Teaching Energy Concepts using Chain Reaction Machines

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Introduction

The Next Generation Science Standards (NGSS), which are based on the Framework for K-12 Science Education, establish principles for overcoming negative trends in K-12 educational outcomes in the United States [2]. The NGSS put forth "a new vision for American education," focusing on student performance rather than on specific curriculum guidelines. The goal of instruction is to provide students with a context for the concepts being taught in order to enhance their understanding of how scientific knowledge relates to the world in which they live [3]. The Framework for K-12 Science Education for middle and high school students (grades 6-12) addresses topics such as

- Definitions of energy
- Conservation of energy and energy transfer
- Energy and matter
- Natural resources
- The influence of science, engineering, and technology on society and the natural world
- Defining and delimiting engineering problems and developing possible solutions [4].

The NGSS sets student performance outcomes based on these topics. One of the five Energy performance outcomes for high school students states that the students should be able to "design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy" [4].

The STEAM Machines™ summer camp curriculum introduces students to the previously mentioned science and engineering topics through the construction of Rube Goldberg-style chain reaction machines. After being given a simple task to complete (e.g. zipping a zipper or hammering a nail), students learn and apply the engineering design process as they plan and build their chain reaction machines. The construction of a chain reaction machine is a powerful vehicle for introducing students to technical information because of the ability of these machines to capture students' interest and to spark their imagination. A 2007 survey of 319,223 students in the United States, Canada, Australia, and Mexico found that "a large portion of K-12 students who have experienced hands-on, tangible activities and group-oriented learning methods in STEM subjects found them to be the most interesting" [1]. The STEAM Machines™ summer camp programs utilize such group-oriented and hands on activities to teach real-world engineering skills, provide experience with systems thinking and multi-team collaboration, integrate arts with science, technology, engineering, and math (STEM), and create a pathway for students to better understand careers in engineering and other STEM fields.

For the Summer 2013 implementation of the STEAM Machines™ summer camp programs, new content modules on energy and anaerobic digestion were integrated into the curriculum and introduced at three high school sites, i.e.; two in Arizona and one in

Trinidad and Tobago. A total of 65 students ranging from age 13 to 18 participated in the experience.

This paper presents: a) detailed account of the design of the energy and anaerobic digestion module and b) descriptions of the ways students applied this learned knowledge in the design and development of their chain reaction machines. The paper concludes with a discussion of how this experience can be adapted for inclusion in formal, in-class science courses at the middle and high-school level.

Overall Structure of the STEAM Machines™ Curriculum

The STEAM Machines™ program usually spans 5-days, with approximately 35 contact hours. Students spend a significant amount of the time learning the engineering design process and applying the process to the design and construction of chain reaction machines. Engineering design activities are a powerful strategy for the integration of science, mathematics, and technology, and for engaging a broad population of students [5]. Dispersed throughout the week are hour-long modules on various science, technology, math and art concepts. Including art concepts in STEM increases interest in science and includes students who are more artistically inclined [6]. These modules are presented just-in-time for the students to apply them to the design and development of their machines. Many STEM program use the "just in time" approach by using remote access technology as a tool to connect with mentors and students at other schools [7]. Figure 1 shows a breakdown of a typical camp schedule.

