

A TEMPLATE FOR ENGINEERING BASED K-12 MATH AND SCIENCE CURRICULUM UNITS

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Abstract — *The urgent need to increase the number of engineering students, including female and minority students, has brought about numerous K-12 engineering outreach efforts. Many of these efforts involve extracurricular competitions while others entail infusing engineering based activities into K-12 math and science classrooms. The latter efforts require effective activities that provide a positive engineering experience and facilitate learning of math and science principles. Adventure Engineering is an NSF funded program developing curriculum for middle grade (5-9) classrooms. Curriculum units are designed to facilitate student learning and application of concepts and skills consistent with national math and science standards. The units are adventure theme or scenario-based (e.g., Engineering the Congo, Asteroid Impact, Surviving the Biosphere) and are designed to replace one to three weeks of existing traditional curriculum. Student teams learn and apply the relevant math and science concepts as they engineer their way through the scenario. The one to three week curriculum units are self-contained such that teachers can download the units from the Internet, gather the required materials, and implement with little extra effort. This paper presents a curriculum unit template that has been developed during the course of Adventure Engineering curriculum development.*

Index Terms — *K-12 outreach programs, middle grade math and science curriculum, engineering education.*

INQUIRY-BASED CURRICULUM

Engineering outreach programs for grades K-12 are continuing to emerge from their unofficial inception in the 1980s (see [1] for a summary of programs). Causal explanations reveal that these programs are continuing to develop due to decreasing overall enrollments and lack of female and minority students enrolling in engineering degree programs [2]. We concur that there continues to be a need for programs to attract students who otherwise may not pursue careers in engineering and technology.

Our efforts have led us to develop Adventure Engineering (www.coecs.ou.edu/aeweb), a K-12 outreach program that emphasizes the construction of engineering based curriculum units that are designed for middle grade (5-9) math and science classrooms. Adventure Engineering strives to (1) to improve the interest in and attitudes toward mathematics, science and engineering; (2) improve the

learning of science and mathematics concepts and processes as outlined in national and state standards; and (3) provide a meaningful, enjoyable engineering experience.

Adventure Engineering curriculum units have successfully improved student attitudes and knowledge towards math, science and engineering [3]. Each unit is structured to facilitate student learning and application of concepts and skills that are necessary to function in our scientific and technological society. The instructional vehicle driving our curriculum is inquiry, an approach advocated by many national [4,5] and state [6] educational reform documents. Inquiry can be defined as the active process of asking questions, collecting and analyzing data to help answer these questions, constructing new knowledge based upon our answers, then finding real-world applications to help make learning more meaningful. Therefore, each curriculum unit has at its foundation inquiry.

Our intentions for each unit are either to replace traditional expository teaching methods used in middle grade math and science classrooms with an inquiry based methodology of direct experience or to supplement curriculum instruction that already incorporates an inquiry approach to teaching math or science principles and concepts. Utilizing the inquiry approach, engineering analysis and design serve as the vehicle to facilitate the learning of science and math concepts.

Curriculum units are developed by members of our Adventure Engineering team. Team members include undergraduate and graduate engineering and education students, engineering and education faculty, and middle grade math and science classroom teachers. We believe the specific contribution of each team member greatly enhances the development of engineering driven, inquiry based math and science lessons. Furthermore, Herbert Thier, a nationally recognized leader in science education curriculum development is quoted as saying, "Indeed, one of the most enduring products of any project is the enriched professional capacities and self-confidence that project team members have gained by participating" [7]. To support enriched professional capacities and self-confidence of all our team members, we have constructed a template that provides a systematic framework to help assist each Adventure Engineering curriculum team member in the development of inquiry based, engineering driven math and science units.

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TEMPLATE FOR DEVELOPING INQUIRY-BASED CURRICULUM

The sections to follow will provide an example of how an Adventure Engineering team developed a curriculum unit for 7th or 8th grade Earth Science within the context of the aforementioned template. We suggest a five-step approach for developing engineering driven, inquiry based science and mathematics curricula. Although we will describe our curriculum development in a linear fashion, we want to articulate that curriculum development is a convoluted process.

