Interconnected STEM with Engineering Design Pedagogy

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Interconnecting STEM with Informed Engineering Design Pedagogy
Abstract

This paper describes how K-12 Engineering can be an important pedagogical approach in mathematics and science courses. K-12 Engineering is examined in a STEM context with examples provided. As part of an NSF middle school science project, a framework was developed using informed engineering design pedagogy. Feedback from science teachers who participated in a professional development workshop using this framework indicated that they were greatly interested in using and confident in their ability to use the engineering instructional pedagogy in science. Furthermore, when surveyed again after several months about their use of the informed engineering design, these teachers provided similar feedback, with several reporting that they had already begun implementing one of the engineering based science lessons introduced during the summer workshop.

Introduction

The forthcoming Next Generation Science Standards (NGSS) will soon require that engineering be taught as part of middle school science classes. However, most science teachers have little experience with engineering pedagogy and content. During a week-long summer training session with 25 eighth grade science teachers (earth science, living environment, physical science), an overview of how to effectively integrate informed engineering design pedagogy into science classes and align engineering with the NGSS was presented. During this professional development, the teachers were given the opportunity to participate and experience an “engineered” science unit, and then create their own engineering infused science units.

K-12 Engineering

What does engineering mean when it is included in STEM? How is it different than the practice of engineering in the business world? One way to begin to understand engineering in a STEM classroom is to look at the differences in thinking in the fields of math, science, engineering and social science/humanities. These differences are displayed in Table 1. As can be seen, science is the study of the natural world, a discipline engaged in discovering the whys and wherefores of natural phenomena. The process for this investigation is scientific inquiry, in which a hypothesis is posed and logical investigations are undertaken to confirm or deny the hypothesis. Mathematics has its own philosophy and patterns, which are also often used by engineers and scientists to model designs or to represent natural phenomena, such as Newton’s second law of motion (Force = mass * acceleration). There are rules of mathematical analysis and theorems that allow for the manipulation of such equations. A publication by the National Research Council, Helping Children Learn Mathematics, discusses the big ideas and habits of mind needed to be mathematically successful. The social sciences and humanities provide an entirely different view of the world, a world shaped by human perceptions and understandings. For instance, a novel or a political or social event can be analyzed from many different perspectives. Although Table 1 presents thumbnail sketches, it highlights the differences among these disciplines and can be used to help think about the overarching themes that define engineering as both unique and interconnected to the other disciplines. Engineering within this context can be considered either a noun or a verb. This means engineering can be either the discipline which solves challenges or the approach to solving challenges.
Table 1. Comparison between different fields of thought.

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Science</th>
<th>Mathematics</th>
<th>Social Sciences and Humanities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study of the human- made world</td>
<td>Study of the natural world</td>
<td>Study of mathematical constructs</td>
<td>Study of human mind and perception</td>
</tr>
<tr>
<td>Engineering design</td>
<td>Scientific inquiry</td>
<td>Mathematical analysis</td>
<td>Rhetoric and criticism</td>
</tr>
<tr>
<td>Iterative design process, optimum solution</td>
<td>Hypothesis testing and evaluation</td>
<td>Theorems, proofs, rational constructs</td>
<td>Eclectic methods, comparative values</td>
</tr>
<tr>
<td>Artifact produced</td>
<td>Theory confirmed</td>
<td>Theorem validated</td>
<td>Opinion rationalized</td>
</tr>
</tbody>
</table>

Engineering, the noun, uniquely connects all three disciplines. In creating the human-made world, engineers must use knowledge from science, mathematics and the social sciences and humanities. Engineering, the verb, on the other hand, enriches and allows for informed investigation within each setting. In contrast to scientific inquiry and mathematical analysis, engineering design does not seek a unique or correct solution, but rather looks for the best or optimum solution after a variety of factors (e.g., cost, materials, aesthetics, and marketability) have been weighed. An important feature of this design process is that it is iterative, creative, and nonlinear. Furthermore, the solutions are tempered by our societal values. As a result, the optimal solution for one person may not be the optimum solution for another. In other words, there is no “one correct solution.” Engineering design can be a very engaging pedagogical strategy, particularly with adolescents, because people can bring their values to their design solution. Optimal solutions are also not stagnant and unchanging. For example, even if a solution were optimum at one moment in time for the specifications and constraints that were imposed, new technologies, new opinions, and new perspectives might lead to redefined or different solutions. This is a very empowering and unique feature of engineering that is in significant contrast to scientific and mathematical understandings where hypotheses and theorems may be refined but generally remain unalterable.

