Incorporating Engineering Research Experiences into High School Physical Science Curricula

Abstract

As high school teachers, it is rare that we have the opportunity to see the engineering applications for the mathematics and science concepts we teach. In Summer 2009, however, we participated in a Research Experience for Teachers (RET) project at Tennessee Tech University. Our research experiences varied: the second author conducted research that explored pack cementation processes and the variables affecting the aluminide coatings on nickel-based alloys in terms of composition and microstructure. Pack runs were conducted on the samples using different methods. Scanning electron microscopy (SEM) was used to look at both microstructure and composition. The third author researched creep strength in alloys with particular interest in whether there were significant differences in creep performance between a lever arm apparatus and a direct load apparatus.

As a result of the RET experience, we each developed a Legacy Cycle module (curriculum unit) that engaged our high school students in (1) a study of metals and ways to increase those metals' ability to withstand high ambient temperatures (in the context of an airplane crash investigation), and (2) a study of creep, stress, and strain tests and how to apply these tests to investigate the properties of aluminum foil. These modules placed students in the role of an investigator and required them to become researchers—giving them ownership in their learning.

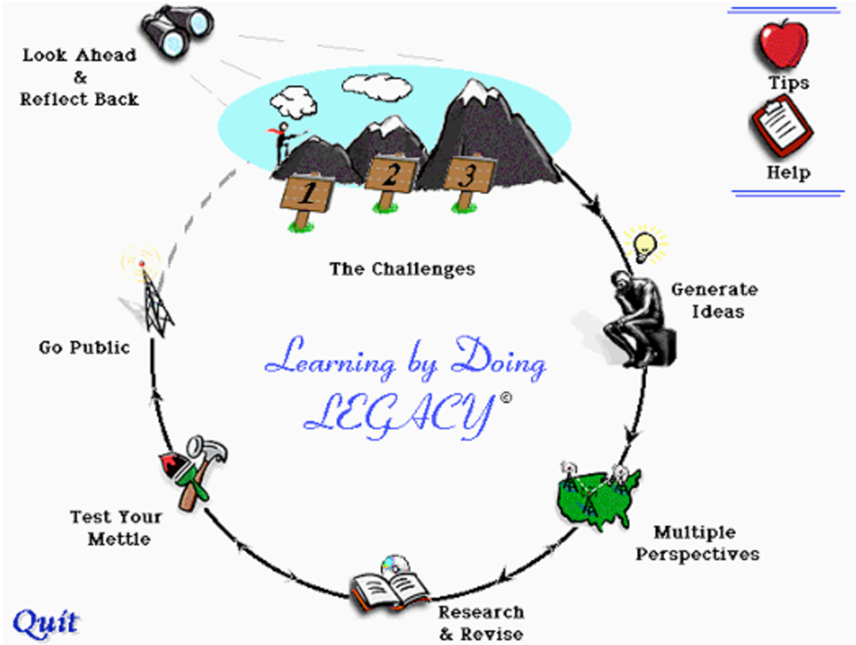
This poster session will highlight features of these legacy cycles and showcase our students' outcomes and products as a result of their engagement in the module. We approached the implementation of a legacy cycle module with both excitement and hesitation, but were pleased to see that our student outcomes were exceptionally positive. The Legacy Cycle model for lesson planning and implementation proved effective as a means for bringing engineering concepts and research into our high school science classrooms.

The Legacy Cycle Model

The Legacy Cycle design (see Figure 1) makes use of a contextually based "challenge" followed by a sequence of instruction where the students offer initial predictions (*Generate Ideas*), gather information from multiple sources (*Multiple Perspectives*), integrate the knowledge gathered and extend this knowledge (*Research and Revise*), and finally the students formalize their solutions in formative and summative assessment activities (*Test your Mettle* and *Go Public*).[1]