Develop a Theme

We define a theme as the premise that under girds each curriculum unit. For example, one earth sciences curriculum unit is called Asteroid Impact and its resulting theme is “an asteroid is on collision course with earth; you are a team of engineers who must determine the best location to build underground caverns to house and thus save the inhabitants of your state.” It is this sense of urgency that we strive to build into each curriculum unit. Other examples of curriculum that we have developed are titled Engineering the Congo, Surviving the Biosphere, and Treasure Hunt.

We concurrently parallel the subject specific national, state or local school district principles and concepts with the underlying theme and then glean those concepts that could be inherently placed within a carefully written unit. Because our instructional vehicle is inquiry, process skill utilization and development is also an essential component of every math and science lesson within each curriculum unit.

Develop Obstacles/Activities/Milestones

With the correlating concepts, principles, and process skills identified, our next task is to develop obstacles, activities, or milestones that would lead to the construction, understanding, and development of these concepts, principles, and process skills. We remind our curriculum teams that these obstacles/activities/milestones should be developed with the learner in mind, meaning each activity must be developmentally appropriate so that each student is given the opportunities to construct pertinent understandings. At this stage of curriculum development, we encourage our team members to brainstorm possible obstacles and activities that correspond to the theme and that must be accomplished to move the student teams towards the final goal. Here, we are primarily concerned with the big picture or idea of each obstacle. More in-depth development of each obstacle/activity/milestone will occur later in this process.

The obstacles/activities/milestones that emerged from the Asteroid Impact theme include: (1) sizing the cavern (this obstacle incorporates algebraic skills, critical thinking, and problem solving); (2) determining candidate locations for underground caverns using geologic maps (this obstacle leads to an understanding of faults, geologic maps, a

mineral/rock identification); (3) testing the rocks and minerals to determine suitable locations for underground caverns (this obstacle incorporates experiential testing and rock/mineral properties); and (4) choosing the best location (this obstacle incorporates engineering problem solving, critical thinking, and synthesis).

Asteroid Impact, like all of our curriculum units, is constructed such that students begin with a clearly delineated challenge, e.g., determining the best possible location or locations to construct underground caverns to save all the inhabitants of their state. Each activity requires engineering analysis and design, e.g., proposing multiple solutions, gathering data, identifying criteria, interpreting scientific knowledge, prioritization. In addition, each curriculum unit is fashioned to promote teamwork and communication. Obstacle 1 requires population estimating, route assessment, per capita size estimating, developing advantages/disadvantages to one vs. multiple locations, etc. - much of which requires student brainstorming, estimating, and critical thinking. Each subsequent obstacle/activity adds more information to the process. Students are required to synthesize all collected information in order to develop a solution.

Conduct Preliminary Research

We ask that each curriculum development team conduct research over the main idea that embodies their particular theme. The accumulated information provides a background necessary to relate the theme to real life and to engineering practice. This preliminary research should eventually lead to the development of the “Teacher Background” to follow.

Example preliminary research for Asteroid Impact resulted in a brief description of asteroid theory, asteroid characteristics, asteroid effects on earth, and how engineering contributed to the knowledge and defense strategies regarding asteroids. This preliminary research accompanied with the concepts, principles, and process skills earlier identified allow the curriculum development team to begin writing the storyline.

Create a Storyline

The lessons within each curriculum unit are connected by an adventure driven storyline; this is where the curriculum unit begins to crystallize. The first step in writing a creative storyline is to understand what is to be conveyed and what the intended curriculum theme is. We believe creating a storyline will help ascertain that the curriculum development team members and the middle grade students understand the intent. Therefore, because our curricula are designed to be exciting, dangerous, urgent, and important, team members must be conscious of these elements when writing the storyline. It is in the storyline where we attempt to incorporate an engineering spin, deliberately weaving the identified math and science principles with engineering analysis and design.

At this point of the curriculum unit development, the Adventure Engineering team has identified the middle grade math or science concepts that are necessary to accomplish the curriculum theme and the corresponding obstacles/activities/milestones. The next order of operations is to brainstorm a coherent sequence of activities.