Another defining feature of engineering design is that it is not trial-and-error gadgeteering. Engineers create design solutions that are intentional and knowledge based. They use their knowledge of science and engineering science to understand what is happening physically, their use of mathematics to create models that may be analyzed, and their understanding of prior technological solutions so they can innovate. This is in contrast to the process used by inventors who typically gadgeteer along with trial and error to arrive at a workable solution that they can patent or manufacture. This use of modeling, with its inherent predictive analysis, is one of the significant differences between engineering and technology education, and engineering and art.

Engineering design and the design process are inherent to engineering, as the roots of the word engineer are linked to the design process. However, this does not exclude optimism and creativity. These are engineering habits of mind (visualization, creativity, connecting science, mathematics, social sciences and humanities, optimism, how things work, systems thinking) and engineering practice (engineering design including optimization, specifications and constraints).
Thus, there are multiple opportunities within the engineering and design process for creativity and optimism.

In summary, engineering (the verb) provides students with problem-solving strategies for understanding the human-made world and for applying concepts in mathematics, science and social science and humanities. Engineering (the noun) can refine these skills for students interested in further exploring the human-made world.

**Engineering as a teaching pedagogy**

Engineering is a natural way to connect STEM in K – 12 classrooms to integrate student knowledge in a contextualized manner. In fact, this may be one reason the NGSS is incorporating engineering within science. In a review of K-12 engineering education, the National Academy of Engineering cited engineering’s potential as “a catalyst” for integrating STEM within the schools. The NAE notes that infusing engineering ideas, activities, projects etc. into already existing STE curricula is a direct and uncomplicated way to make STEM more integrated. Moreover, Roehrig, Moore, Wang, and Park state that using engineering in the K-12 curriculum helps to align the lessons with interdisciplinary problems of the 21st century.

While there is still a paucity of research in the area, some preliminary work showing the benefits of infusing engineering design into the STM curricula has been completed. Koch and Burghardt explored the use of engineering design in elementary school math and science units as part of a STEM (at that time called MST) graduate program in elementary education. The results indicated three changes. These were (1) changes in teachers' own perceptions of their abilities to create student centered classrooms where each student group has control of the direction of their learning; (2) changes in students' attitudes towards mathematics, science and/or engineering/technology and in their understanding of the materials relating to the design process; (3) changes in the ways in which children with special needs engaged in group work and contributed to the final design project. These three themes which emerged during the study have remained consistent through further investigation.

In addition, Atkins and Burghardt investigated a connected mathematics and engineering design curriculum (construction of a food dehydrator) in middle and high schools. When dividing the students into quartiles and looking at pre-post test difference on content knowledge, all students showed growth, but the bottom two quartiles showed the greatest gains in performance. Furthermore, a study by Burghardt and Krowles with low-performing fifth grade students in a remedial mathematics class indicated that the use of engineering design pedagogy in a geometry unit provided dramatic shifts in mathematics content knowledge, from a pre-assessment average of 18% to a post –assessment average of 88% correct responses to a unit assessment. There were equally dramatic improvements in student attitude towards mathematics.

Valuable links also exist between engineering and informal science and mathematics. Lachapelle and Cunningham utilized an engineering curriculum at the Museum of Science in Boston to determine its effect on student learning of mathematical and science concepts. Although there was no comparison group, students who participated in the curriculum showed significant growth in both science and engineering. In another design based science curriculum,
Klein and Sherwood followed schools over three years to see if mathematics and science scores rose. They found that students in the experimental group which used the design based science curriculum demonstrated statistically larger increases on assessments of both science knowledge and concepts.

**Informed engineering design pedagogy**

Effective use of engineering design pedagogy requires careful planning and intentional instruction before the design challenge begins. Informed design is a pedagogical approach that engages students in the development of knowledge and skills relevant to the design challenge at hand. This approach requires that students apply understanding and knowledge to create informed design solutions rather than use of trial-and-error problem solving. This understanding and knowledge is learned in a just-in-time manner through explicit learning events called knowledge and skill builders (KSBs). KSB’s provide structured inquiry learning about key STEM concepts that underpin the design challenge that is presented.