This process allows students to construct meaning of concepts and make connections, which is strongly associated with students' ability to use knowledge effectively in diverse situations.[2] The Legacy Cycle benefits students by positioning them to understand material by providing time for them to reveal prior misconceptions and demonstrate changes in thinking. The challenge question provides a real-world context, which prompts learners to utilize concepts as opposed to memorizing facts, increasing comprehension and adaptive reasoning.[1]

Figure 1: Legacy Cycle (ref: http://aaalab.stanford.edu/complex_learning/cl_star.html)



Teacher-developed Legacy Cycles

In the paragraphs that follow, we will first outline the research we conducted alongside mentors as participants in a Research Experience for Teachers (RET) project that was hosted by Tennessee Tech University (TTU) through funding from the National Science Foundation (NSF). We will then share the components of our legacy cycles and describe how we intend to use them with our students.

Overview of Research: Teacher 1

Pack cementation is a method of applying diffusion coatings to metals in an attempt to make them more heat and corrosion resistant. It is the means by which aluminide bond coats are applied for thermal barrier coatings (TBCs). This process is cost-effective as compared to other means such as chemical vapor deposition (CVD). My research looked at the variables affecting the aluminide coatings on nickel-based superalloys in two respects: composition and microstructure. This research was an extension of current research already underway at TTU. Pack cementation runs were conducted on samples that were prepared in the lab using several methods. One method included mixing the pack powders in a single plastic container using ten ceramic balls. The other method included mixing the powders in two separate containers using five ceramic balls over the course of three days. Scanning electron microscopy (SEM) was used to analyze both microstructure and composition.

Consistency of the aluminide surface layer was most prevalent when the powders were mixed in a single container (Method 1). Method 2 produced poor results. The purpose of these runs was to eliminate variations in the aluminide coatings. The coatings produced were more consistent than previous runs in terms of composition (indicated by color) and quantified by EDAX analysis. Inconsistent results were observed when pack powders were mixed for extended periods of time, which resulted from the greatly diminished particle size.

Legacy Cycle: Teacher 1

Given the nature of my research in the RET experience, I designed a Physical Science legacy cycle that featured a study of metals and ways to increase those metals' ability to withstand high ambient temperatures (in the context of an airplane crash investigation).

A central goal of this legacy cycle design was to incorporate the concepts of engineering research into my high school classroom. I teach at a Title I rural high school with a total student population of around 300. Most of the students fall into the low socio-economic status (SES) category. The class (15 students) in which I implemented the legacy cycle consisted of fourteen Caucasian students and one African-American student. There was an even mix of boys and girls in the class.

The legacy cycle I developed began with the following challenge statement: You are an investigator with the FAA. You have been called in to the scene of an airliner crash where a Boeing 777 traveling from LA to Chicago went down. 777s are among the safest aircraft in the world, so this accident is particularly puzzling. The probable cause is fatigue of the metal turbine blades inside the jet engine. Your assignment is to research and analyze the type of metal used in the engine and to research processes that will help those metals to better withstand the high ambient temperatures of the engine.

This challenge presented students with the opportunity to relate engineering to science concepts in the high school classroom. The first step came directly after I presented the challenge question to the students on Day 1. In this portion of the legacy cycle, the students brainstormed and made predictions about the challenge question. Next, in the *research and revise* part of the legacy cycle, students gathered information about the topic through multiple sources including: journal articles from scholarly sources, websites, and videos. I directed the students to particular sources, but some sources were located and identified by the students. At the beginning of Day 2, students reviewed the information that they had recorded in their journals. Next, during *multiple perspectives*, students received information from sources other than the teacher. Those sources included videos, journal articles, and professional interviews (with FAA staff) provided by me. During this portion of the legacy cycle, students completed projects and presentations that I used to assess their thinking. This gave them a chance to "try out" any ideas that they had. These parts of the legacy cycle took approximately one week to complete. In the final part of the legacy cycle, students had the opportunity to present their findings (*go public*) to their peers, parents, and members of the community. A complete version of the legacy cycle can be viewed in Appendix A.