Develop Inquiry Based Activities

Middle grade inquiry based lessons should be taught the way middle grade students learn. The inquiry based activity or lesson should begin with the students doing “hands-on” activities using physical manipulatives. During these activities, students take in or assimilate information (data), which will help them later make meaning of the data. After data have been collected, students are then required to do “minds-on” activities. Activities, in this sense, usually mean students are asking questions about the data they have just collected or students are asked questions by the teacher about the recently collected data. Ultimately, the students discover the concept or principle through a series of questions led by the teacher. Proper question construction is vitally important at this stage of the lesson. Finally, students are allowed to apply the newly discovered concept or principle. Ideally, this is where the middle grade students apply the concept or principle to help them solve problems inherent in the scenario and ultimately move them towards the final goal of the unit. This stage of applying the concept to a real situation leads to meaningful understanding by the students. For more information concerning this approach to inquiry teaching see [8].

TEACHER’S GUIDE

Once each Adventure Engineering curriculum development team has amassed the components of the aforementioned template, the curriculum is now ready to be configured into a document that is suitable for middle grade math or science teacher implementation. We believe that a carefully structured Teacher’s Guide provides an easy to follow blueprint that enables middle grade math and science teachers to implement our curriculum with little prior engineering knowledge. Teacher’s Guide is organized into two main components. Each component comprises several sections.

General Introduction

After a brief introduction to Adventure Engineering, the Teacher’s Guide incorporates a Project Overview that provides a synopsis of the inquiry based, engineering driven theme for the classroom teacher.

Next, the Teacher’s Guide provides a grid that captures the name of each obstacle/activity/milestone, a description of each obstacle, the estimated time for implementing each obstacle, and the concepts, principles, standards, and/or process skills that are expected to be developed as a result of the obstacle. Table I conveys an example of one obstacle

that was incorporated into the Asteroid Impact curriculum unit.

TABLE I
GRID ENTRY

Obstacle	Description	Time	Concept
Sizing the cavern	Students will use algebraic skills, problem solving, and critical thinking to determine a suitable size of one or more caverns to accommodate the inhabitants of their state	50 min.	Students should develop abilities necessary to do scientific inquiry

The information collected as a result of the previously described preliminary research, is organized into a final section of the general introduction component, entitled Teacher Background Information. In this section, the curriculum team provides useful and meaningful information about the scientific or mathematical principles that are necessary to accomplish the inquiry based, engineering driven theme.

Storyline and Related Obstacles

Once each section of the general introduction has been constructed and put into a logical progression, the storyline is then polished and then placed in this component of the Teacher’s Guide. Reference [7] articulated that the “[curriculum unit] developer’s challenge is to create for every teacher the educational materials that embody academic concepts and principles in a rigorous way and also empower teachers to use their full range of skills, imagination, and creativity” (p. 7). Our hope is that the storyline is creatively developed to motivate middle grade math and science teachers to implement our curriculum and is presented to students to sustain their motivation for the duration and accomplishment of the curriculum unit theme.

We suggest following a prescribed format for each obstacle/activity/milestone. The title of the obstacle is given that does not reveal the concept or idea to be learned. For example, in the Asteroid Impact curriculum unit, one obstacle is titled, “Mineral Identification to Help Determine Cavern Locations.” The concept or principle to be learned is then provided. By stating the concept early in the inquiry based lesson, the goal has been identified and direction for the obstacle has been determined. The resulting concept of the “Mineral Identification to Help Determine Cavern Locations” obstacle is “Minerals can be identified according to their physical properties.” Coupled with the overall scenario objective, the title and concept provide a rationale for the activity. The estimated duration to complete each obstacle is provided for the teacher. We suggest listing the purpose of the obstacle followed by any prerequisite knowledge that is necessary for student understanding of the concept at hand. The objectives and process skills expected to be developed are then listed followed by the list of essential materials or equipment required for the specific obstacle/activity/milestone.

