).

The teacher frequently reassured students in the standard-level class that it was alright to be wrong. She obviously wanted them to take risks and try to answer questions they might not have fully understood. However,

this philosophy was often disregarded as the teacher would ask a question, and then without a pause, go ahead and answer her own question in the next breath. The following examples of paired exchanges at the same juncture in the curriculum are typical (Table 4).

She did *provide* more real-life examples to students in the standard-level class, but did not *ask* them for examples. There was more emphasis on writing down definitions in the standard-level class, and more focus on words and definitions than on big picture concepts.

Students in the advanced-level class were required to create story boards as they reflected on demonstrations, concepts, design plans, and test results. They spent 13% of the unit time on story boards. Students in the standard-level class did not complete story boards, but they did take notes and do some writing on a small poster. Twenty minutes, or 2% of the unit time, was spent on the small posters. While not much science was discussed as a class during group storyboard time, something else unique happened. Students in the advanced-level class were asked to *draw* their conceptions of conduction, convection, and radiation in addition to writing down the definitions on their storyboards. Students in the standard-level class were only asked to write down definitions and data on their posters. Also, students in the advanced-level class were asked to draw their penguin dwelling design and “put explanations of what you’re using and why you’re using it.” Students in the standard-level class were simply asked to draw their design, and not justify their design decisions. In summary, students

Table 1
Time Spent on Different Activities in Both Classes

Unit-related activity	A-Level Class	S-Level Class	% Difference
Science discussions	36.5	44	17%
Penguin discussions	3	3	0%
Engineering discussions	19	15	−27%
Environment	11	14	21%
Demonstrations	48	31	−55%
Seat work	50	49.5	−1%
Group storyboard work/poster	50	20	−150%
Discuss design project	29	24	−21%
Walk throughs	12	9	−33%
Testing materials	20	22	9%
Designing	16.5	16	−3%
Building houses	44	44	0%
Video	0	25	100%
Non-instructional time	4	30	87%
Classroom procedural time	55	51.5	7%
Total (minutes)	398	398	0%

Advanced-Level Class

Figure 2. Time spent in advanced-level class during unit.

who worked on storyboards were encouraged to be metacognitive about their design decisions and to express abstract concepts through drawings that represented heat transfer. Students in the standard-level class were only asked to draw their designs, write definitions about heat transfer, and record data.

More time was spent on demonstrations in the advanced-level class; however demonstrations were done equivalently in both classes. There were predictions made before the demonstrations, and class discussions afterwards. The exact same procedures were used in both classes, but they just took a few minutes longer in the standard-level class. In the first demonstration, the teacher asked students in the advanced-level class to make predictions in groups at their tables, while students in the standard-level class were asked to only make predictions to themselves. This did not happen with the other demonstrations, as students were asked to make predictions silently or on paper in both classes.

Students in the standard-level class watched a 25-minute science video (Nye, 1996) about heat and temperature. This video was not in the curriculum lesson plans, but the teacher wanted to provide extra instruction in a way she thought would be engaging to them. Students were asked to write down ten facts they learned from the video.

Teacher: Alright, so your job is while you are watching this video it shows lots of good demonstrations and it has lots of good ideas and good facts you don't have to write 10 sentences. You are just writing down 10 facts, 10 things that you hear that you think are going to be important.

Nye demonstrated heat transfer through conduction, convection, and radiation. He talked about heat, saying that "Even glaciers have heat." Nye demonstrated a spiral piece of paper over a heat source and students watched the warm air rising to make the snake dance. Nye said that glass pans

Standard-Level Class

Figure 3. Time spent in standard-level class during unit.

Table 2
Examples of Encouraged and Halted Science Discussions

Advanced-Level Science Discussions	Standard-Level Science Discussions
Teacher: How is this all relating together? Think about it. How are these all interconnected? You can talk to people at your table.	Teacher: How is this all going to kind of come together in one thing? What I want you to do is (students talking) shhhh! Listen. What I want you to do is look at this graphic up here.
Teacher: Start thinking about what a conductor is. Throw out some ideas at your table. Come up with a definition or example. Talk about it.	Teacher: Think about what a conductor might be. You don't have to write anything, just think about it. (Teacher walks around while students write.)

Table 3
Examples of Open and Closed Questioning

Advanced-Level Questioning	Standard-Level Questioning
Teacher: Think about what an insulator is. Talk about it with your group. What do you think an insulator is, what it means, maybe an example.	Teacher: Nate, do you know what an insulator is, if you had to just guess and tell me like a definition, could you do that?
Teacher: Take a second with your group and discuss. What caused the ice to melt?	Teacher: You are going to write the definition for conduction, and that is the way heat transfers from one substance to another by direct contact. So your hands were in direct contact with the spoons and the spoons were in direct contact with the ice cubes.