Implementation of this legacy cycle into my high school science classroom increased student motivation, generated excitement, and made students aware of possible careers in engineering. I feel strongly that the legacy cycle experience broadened my students' knowledge of the application of engineering in not only the science classroom, but also in life. Student products, pictures documenting the implementation, and reflections (from both me and the students) will be included in the poster presentation.

Summary/Impact: Teacher 1

The RET experience has had a very positive impact on my personal and professional life. First of all, I have had the opportunity to work with many wonderful teachers and the RET faculty. Secondly, I feel like I have gained valuable insight in to the research process itself. For example, when I teach the scientific method to my freshman in high school, I can teach from experience as I have taken part in actual research myself. The opportunity to use equipment like the scanning electron microscope and the furnace apparatus was a once-in-a-lifetime experience for me…I can take my excitement and experience of seeing and using the SEM back to my classroom and share it with my students. I believe that having experience is much more useful than simply having knowledge of a topic. Having spent six weeks on this research project, I have the experience to back up what I will be teaching. Finally, I believe that the experience added depth to my instruction and positively impacted my students' learning. I did not see the same levels of thinking and engagement with students in courses in which I did not use a Legacy Cycle planning model.

Overview of Research: Teacher 2

My research focused on "creep" properties in ferritic steel. Ferritic steel is the common choice of material for the high-pressure steam pipe applications such as those found in coal-fired, steam power plants. My work attempted to determine if the test apparatus used provided repeatable results. Creep is defined as a permanent deformation in a material under high stress applications. During my time at TTU, we were unable to make any defensible conclusions based on the data gathered but were able to reconfigure the testing apparatus to provide a more stable environment for further testing. This research experience was valuable to me personally because it provided an opportunity to see actual, primary research in process while actively participating as well. The members of the research team made me feel welcome as a member of the team and gave me assurance that I had made a contribution to the research.

Legacy Cycle: Teacher 2

One of the key elements of the RET experience was the development of a Legacy Cycle (inquiry-based lesson) intended to bring my experience of research back to the high school science classroom. The idea of the Legacy Cycle was to provide a vehicle for addressing the engineering, science, mathematics, and technology strands (as outlined in the TN curriculum standards) in my classroom in a new and exciting way. This paper focuses on a physical science legacy cycle I implemented during the 2009–10 school year that featured a study of creep, stress, and strain tests and how to apply these tests to investigate the properties of aluminum foil.

The Legacy Cycle was introduced to approximately 125 students. The students were in ninth-grade and provided an excellent sample from all demographics. Classes were comprised of approximately an equal number of male and female students with a variety of learning challenges, including students that qualify for (Individualized Education Plans) IEPs and those who are English Language Learners (ELLs). There were also a number of students that were at or below grade level in mathematics and who have had limited success in previous educational settings.

This Legacy Cycle was written to be used in Grades 9–12, but could easily be modified for use in Grades 6–8. The students were not expected to have prior knowledge for the project—in fact most of the students had never been exposed to the terms introduced during the lesson.

The Legacy Cycle included a number of Tennessee curriculum standards for Physical Science including the Embedded Inquiry, Embedded Technology, and Embedded Engineering strands. A detail of learning expectations, performance indicators, and checks for understanding can be found at the end of the Legacy Cycle in Appendix B.

Summary/Impact: Teacher 2

Although the terms and information associated with the Legacy Cycle appeared to prove challenging for the ninth grade, the challenge seemed to inspire most students to delve deeper into the research. The Legacy Cycle was implemented during the chemistry section of Physical Science, specifically during the *properties of matter* section of the course. The Legacy Cycle provided the students with real-world problems and applications in the classroom, and allowed me as a teacher to facilitate the learning environment instead of directing the learning. I plan to make some changes to the lesson and use it in future classes.