The next part of the Teacher's Guide for each obstacle is the carefully written procedures that guide students in the collection of data that is related to the underlying concept. This phase of the lesson is referred to as Exploring the Idea. The second phase of the procedure is the crux of inquiry based units. Here, the students either asks questions about the data they have just collected and/or the teacher poses questions that require the students to think critically about the experiences gained in Exploring the Idea. Through this series of questioning, students construct the concept or principle under the guidance of the classroom teacher. This phase is called Getting the Idea. The final phase of the procedure is referred to as Applying the Idea. Students are given opportunities to apply their newly developed concept to solve problems that are related to their engineering driven curriculum unit. This three phase approach of inquiry learning is called the Learning Cycle [8].

To determine mastery of the concepts, principles, standards, and process skills previously identified for each obstacle and/or the entire curriculum unit, each curriculum development team then constructs an appropriate assessment instrument. We concur with reference [8] that an appropriate assessment instrument is one that matches the philosophy, form, and goals of instruction. Therefore, since students experience math, science and engineering through an inquiry approach where they manipulate materials to collect data and ultimately construct concepts, principles, and process skills to then apply these to the overarching theme, they must be assessed in a way that reflects how they came to understand.

An excerpt from the Asteroid Impact obstacle titled "Mineral Identification to Help Determine Cavern Location(s)" is found below.

Activity 3: Mineral Identification to Help Determine Cavern Location(s)

Concept: Minerals can be identified according to their physical properties.

Duration: 120 minutes (two class periods)

Purpose: Some minerals have good characteristics for cavern design and construction, yet some minerals have poor characteristics. Each mineral has its own unique characteristics and several tests can be used to distinguish one mineral from another. However, a particular mineral can resemble others in some ways, and frequently more than one test may be applied—even several—to insure accurate identification. By identifying minerals according to their physical properties, students gain valuable skills that will benefit them as they later refer to geologic maps and identify rock characteristics to determine a suitable place for their underground cavern.

Prerequisite Information:

Minerals are inorganic chemical compounds that are found in the Earth's crust and have a definite crystalline structure. Minerals are the building blocks of rocks, and most rocks consist of more than one mineral. Minerals do not include organic materials, such as fossil fuels (coal, oil, and natural gas).

Learning Objectives: The student will:

- Use observable properties to identify a set of objects, organisms, or events;
- Identify properties by which a set of objects, organisms, or events could be ordered;
- Place an object, organism, or event into a classification system;
- Select the most logical conclusion for experimental data
- Communicate scientific procedures and explanations
- Interpret geologic maps;
- Formulate and evaluate explanations proposed by examining and comparing evidence and suggesting alternative explanations;

Materials:

- One small sample of minerals that are indigenous to your state (per group)
- One mineral identification kit (per group). Mineral identification kits can be purchased at www.infowest.com/life/identify.htm.
- If mineral identification kits are unavailable, the following materials can be used: steel nail, copper penny, streak plate (unglazed porcelain tile), magnet, vinegar (acetic acid), magnifying glass, small piece of glass, Mohs hardness scale
- One plastic graduated cylinder (per group)
- One triple beam balance or other mass measuring device (per group)
- One mineral identification testing sheet (per group)
- One mineral test data sheet (per group) Note: The teacher should prepare an answer key with the appropriate data for each mineral sample used in this activity
- One mineral identification question sheet (per group)

Procedures:

Exploring the Idea:

1. Administer one small sample of minerals, one mineral identification kit, one mineral identification testing sheet, and one mineral test data sheet per group.
2. Have each group conduct each mineral identification test and record their data.