Table 4
Examples of Teacher Answering Own Question

Advanced-Level Q&A	Standard-Level Q&A
Teacher: Why would you choose the metal? Carlos: because I don't want splinters. Teacher: if you are talking about keeping your hands warmer? Tommy: oh, wood. Teacher: Why? Walker? Walter: Wood doesn't conduct heat well and wouldn't take the heat from your hand. Teacher: Do both bars have relatively the same temperature? The wood and the metal? Yes. The silver or metal bar definitely is a conductor so it pulls the heat faster from the hand. What is this similar to? Erick: when we held the silver spoon and our heat went into the penguin. Teacher: From that demo we did the plastic versus the silver spoons. Teacher: So the house is upside down, so what are the arrows going to look like? What do we call those arrows, Deepa? Dot: Convection current. Teacher: Show how the heat is being transferred. Sakura: Heat rises, oh, I mean hot air rises. Zach: Hot air goes up and is forced into that place where the cold air was and the cold air sinks. Cool air doesn't go up, the hot air goes up there.	Teacher: Metal is a conductor so the metal is going to pull heat from your hand more rapidly than the wooden bar or wood. The wood bar is going to pull some of that heat, but it doesn't happen as quickly and doesn't feel as cold. Remember what does this remind you of? Which demonstration? The two spoons. Where you held onto the silver spoon and the plastic, and remember that the silver spoon actually felt cold after a while because it was pulling all the heat away from your hand, from your body. Alright, good. OK guys, there are going to be questions like this on the test so you want to be aware of that. Teacher: Remember in the house. We flipped the house upside down and what happened with that what do we call that? Convection....current. Remember the hot air was rising and the cool air was sinking, so it wasn't the heat rising it was the hot air rising and then when it cooled off it would sink down, that is your current.

do not need to cook food as long because radiation passes through them, but metal pans reflect the radiation, so food in the metal pans have to cook longer. The video showed a snow cave, and Nye talked about how the snow was an insulator. Nye talked about coats, hats, and gloves. He said, "It keeps out the cold. It keeps you warm. It keeps in the heat." This may have confused students because the teacher emphasized frequently that cold does not transfer. It was a very quick video with frequent sound effects, and a fast-talking Nye zipping from one visual to another, one fact, one topic to another. After the video ended, there was no discussion about the video or the facts students learned from it.

The same amount of time was spent in both classes designing and building the penguin dwellings, but less time was spent in the standard-level class discussing the designs, sharing ideas between groups, and discussing the designs within groups.

During the 7-day unit, there was a significant amount of non-instructional time in the standard-level class: 30 minutes in the standard-level class as compared to 4 minutes in the advanced-level class. Students in the standard-level class were frequently given the last 5–10 minutes of class to get a head start on their homework. For the most part, students in the advanced-level class worked on curriculum tasks from the minute class began until the bell rang 83 minutes later.

Engineering designs

Students worked in groups of 3–4 to design and construct their ice penguin dwellings. On day 6 of the unit, dwellings were tested in an oven constructed of black

plastic lined in aluminum foil, with four 150 Watt shop lights shining into it. Ice cubes were placed in the dwellings, and then dwellings were placed in the oven for 20 minutes. After ice cubes were removed, they were placed in plastic cups and massed. All ice cubes started with a mass of 10 grams because they were each made with exactly 10 mL of distilled water. There were six design groups in each class. On day 7 of the unit, students were given the chance to discuss the results of their first trial, compare their dwellings with others in the class, and make any changes they wanted to within their existing budget. Some groups re-arranged existing materials, other groups purchased more materials from the Igloo Depot. Ice penguins were again placed in the dwellings and tested for exactly 20 minutes in the hot box. Figure 4 illustrates six of the designs in each class, a mixture of first iteration and second iteration designs.

The mass remaining (in grams) after 20 minutes for each group and each trial is recorded in Table 5. Note that the change represents the improvement of the dwelling or in some cases, the reduced performance.

All but one of the groups in the standard-level class had a positive change in performance of the design of the dwelling. The one group that ended up with a smaller ice penguin in the second trial did so because they failed to secure the ice inside the dwelling properly, and it fell out to melt in the open on the black bottom of the oven. There were positive and negative changes in the performance of dwellings in the advanced-level class. Overall, students in the advanced-level class were able to "save more penguins." Figures 5 and 6 illustrate that there were three teams in the standard-level class that improved by 2 grams or more, whereas none of the teams in the advanced-level

Figure 4. Designs in both classes.