Time	Monday, July 22	Tuesday, July 23	Wednesday, July 24	Thursday, July 25	Friday July 26
9:00 AM	SDP 01 (1 hr) Introduction to Chain-Reaction STEAM Machines™	ASM 15_1, ASM 06_1 (15 min) ▪ STEAM Interest Pretest ▪ Simple Machines Pretest	ASM 06_2, ASM 08_1 (15 min) ▪ Simple Machines Postest ▪ Electricity Pretest	ASM 15_2 (15 min) ▪ STEAM Interest Posttest	ASM 05_2 (15 min) ▪ Career Plans Posttest
9:15 AM		CNT 09 (1 hr) Simple Machines	CNT 05 (1 hr) Electrical Energy	SDP 10 (30 min) Plan and Create	SDP 16 (1 hr + 15 min) Systems Integration, Test and Improve
9:30 AM	▪ ASM 01 Tell Us ▪ ASM 02_1 Design Scenario Pretest				
9:45 AM				CNT 08 (45 min) Testing for Reliability	
10:00 AM	SDP 02 (30 min) Human STEAM Machine™				
10:15 AM		Break	Break		
10:30 AM	Break	CNT 02 (30 min) Machine Quality and Storyboarding	SDP 04 (30 min) Ask, Imagine, and Plan	Break	Break
10:45 AM	CNT 01 (45 min) Introduction to the Engineering Design Process			CNT 10 (30 min) Anaerobic Digester	SDP 16 (1 hr) Systems Integration, Test and Improve
11:00 AM		SDP 04 (1 hr) Ask, Imagine, and Plan	SDP 10 (1 hr) Plan and Create		
11:15 AM				SDP 10 (45 min) Test, and Improve	

Figure 1: In the color-coded schedule, most of the sessions, shown in brown, were geared towards learning and applying the engineering design process. The sessions in yellow are the science, technology, arts and math content modules. These sessions are presented just-in-time for students to apply them to the design and development of the machine.

A chain reaction machine consists of a number of action–reaction steps in sequence. According to the official Rube Goldberg Machine Contest rule book, a step is defined as "the transfer of energy from one action to another action." [8]. Understanding energy and how it facilitates work, is essential to the task of designing and building chain reaction machines. It is vital that students establish a strong foundational understanding of energy concepts and the roles that energy plays in engineered devises. Given the urgency of energy issues in our world today, it is essential for energy to take a prominent role in the science curriculum [9]. Therefore, the energy and anaerobic digestion modules were scheduled on the first day of camp. They were both presented in the later part of the day prior to a mini exercise in creating a chain reaction machine. This mini exercise provided a shared experience that could be referred to and used to introduce and explain energy and anaerobic digestion concepts.

Like all of the instructional activities in the STEAM Machine™ curriculum, the delivery of the energy and anaerobic modules incorporated three key pedagogical strategies: 1) building off of prior knowledge; 2) hands-on engagement; and 3) collaborative learning. The implementations of these strategies will become more evident through the discussion that follows, on the design and implementation of both modules.

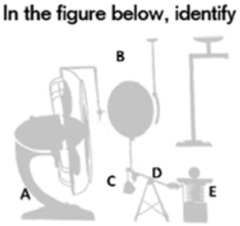
Energy Module

The energy module was designed to help student learn about the different states, forms and sources of energy. On completion of the energy module students were expected to:

- Identify the different states and forms of energy
- Describe the Law of Conservation of Energy
- Describe the difference between renewable and non-renewable sources of energy
- Describe things that can be done on a national and individual level to use energy sustainably
- Design chain reaction machines with constraints related to forms of energy

The interactive energy lesson plan engages students by first assessing their prior knowledge. Below in Figure 2, is a picture of an assessment question that was asked to evaluate whether or not students were familiar with forms of energy. A few days later a post assessment was administrated to the students. The pre- and post-assessments were used afterwards to gain insight on the impact of learning.

6) In the figure below, identify the form of energy in each of the following steps?



STEP	FORM OF ENERGY
A: Makes the fan motor spin	
B: Moves the balloon towards the tack	
C: Stored in the elevated weight	
E: Stored in the spring	

Figure 2: Pre-assessment was administrated to the students to measure the impact of the curriculum.

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The lesson began by introducing all of the concepts that would be covered in the presentation. Throughout the presentation before a new concept was discussed, the presenter gathered information from the students on their prior knowledge and understanding. This insight was then tied into the discussion and helped facilitate the presentation of new material. To continue to engage the students, challenges were placed throughout the presentation to reinforce concepts that were previously covered. For example, teams of students were given a stack of Post-It-Notes™ to label the forms of energy in their mini chain reaction machine. Each team then presented their completed challenge, followed by oral feedback from other students and the instructor.