Once the design challenge is presented, there are various phases of the informed design process that guide student work. These are:

*Clarifying Design Specifications and Constraints.* Design challenges have particular specifications and constraints that must be addressed when developing a solution. For example, typical constraints emphasized in a project might include the time or cost needed to complete the project. Specifications can emphasize particular concepts to be learned during the project and require students to develop and apply their understandings of these concepts.

*Developing Knowledge.* Consideration of the specifications and constraints should lead to investigation or inquiry into related concepts needed to solve the problem. The use of the KSBs are included in this section.

*Ideating Solutions.* Ideating Solutions is not simply brainstorming, rather, ideation encourages students to develop multiple, appropriate solutions to the task at hand.

*Justifying an Optimum Solution.* Students need to apply their knowledge to provide justification for one model over another. The use of predictive and representational modeling is included here.

*Building a Prototype.* Building a prototype is an important step during which time student select from their potential solutions and then construct virtual models or physical prototypes.

*Testing and Evaluating the Design.* Students test designs and evaluate whether they satisfy the project criteria.

*Refining the Design.* Based on tests, students revise designs to optimize their solutions.
The informed design phases, while unique, are not considered to be linear. Rather, students are encouraged to revisit steps iteratively, revising design solutions with the aid of repeated research and investigation. This explicit representation of an informed engineering process also serves as a way to help students develop engineering habits of mind. By using this representation to guide the student experience, the aim is to foster a classroom environment in which students will be aware of and involved in systems thinking, use creative thinking and problem solving skills, work to optimize and consider tradeoffs in design, and collaborate with classmates.

A recent project, WISEngineering\textsuperscript{14}, funded by the Bill and Melinda Gates Foundation, investigated the use informed design engineering and digital fabrication in seventh grade math classes. WISEngineering used the informed engineering design pedagogical approach to provide an explicit design cycle to guide students’ design projects (Figure 1).

![Informed Design Cycle used in WISEngineering projects](image)

In this approach additional elements were included to increase student engagement and learning. The design challenge itself was connected to interests of the students, often framed in socially relevant ways. For instance, in WISEngineering, one of the challenges had to do with creating a scale model of a community center for the community they were living in. Students were instructed to consider different aspects of community centers, such as temporary housing, cooking facilities, and exercise rooms. This personal and social connection to students own lives was found to be a strong motivator for engagement in the activity.
Decision rules for interconnecting informed engineering design pedagogy into math and science units

The conduct of experiments is important in the learning of science. However, while it is possible for students to design science experiments, in practice most science experiments are prescribed. This is in sharp contrast to engineering design in which students are expected to be responsible for their design. This difference highlights the need for a different approach when introducing design or engineering within science. To interconnect the two subjects, the essence of the existing science experiment must remain but be transformed in a way that will incorporate a design challenge that incorporated KSBs that include both science and engineering. Use of informed design provides an addition benefit for classroom instruction by introducing opportunities for teachers to observe and consider student process and decision making strategies. Since completing the design challenge requires that students understand the specifications and constraints and since there are multiple solutions rather than one correct answer, assessment of student learning is naturally evident when a teacher examines student work and consider the choices they made. Creating design challenges that have explicit specifications and constraints, allow for multiple solutions, engage students’ creativity, and can be accomplished with the resources in the classroom, is very demanding. Although not all science topics are amenable for design solutions, many are and can be easily transformed. However, it is likely many teachers would require support in doing so since they would not be familiar with the engineering design process.

The Math Infusion in Science Project (MiSP)\textsuperscript{5,11} provided an initial framework for thinking about interconnected STEM. This study investigated the benefits of infusing mathematics into eighth grade science curriculum. Results showed that student understanding of math, as demonstrated on project and standardized state exams, increased and that teachers and students found the inclusion of math within science natural and doable. Analysis of phase 1 data from over 700 experimental (infusion) and 700 control students revealed statistically significant improvements in student performance on NY State standardized exams in math, as well as on project attitudinal and mathematical content assessments. During this work decision rules for infusing math into science were developed, studied and refined.