Getting the Idea:

1. Looking at your data, which mineral proved to be the hardest according to the hardness test? What number did this mineral rank? How does hardness affect the design and construction of a cavern? *Answers will vary depending on which minerals were used. The strength and stiffness of a rock is directly related to hardness; however, harder minerals and rocks would be more difficult to construct within.*
2. What were the differences in color between results found in the color test and the streak test? *Answers will vary depending on which minerals were used.*
3. Which test do you think is a more accurate test to determine a mineral's color, color test or streak test? *The streak test is more accurate.*
4. What evidence do you have to defend your answer to question #3? *The streak test reveals the mineral's true color. The color of a mineral may vary, but the streak does not. For some minerals, the mineral color is different from the streak color.*
5. Is there a relationship between a mineral's hardness and its density? Provide two specific examples of minerals that you investigated. *In most cases, hardness is not related to density. Quartz has a hardness equivalent to 7 but a density approximately 2.6 g/cm^3 , whereas azurite has a hardness equivalent to 3.5 but a density approximately 3.8 g/cm^3 .*
6. Was one test sufficient for determining the name of a mineral? Provide a specific example where one test was not sufficient and where one test could have been sufficient in naming a mineral. *In most cases, mineral identification requires more than one test. Answers will vary depending on which minerals were used.*
7. Each test that was conducted measured a specific characteristic of each mineral. These characteristics, such as, hardness, color, luster, density, and magnetism, are all considered *physical properties* of a mineral. A mineral's reactivity with acid is considered a chemical property of that mineral.

Students should now use their data (physical properties) and the class answer key (as prepared by the teacher) to determine the name of each mineral. If the students' chosen name for a mineral does not match the name printed on the answer key, have students determine how they can correctly identify the misidentified mineral. How was your group able to identify each mineral? *Identification of each mineral was possible by determining the mineral's physical properties.*

Applying the Idea:

Have students reference additional information in your classroom text and/or from the Internet that reinforces the description and identification of minerals. We suggest referencing additional information after students have collected data and constructed meaning of that data.

Information that is found from research will reinforce the concept(s) that were developed in Activity 3.

After researching additional information and completing the Exploring the Idea, students should hypothesize which minerals or properties of minerals they think would be appropriate for building an underground cavern. Each curriculum unit includes engineering-related questions to facilitate the application of science and math concepts. For example, the teacher could pose the question, "Of those minerals that were identified, what physical or chemical properties would be important when considering where to build your underground cavern? Why?" *A mineral's hardness, density, and/or reactivity to acid could all be important when considering where to build an underground cavern. These properties could lead to a suitable destination for protection from an asteroid impact.*

Each curriculum unit conveys the related engineering fields. For example, the Asteroid Impact curriculum unit conveys that the application of mineral testing and identification skills and information are used extensively in the fields of Geological, Civil, Petroleum, Environmental and Mining Engineering. These engineering disciplines entail: (1) the exploration for, and the extraction of, mineral and energy resources; (2) site investigation for the construction of engineering structures (e.g. dams, buildings, roads, underground caverns, etc.); (3) detection, prevention and remediation of environmental contamination; and, (4) study of large-scale earth processes (e.g. continental drift, mountain building, earthquakes, volcanoes, etc.).

In the follow-up activity, students consult geologic maps to determine specific places within their state that contain those minerals that share characteristics or properties students previously determined. Students should record those places within their state that contain minerals that have suitable building characteristics for an underground cavern. As the student teams march through the obstacles, they apply critical engineering analysis and design techniques to develop *their* proposed solution. Students are asked to address proximity of candidate locations to population centers, constructibility, etc. Ultimately, they reach a best answer that may include numerous locations.

Assessment is built-in for this particular obstacle. In the process of developing identification skills, students will be able to correctly match the name of a mineral to the physical properties of that mineral. By recognizing suitable mineral properties for the construction of underground caverns, students can also be assessed as to their determined location(s) for their underground cavern.

CONCLUSION

We have described the template used to construct middle grade math and science inquiry based, engineering driven curriculum units. Principles of engineering analysis and design play an important role in linking science and math concepts to real world applications within each curriculum

unit. We are certain that as we develop more of these units for implementation in the classroom we will continue to learn more about curriculum development and curriculum formulation. We are learning that each member of our curriculum development team plays a critical role in this development. We agree with reference [7] in that the role of the classroom teacher is one who promotes lasting change. In order for our curriculum units to make an impact in middle grade classrooms, the classroom teacher must be involved in the development of the lessons and materials. "It is teachers whom the materials must first engage if a successful curriculum is to grow from them" [7].

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