Within the module, statistical energy consumption data was presented to the students according to their region. This made the content more relevant to the students. For example, Trinidad and Tobago energy consumption was rich in natural gas while Arizona was rich in coal. By posing and answering question that are relevant to their own lives and communities, students ultimately produce tangible products that can have meaning far beyond the walls of the science classroom [10].

Anaerobic Digestion Module

Biofuels and biomass are the most used forms of renewable energy in the world [11]. Therefore, the anaerobic digestion module was designed and developed to teach students about anaerobic digestion, anaerobic digestion process, and the bi-products produced. Upon completion of the module, students were expected to:

- Describe the process of anaerobic digestion
- Describe how biogas is created and its applications
- Create biogas and use the resulting energy to power a step in a chain reaction machine

Similar to the energy module, students were first assessed, and, prior to the introduction of a related concept, the instructor gathered information from the students on what they already know about the concept. This insight was used to facilitate the introduction of new knowledge. Figure 3 is an image of a poster that was used to facilitate the presentation and discussion on anaerobic digestion.

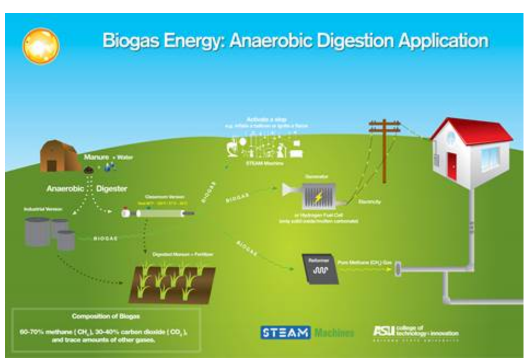

Figure 3: Pictorial demonstration of anaerobic digestion used to show the benefits and its applications

In an effort to strengthen concepts taught on anaerobic digestion, student used their knowledge of the human digestive system to describe how an anaerobic digesters works. Refer to Figure 4 below.

Figure 4: Collaboratively, students discussed how anaerobic digesters and human digesters had similar processes

Teams of students worked even closer with anaerobic digestion by setting up anaerobic digesters. As shown in Figure 5, students set-up an anaerobic digester. Items needed to set-up for the anaerobic digesters were inexpensive and easily accessible. Students followed the laboratory and safety procedures, which were provided and included in the appendix.

Figure 5: Students mix manure and water to make slurry

Application of Energy and Anaerobic Digestion concepts

Throughout the energy and anaerobic digestion module, students directly applied prior and new knowledge to complete the challenges in each presentation. To further reinforce the modules students were required to have at least three forms of energy when building their final chain reaction machine. During the design reviews both prior and during building students had to defend their design in terms of the forms of energy requirement. In the final machine some sites had students label all forms of energy applied. An example of this is shown in Figure 6.

Figure 6: Student labeled the forms of energy in their chain reaction machine.

Due to the physical design and limitations, students were not able to use the biogas from the anaerobic digester to power a step in their chain reaction machines. One limitation was that students were not able to use fire without special supervision and lab equipment. However, some student did conceptualize ideas such as inflating a balloon with the biogas in order to activate another step.

Results

Learning in the energy module was assessed based on the pre- and post-assessment that was administered before and three days after the energy and anaerobic digestion modules were taught, respectively. The energy module consisted of questions that tested students' recall and understanding of: different states and forms of energy, Law of Conservation of Energy, difference between renewable and non-renewable sources of energy, and things that can be done on a national and individual level to use energy sustainably.