Over the past year we have been involved in the development and review of similar decision rules for introducing informed engineering design pedagogy into science and math. These decision rules provide a way to infuse engineering design and engineering thinking, thereby further interconnecting STEM learning. As can be seen in Table 2, there are various ways to systematically use engineering design in science and mathematics classes.

Table 2: Decision Rules for Informed Engineering Design Pedagogy into Science and Math

<table>
<thead>
<tr>
<th>Decision Rules</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Each subject (math and science) maintains its own perspective.</td>
<td></td>
</tr>
<tr>
<td>2. Informed Engineering Design is \textit{infused} into various math and science units.</td>
<td></td>
</tr>
<tr>
<td>3. Math and Science remain the primary subjects.</td>
<td></td>
</tr>
<tr>
<td>Informed Engineering Design Pedagogy is introduced multiple times within different science and math lessons to allow for transference of understanding of concepts.</td>
<td></td>
</tr>
<tr>
<td>The sequence of science and of math topics is determined by the teacher/school.</td>
<td></td>
</tr>
<tr>
<td>The Math topics, the Science topics, must be challenging for students and key for later</td>
<td></td>
</tr>
</tbody>
</table>
understanding of more complex math or science concepts.

- Informed Engineering Design fits naturally within the science unit or math unit.
- Science units, or math units, must be taught in an inquiry based way and be of long enough duration to allow for students to engage in hands-on activities (typically at least a week long.)
- Teachers must receive professional development in both content and pedagogy to teach math infused science lessons.
- All lessons must be aligned with the Common Core Math Standards and the emerging Next Generation State Standards to assure the lessons have district and school relevance and face validity.

### What does it look like?

In addition to development of decision rules, we created a protocol for infusion of Engineering into Science activities. This can be found in Appendix A. The Rocket Unit, Appendix B, was the first MiSP science unit adapted using this protocol; several more are currently under development. Since being written, the Rocket Unit has undergone several reviews, been tried out with students, and was included as part of a week long professional development experience for 25 science teachers who had participated in delivery of the MiSP lessons.

The Rocket Unit was originally created as a math infused (MiSP) science lesson as a way to introduce the concept of chemical reactions. In this inquiry-based science unit, students investigate the rate of chemical reactions as a function of the amount of reactant (water and Alka Seltzer) and the temperature of the water. The rate of reaction is timed and measured by the top popping off a 35 mm film canister (Fuji works best). All 25 science teachers who participated in the summer professional development experience had been trained the prior summer to teach this lesson as part of their work in MiSP. Several teachers had also implemented the unit with their students during the school year.

An engineering design challenge was added to the Rocket Unit by having students apply their knowledge of chemical reactions to design a rocket (using paper wrapped around the film canister) that would pop “the highest.” Since the focus was on applying their science knowledge, students were provided with a template they could fit around the film canister helping assure students time was focused on making student canister top pop (i.e., the chemical reaction) rather than designing their rocket. In creating the engineering enhanced Rocket Unit, the original science lesson was essentially folded into the Knowledge and Skill Builders needed to create the rocket. After students complete their science experiments, draw their graphs and analyze their data, they are challenged to apply this knowledge and higher level thinking according to Bloom’s taxonomy, to create a rocket which will go the highest. Students must consider, if the reaction occurs too quickly, students will not be able to secure the top on the film canister and set the rocket up before it pops. If the reaction occurs to slowly the rocket will fail to reach a peak height.

During the summer 2011 professional development, teachers’ role played students as they engaged in the lesson. The teachers worked in teams and shared data as they worked. There
was a great deal of enthusiasm for completing the activity, and certainly disagreements as to what would be the optimum amount of water, water temperature, and amount of Alka Seltzer in the canister.

The Rocket Unit was embedded within a two day discussion of engineering design. Prior to beginning the Rocket Unit activity, there was a brief introduction to engineering design thinking—specifications, optimization, testing—and then the teacher engaged in the activity. Following the activity, once the teachers had experienced an “engineered” science unit, the framework (Appendix A) was introduced and the group discussed the process used to adapt the Rocket unit was discussed. Working in teacher teams, they applied the framework to a different MiSP science unit that they had taught during the prior year. Their goal was to create an “engineered” science lesson. After these new lessons were drafted, project staff and fellow teachers critiqued the new lessons which were then refined based on this feedback. Finally, the teachers were challenged to develop a one hour awareness workshop for science colleagues in their district discussing the “engineering” in STEM would be discussed. All materials that had been used during the summer workshop were made available for teachers to use or adapt.