Table 5
Design Results

Standard-Level Class				Advanced-Level Class			
Team	Trial 1	Trial 2	Change	Team	Trial 1	Trial 2	Change
25	3.5	5.7	2.2	7	4.9	6.3	1.4
26	5.6	6.2	0.6	8	5.7	6.4	0.7
27	3.5	6.2	2.7	9	4.7	6.3	1.6
28	2.8	4.8	2	10	6	5.4	-0.6
29	5.9	6.3	0.4	11	5.6	5.2	-0.4
30	5.7	2.7	-3	12	5.5	7	1.5
Average	4.50	5.32	0.82	Average	5.40	6.10	0.70

class improved to that degree. However, the standard-level groups had more room to improve than the advanced-level groups. In my experience testing this curriculum with various groups over several years, typically, middle school students, pre-service teachers, and even engineering students cannot preserve much more than 7 grams of ice when the dwelling is subjected to 20 minutes in the pre-heated oven.

Discussion

Findings indicated that students in both the advanced and standard-level classes possessed broad misconceptions about the science of heat transfer and about engineering

Figure 5. Changes in performance of designs in standard-level class groups.

Figure 6. Changes in performance of designs in advanced-level class groups.

prior to the intervention. While students both classes made gains in knowledge about the science content of the unit, students in the standard-level class did not learn the science content to the same conceptual level. Attitudes about engineering increased slightly in the advanced-level class, but decreased slightly in the standard-level class. The teacher's expectations of her students differed widely between classes, and her treatment of students differed to such a degree that students in the standard-level class were not given the same opportunities to discuss their designs and explore the science content through demonstrations and discussion. It is not known whether the teacher's pedagogical and curriculum modifications for her standard-level class caused those students to be less successful in the science content understanding and in the engineering design activity, but it is an inference worth considering. Despite the differences in instruction, and the differences in the level of trust and expectations afforded each class, students in the standard-level class were very creative engineers. They modified "free" materials to avoid purchasing them from the "Igloo Depot" and developed designs that utilized the science concepts they had learned, preventing heat transfer through insulation, reflective materials, layers, and sealed seams. They were very successful at making improvements to their designs after one iteration. Perhaps if given more time to work with the materials, make modifications, discuss the science content in groups, and draw and reflect upon their learning, they would have made more conceptual gains and created more efficient designs.

There is a large body of literature suggesting specific adaptations that general education teachers can make for their special education students (Brown, Gable, Hendrickson, & Algozzine, 1991; Christenson, Ysseldyke, & Thurlow, 1989). However, when these adaptations are not understood or practiced, or if the teacher does not believe that these adaptations will make a difference, all students are not given the same opportunities to learn. When given the opportunity to teach science through engineering design set in a context related to students' lives, the teacher in this case study fell back on her assumptions that students with lower achievement levels needed more passive, didactic instruction and fewer opportunities to discuss their conceptions in groups and in class. She was afraid that the classroom would get out of hand if her lower-achieving students were given the same opportunities to learn as her higher-achieving students. However, after seeing the results of their efforts, she experienced a shift in her attitude and voiced the determination to afford her struggling students with more opportunities in the future. After the study, the teacher remarked that she short-changed these students, and that she should have given them more credit for being able to apply the science they had learned to solve engineering problems through creative design solutions: "I think they all worked really well, to tell you the truth. I was pretty impressed with that. I thought at first it would be a disaster." (exit interview).

Limitations and Implications

This was a small case study of one teacher and two groups of students, so the observations and inferences made here cannot be generalized to a greater population. It is not known exactly what influenced the teacher to make these curriculum and pedagogical modifications for her lower-level class other than implied expectancies. She indicated that she had taken one special education class in college while getting her bachelor's degree in middle-level education, but that it was "worthless." Future research should examine the reasons why general education teachers make certain modifications for their special education students.

However, this study does have implications for 21st century science education, as creativity, problem solving, inventiveness, and big-picture thinking are integrated into the new national science education standards as engineering design. Daniel Pink, author of *A Whole New Mind* (Pink, 2005), said in a recent lecture I attended, "Design thinking is part of what it means to be human. It is not just for the elite." If engineering design activities are to be integrated into the state and national science standards for all students in this country, we need to begin thinking about how teachers will enact these goals with *all* their students.