Thirty students participated in the research analysis in Arizona and Trinidad and Tobago. The overall mean pre-assessment score was ($M \pm SD$) = 5.83 ± 2.18, with the mean pre-test score based on energy module objectives. The overall mean post-assessment score was ($M \pm SD$)= (7.47 ± 1.5), with the mean post-test score based on energy module objectives also.

This study found that students' knowledge of energy concepts after module (7.47 ±1.5) was statistically higher than their knowledge of energy before the module (5.83 ± 2.18), $t(29) = -4.001$, $p<0.05$.

Table 1: Paired t-test showing that students gained knowledge of energy concepts after module

	Mean	**Std. Dev**	**Std. Error Mean**	**95% CI Lower**	**95% CI Upper**	**t**	**df**
Pair 1 pre-post	-1.633	2.236	0.408	-2.468	-0.798	-4.001	29

Learning in the anaerobic digestion module was assessed based on the pre- and post-assessment that was administered before and three days after the energy and anaerobic digestion modules were taught, respectively. The anaerobic digestion module consisted of questions that tested students' recall and understanding of: anaerobic digestion processes and description of how biogas is created and its applications

Eight students participated in the research analysis in Trinidad and Tobago. The overall mean pre-assessment score was ($M \pm SD$) = 0.14 ± 0.15, with the mean pre-test score based on anaerobic digestion module objectives. The overall mean post-assessment score was ($M \pm SD$)= (0.84 ± 0.16), with the mean post-test score based on anaerobic digestion module objectives also.

This study found that students' knowledge of anaerobic digestion after the module (0.84±0.16) was statistically higher than their knowledge of anaerobic digestion before the module (0.14± 0.15) $t(7)= -9.975$, $p<0.05$.

Table 2: Paired t-test showing that students gained knowledge of anaerobic digestion concepts after module

	Mean	**Std. Dev**	**Std. Error Mean**	**95% CI Lower**	**95% CI Upper**	**t**	**df**
Pair 1 pre-post	-0.69643	0.19747	0.06982	-0.86152	-0.53134	-9.975	7

Discussion

Through our energy and anaerobic digestion modules the students were able to better comprehend not only the energy concepts, but also the engineering processes. Our research shows that students now comprehend energy concepts and are familiar with anaerobic digestion. Conducting energy projects is an effective way to engage students in the subject matter while applying this knowledge to solve problems that the students will ultimately inherit [9]. We are hopeful that the introduction of the new energy content modules will influence students and teachers capabilities and desire to alleviate current energy issues on a global and individual scale. The anaerobic digester module described above could be incorporated into the renewable resources lesson of a science class in order to help students understand the practical application of this concept. The STEAM Machines ™ summer program encourages students to pursue STEM careers and positively impact their community.

In accordance with the NGSS, the STEAM Machines ™ summer program exemplifies a 21st century approach to scientific learning in America. Students are exposed to foundational scientific principles in an interactive environment. Emphasis is placed not only on retaining scientific knowledge but also on applying that knowledge to solve a problem and on understanding the roles that scientific principles play in the world outside of their classroom. Students are taught that they have the ability to address complex problems in a systematic way in order to achieve functioning solutions.

Work Cited

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Appendix

1.1 Anaerobic Digestion Lab Procedure

Anaerobic Digestion Set-Up Lab

Name: ________________________________

Team Name: ________________________________

1.) Review Safety Protocol and handle manure carefully

2.) In a large beaker, measure 0.725L of manure and 1.25L of water, Combined amount should not exceed 2.0L

   a. Be sure to record exact amount of manure and water added on data sheet

3.) Combine the mixture until the consistency resembles a milkshake

   a. Don't drink it!

4.) Make sure digester bottom (closet to gas valve) bulb valve and gas valve is off

5.) Place funnel on open ball valve closets to gas valve and pour mixture (There should be enough space away from gas valve for the gas to accumulate)

6.) Close ball valve and wipe excess manure off of digester with Clorox wipes

7.) Ensure that all valves are turned off

8.) Clean work station with disinfectant