What was learned

Following the teacher Professional Development experience, teachers were asked to complete a survey designed to gather feedback about the usefulness of the templates and assess changes in teacher knowledge and confidence in their ability to use engineering pedagogy in the science classroom.

The survey included ten questions asking teachers to rate how interesting they found certain aspects of the workshop, and eleven questions asking teachers to rate how confident they felt in their ability to do the engineering lessons at a later time. The first ten questions were on a four-point scale ranging from one, “not at all interesting,” to four, “this was one of the best parts of today.” Confidence questions were rated on a four-point scale ranging from one, “not at all confident,” to four, “very confident”; a “don’t know” option was also included. In addition, teachers were given the opportunity to describe what they would have liked presented in more detail, what aspects of the workshop surprised them the most, and any general comments about the training session.

Survey results

Most teachers reported that they found the engineering material introduced during the workshop interesting. Over 75% of these teachers indicated that learning about the connections between engineering and the new science standards was very interesting or one of the best parts of the workshop. Furthermore, nearly 72% of the teachers reported that the engineering infused MiSP lesson, Rocket Design, was very interesting or one of the best parts of the day. When asked about the opportunity to think about and discuss the challenges and benefits of engineering in science pedagogy, 71% of teachers said they found it very interesting, and all teachers found it at least somewhat interesting.
Teachers also expressed confidence in their ability to explain, teach, and meet new science standards using engineering pedagogy. Approximately 62% of teachers felt at least somewhat confident in their ability to explain to a peer how engineering can support science instruction. Additionally, over 71% of teachers felt at least somewhat confident in their ability to teach a lesson with added engineering components, and nearly 64% of teachers reported feeling at least somewhat confident that they would be able to meet the new science standards with an engineering approach.

Moreover, the same teachers filled out a follow up survey four months later to further explore the impact of the summer professional development. Teachers were asked to indicate whether they were still comfortable with engineering pedagogy, and whether or not they would be using engineering in their school. Approximately 57% of the teachers responding to the follow-up survey indicated they were still at least moderately comfortable with engineering design pedagogy. The teachers also reported that the workshop had impacted their perceptions of engineering. Several teachers, for example, noted that they now realized engineering did not need to be as complicated as they had originally thought and that engineering was more compatible with science curricula than they originally perceived. Other teachers indicated that the workshop introduced them to new content and ideas that had helped them in their classroom. Furthermore, nearly 86% of the teachers remained somewhat or very interested in implementing engineering design into their classes, with the proper professional development. A handful of teachers also reported taking the model lessons from the summer workshop and integrating them into their fall science classes.

**Conclusions**

The survey results suggest that this pilot program for introducing science teachers to engineering pedagogy addresses the needs and interests of teachers. Teachers felt that the workshop taught them about the connections between informed engineering design pedagogy and science pedagogy and gave them an opportunity to discuss the challenges and benefits of engineering content in science classes. It also provided them with the knowledge to confidently integrate engineering into their science classes. Teachers reported feeling confident that they could explain the benefits of engineering pedagogy to their peers, as well as effectively teach lessons with engineering and meet new science standards. This workshop was also effective at demonstrating how easily engineering can be integrating into science education and did it in a way that engaged teachers. Teachers noted that they enjoyed the design of the professional development that engaged them in the process of creating these lessons and trying them out with other teachers. They reported that the materials introduced during workshop were interesting and relevant for them.

**Acknowledgements**

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Bibliography

Science Using Engineering Design Pedagogy

As a result of doing this activity, what do I want students to know and be able to do that is related to the science unit?

_____________________________________________________________________________________

How will I know that students have demonstrated the knowledge and skills I want them to demonstrate? (Be specific) What is the evidence?