References

- Baker, J.M., & Zigmond, N. (1990). Are regular education classes equipped to accommodate students with learning disabilities? *Exceptional Children*, 56, 515–526.
- Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavior change. *Psychology Review*, 84, 191–215.
- Bleicher, R.E., & Lindgren, J. (2005). Success in science learning and preservice science teaching self-efficacy. *Journal of Science Teacher Education*, 16, 205–225.
- Botte, B.A. (2001). Reconceptualizing math problem solving for low-achieving students. *Remedial and Special Education*, 22, 102–112.
- Brown, J., Gable, R., Hendrickson, J., & Algozzine, B. (1991). Pre-referral intervention practice of regular classroom teacher: Implication for regular and special education preparation. *Teacher Education and Special Education*, 14, 192–197.
- Carlisle, J., & Chang, V. (1996). Evaluation of academic capabilities in science by students with and without learning disabilities and their teachers. *Journal of Special Education*, 30, 18–34.
- Cawley, J., Hayden, S., Cade, E., & Baker-Kroczyński, S. (2002). Including students with disabilities into the general education science classroom. *Exceptional Children*, 68, 423–435.
- Christenson, S. L., Ysseldyke, J. E., & Thurlow, M. L. (1989). Critical instructional factors for students with mild handicaps: An integrative review. *Remedial and Special Education*, 10(5), 21–30.
- Erickson, F. (1986). Qualitative methods in research on teaching. In M. Wittrock (Ed.), *Handbook of research on teaching*, (3rd Ed.), pp. 119–161. New York: Macmillan.
- Ferguson, R.L. (2007). Constructivism and social constructivism. In G.M. Bondner & M. Orgill (Eds.), *Theoretical frameworks for research in chemistry/science education* (pp. 28–49). Upper Saddle River, NJ: Pearson Education, Inc.
- Gamoran, A. (1987). The stratification of high school learning opportunities. *Sociology of Education*, 60, 135–155.

- Gibson, S., & Dembo, M.H. (1984). Teacher efficacy: A construct validation. *Journal of Educational Psychology*, 76, 569–582.
- Gusky, T.R. (1987). Context variables that affect measures of teacher efficacy. *The Journal of Educational Research*, 81, 41–47.
- Hoffer, T.B. (1992). Middle school ability grouping and student achievement in science and mathematics. *Educational Evaluation and Policy Analysis*, 14, 205–227.
- Ireson, J., & Hallam, S. (1999). Raising standards: Is ability grouping the answer? *Oxford Review of Education*, 25, 343–358.
- Krajcik, J., & C. Czerniak. (2007). *Teaching science in elementary and middle school: A project-based approach*. 3rd edn. New York: Lawrence Erlbaum.
- Motto, A., Evans, M.A., Jones, B., Schnittka, C.G., & Brandt, C. (2011). Studio STEM/Save the Penguins: Connecting youth to environmental issues through design-based projects. A paper presented at the Annual Meeting of AERA, New Orleans, LA, April 6–11, 2011.
- National Research Council (NRC) (2010). A framework for science education: Preliminary public draft. Washington, DC: National Research Council, Committee on Conceptual Framework for New Science Education Standards. Downloaded August 2, 2010 from http://www7.nationalacademies.org/bose/Standards_Framework_Preliminary_Public_Draft.pdf
- National Science Foundation (NSF) (1997). Presidential awards recognize world's best teaching. Retrieved from: <http://www.nsf.gov/od/lpa/news/press/pr9744.htm>
- Norman, K., Casseau, D., & Stefanich, G. (1998). Teaching students with disabilities in inclusive classrooms: Survey results. *Science Education*, 82, 127–146.
- Nye, B. (1996). *Bill Nye the Science Guy: Heat* [Motion picture]. United States: Disney Educational Productions.
- Palinscar, A.S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology*, 49, 345–375.
- Patton, J., Palloway, E., & Cronin, M. (1990). A survey of special education teachers relative to science for the handicapped. Unpublished paper, University of New Orleans.
- Pink, D. (2005). *A whole new mind*. New York, NY: Penguin Group.
- Schnittka, C.G. (2009). *Save the penguins engineering teaching kit*. Charlottesville, VA: VMSEEL. Available at: <http://www.uky.edu/~csc222/ETK/SaveThePenguinsETK.pdf>
- Schnittka, C.G., & Bell, R.L. (2011). Engineering design and conceptual change in the middle school science classroom. *International Journal of Science Education*, 33, 1861–1887.
- Schnittka, C.G., Bell, R.L., & Richards, L.G. (2010). Save the penguins: Teaching the science of heat transfer through engineering design. *Science Scope* 34(3), 82–91.
- Schnittka, C.G., Evans, M.A., Jones, B. & Brandt, C. (2010, June). Studio STEM: Networked engineering projects in energy for middle school girls and boys. *Proceedings of the American Society of Engineering Education*, Louisville, KY.
- Schumm, J.S., & Vaughn, S. (1991). Making adaptations for mainstreamed students : General classroom teachers' perspectives. *Remedial and Special Education*, 12(4), 18–27.
- Schumm, J.S., Vaughn, S., Gordon, J., & Rothlein, L. (1994). General education teachers' beliefs, skills, and practices in planning for mainstreamed students with learning disabilities. *Teacher Education and Special Education*, 17, 22–37.
- Slavin, R.E. (1993). Ability grouping in the middle grades: Achievement effects and alternatives. *The Elementary School Journal*, 93, 535–552.
- Tobin, K., & Tippins, D. (1993). Constructivism as a referent for teaching and learning. In, K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 3–21). Hillsdale, NJ: Lawrence Erlbaum.
- Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.