_____________________________________________________________________________________

THE DESIGN CHALLENGE

Brainstorm and list some ideas for an engineering design challenge that requires knowledge and skill from the items above. Indicate how challenge requires knowledge and skill. The challenge must allow for multiple solutions, engineering pedagogy, and primarily assessing process.

_____________________________________________________________________________________

_____________________________________________________________________________________

_____________________________________________________________________________________

Which of the ideas above will you use as your design challenge for this activity?

_____________________________________________________________________________________

Does the Design Challenge you selected meet the general specifications of what you want students to know and do? Can you assess their learning? If not, revise/reselect a different design challenge that does meet these specifications.

NEEDED KNOWLEDGE AND SKILLS
What do students need to learn in order to complete this challenge? Be specific and list up to 3 things a student needs to know.

1

2

3

What activities can you engage students in to help them learn these skills?

THE DESIGN CHALLENGE ELABORATED
What are the Specifications of the challenge? (list)

What are the Constraints of the challenge? (list)

EXPANDED DESIGN CHALLENGE: Reword the design challenge to include the specifications and constraints.

DESIGN PORTFOLIO
The design portfolio has several elements—challenge (including specifications and constraints), developing knowledge (knowledge and skill builder activities), creating alternative solutions (evaluating trade-offs and selecting the optimum solution), building and testing a prototype, evaluating the design and refining the design. There is also a reflection section and an extension section for students. Indicate the topics for the KSB activities.

Indicate reflection and extension questions related to the unit.
Answer the following questions related to the assessment of your student's knowledge, skills, or both as they relate to this activity:

*How will you measure student knowledge, skills or both?*

*What science knowledge do you expect students must demonstrate in order to complete this challenge?*

*What “observable” products do you expect to see?*

*What would you include in a rubric to guide evaluation of student work?*

*If using a paper assessment, what items would you include?*
APPENDIX B

ROCKETS

CHALLENGE: Several of your friends are interested in rockets and some research shows it is possible to make a simple rocket using Alka Seltzer as the power supply. This could be a cool way to learn about chemical reactions and find a use for them. Further investigation shows there is a simple way to make a rocket body from a piece of paper that is rolled up and a film canister with water and Alka Seltzer provides the boost. The rocket should go as high as possible while varying the amount and temperature of the water in the film canister. A maximum of one-half tablet of Alka Seltzer can be used in the design and everyone will use the standard rocket design body.

In this design challenge, what is the problem you need to solve?

______________________________________________________________  
______________________________________________________________  
______________________________________________________________  

Specifications are the things that my solution must have or do. They are the project requirements. Constraints are things that limit my solution. For example, a constraint may be how much I’m allowed to spend, or how much time I have to complete the challenge.

Fill in the chart on the next page with the specifications and constraints for this challenge.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
RESEARCH AND INVESTIGATION
KNOWLEDGE AND SKILL BUILDER I: EFFECT OF TEMPERATURE AND ALKA SELTZER AMOUNT ON CHEMICAL REACTION RATE.
INTRODUCTION:
Alka Seltzer in water produces carbon dioxide. It is the same reaction as vinegar and baking soda (sodium bicarbonate) because the Alka Seltzer has a chemical in it that makes water acidic like vinegar. When the reaction occurs in a closed container, in this lab a film canister, the gas pressure builds up until the lid "pops." The faster the chemical reaction, the faster the carbon dioxide gas pressure builds up, and the shorter time until the lid pops. In other words, if two reactions in film canisters are compared, the one that pops in the shortest time is the one with the fastest rate of reaction.

PROBLEM: How does temperature effect the time of (and the rate of) a chemical reaction?

HYPOTHESIS (complete sentence below):
If temperature affects the rate of a chemical reaction, then increasing the temperature will cause the Alka Seltzer reaction to _________________________________.

Safety Notes: GOGGLES SHOULD BE WORN. All safe handling of chemical precautions should be followed.
MATERIALS:
- 1 timer
- 1 film canister with cap
- 1 thermometer
- 1 25, 50, or 100 ml graduated cylinder
- 1 tray
- 1 waste beaker

CHEMICALS:
1 Alka-Seltzer Tablets (or other generic effervescent product) divided into four equal sections – you will need a total of 3 quarter pieces
Cold water, about 5° C, room temperature water, water, about 20° C, water, about 45° C (Your teacher will provide the water at the three different temperatures and will tell you the approximate temperatures.)

Procedures:
Do your work on the tray to help control spills. Check off each step as you complete it.

1. Add 10 ml of cold water to the film canister
2. Measure and record the temperature of the cold water.
3. Drop a quarter tablet of Alka Seltzer into the water inside the canister, quickly cap and begin timing the reaction. Stop timing when the lid of the film canister pops off. Record the time in seconds. Dispose of the used solution in the canister into your waste beaker (or sink).
4. Repeat this procedure for the warm water.
5. Repeat this procedure with the hot water.
6. Give your data to your teacher and determine a class average for each temperature.

<table>
<thead>
<tr>
<th>Water Temperature</th>
<th>LAB GROUP: Time (seconds) until the lid pops</th>
<th>CLASS AVERAGE: Time (seconds) until the lid pops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold: _____ °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot: _____ °C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph the CLASS AVERAGE data on the next page.
- Label the X axis
- Label the Y axis
- Draw a best fit line.
Discussion

1. Which temperature caused the fastest reaction (the lid popped off in the shortest time)?

2. Suggest a reason based on chemistry for your answer in #1

3. Use the graph to predict the number of seconds for the lid to pop off when the water temperature is:
   - 30° C ________________
   - 90° C ________________

KNOWLEDGE AND SKILL BUILDER II: BUILDING YOUR ROCKET BODY

Step 1
Cut out the rocket template pieces. You will need the big rectangle piece first.

Step 2
Take the lid off the film canister and use cellophane tape to attach the paper to it.

Step 3
Now roll the paper around the canister and attach with cellophane tape. The canister should be at the bottom.
Step 4
Take the nosecone template and cut out the triangle to make a cone. *You may need to cut out a bigger triangle.*

Step 5
Use cellophane tape to stick the ends together to form the cone. It should look like this.

Step 6
Using cellophane tape, stick the cone on to the top of the rolled piece of paper. Make sure the film canister is at the bottom.

Step 7
Now cut out all the fins for the rocket and fold along the dotted line.

Step 8
Attach the fins to the base of the rocket using the folded strip and tape.
Step 9
Your rocket is now ready to launch!

Insert Alka Seltzer Rocket Template

ALTERNATIVE SOLUTIONS:
Draw two sketches of possible designs that you want to create. Write two reasons why each sketch fulfills the specifications. Include the amount and temperature of the water and the amount of Alka Seltzer in each sketch.

Sketch 1
Reason 1:
Reason 2:

Sketch 2
Reason 1:
Reason 2:
OPTIMUM SOLUTION
Circle your best idea/sketch. Why is this the best design?
_____________________________________________________
_____________________________________________________
_____________________________________________________

What will you need to make your design?
Materials _______________________________________________
_____________________________________________________
Tools __________________________________________________

INSTRUCTOR SIGN-OFF.____________________________

CONSTRUCTING THE PROTOTYPE
Construct your rocket. Indicate below the amount of water, water temperature, and Alka Seltzer size that you are using.

Place a photograph or make a drawing of your Rocket in the space below. Label the important features. Show how all of the specifications have been met.
TESTING AND EVALUATION
How will you test and evaluate the ROCKET to determine whether the specifications have been met? (Explain the testing procedure)

_____________________________________________________
_____________________________________________________
_____________________________________________________
_____________________________________________________
_____________________________________________________

What are the test results? (Please display data in the form of graphs, tables, charts)

What are some trade-offs or modifications that you had to make in order to be sure that your design fit all of the specifications?

_____________________________________________________

REVISING YOUR DESIGN
How did your final design differ from your initial design? Why did you make the changes you did?

If you had more time, how would you improve your design?
REFLECTIONS
What are examples of trade-offs you made in your final design?

What constraint was the most difficult to adhere to?

Would you change the specifications and constraints? If so, indicate how you would change them and why?

How did your knowledge of chemical reaction rate influence the design solution you selected?

EXTENSION
A team member says there is a way to join two canisters together forming one twice as large as the one you used. What amount of water and Alka Seltzer would you use? Why?
Daily Learning Log

Day____
This is what I did
today:____________________________________
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This is what I
learned:____________________________________
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