Conclusions

As high school teachers, we learned about the nature of engineering research and design and are excited to bring those experiences into our classrooms. This poster session highlights features of these legacy cycles and showcases our students' outcomes and products as a result of their engagement in the modules. The Legacy Cycle model for lesson planning and implementation has given us an organized and structured means for bringing engineering concepts and research into our high school science classrooms, and we have witnessed firsthand the positive impacts on student learning, engagement, and interest in STEM. Our poster presentation will report the learning outcomes for our students and feature their work, while providing insights into how others could develop similar experiences for their students. We think the benefits we have seen for our students far outweigh the costs associated with planning, implementing, and assessing their efforts.

Bibliography

1. Klein, S., & Geist, M. J., (2006). The effect of a bioengineering unit across high school domains: An initial investigation into urban, suburban, and rural domains. In A. J. Petrosino, T. Martin, & V Svihla (Eds.), *Developing Student Expertise and Community: Lessons from How People Learn.* San Francisco: Jossey-Bass.

2. Klein, S., & Sherwood, R. D. (2005). Biomedical Engineering and Your High School Science Classroom: Challenge-Based Curriculum that Meets the NSES Standards. In R. E. Yager (Ed.), *Exemplary Science in Grades 9–12: Standards-Based Success Stories*. Arlington, VA: NSTA Press.

Appendix A: Legacy Cycle (Metals)

Challenge Statement: You are an investigator with the FAA. You have been called in to the scene of an airliner crash where a Boeing 777 traveling from LA to Chicago went down. 777s are among the safest aircraft in the world, so this accident is particularly puzzling. The probable cause is fatigue of the metal turbine blades inside the jet engine. Your assignment is to research and analyze the type of metal used in the engine and to research processes that will help those metals to better withstand the high ambient temperatures of the engine.

Step I: Generate Ideas

This step will come directly after I present the challenge question to the students on Day I. This portion of the legacy cycle is where the students will do brainstorming and make predictions about the challenge question.

I: Think Aloud/Share Ideas Activity: Students will make a know/need-to-know list on the board. I will assist in some of the need-to-know topics.

II: Students will create a journal that they will keep throughout the course of the legacy cycle. Students will record know/need-to-know information in journal.

III: Students will make any predictions about why the engine metal failed. They will also state why they think this challenge is important.

IV: Divide students up into groups. Each group will be responsible for researching a specific type of metal. Groups will be given posters on which they may record any ideas or progress. Students will record this information in their journals. Students will put posters on display.

Research and Revise

The research and revise part of the legacy cycle is where the students begin to gather information about the topic through multiple sources. At the beginning of day II, review information that the students have recorded in their journals.

I: On board, review what students already know. This should include some basic knowledge of metals, heat, and temperature.

II: Discuss any ideas that may have been generated that suggest a tentative course of action.

III: Begin lecture on metals and alloys. This lecture will take at least two days and students may record lecture notes in their journal. (Days III-IV)

IV: Brain Storm #1: Students will b asked to write a short essay explaining what they think will happen to metals that undergo heat stress.

V: Quiz at beginning of class on day V over metals lecture. Begin lecture on heat and temperature, and again students will record lecture notes in their journals. Students should now understand the properties of metals concerning heat conductivity.

VI: Students will look at SEM images of metals that have undergone heat stress and compare those images to metals that have protective coatings. I will provide images of metals with coatings from my research at TTU. At this point, I will give a brief summary of my work this summer. This will give them a foundation for research that they will be required to do later in the legacy cycle.

VII: Wrap up heat/temperature lecture by end of day VII.

VIII: Quiz over heat and temperature. Give a brief crash-course lecture on jet engines.

Multiple Perspectives

In this part of the legacy cycle, students will receive information from sources other than the teacher. Days VII-IX will include videos, professional interviews, and other multiple perspective activities.

I: Students will watch a short video on the principles of flight and jet engine operation.

II: Pending permission from the school board, I will take students on a field trip to the Embraer Maintenance Facility at the Nashville Airport.

III: I will have a pilot as a guest speaker in the classroom. Students may ask any questions that will help them in their research of the challenge question.

IV: After these multiple perspective exercises, students may go back and reevaluate why this research is important. They will record their ideas in their journal.

Test Your Mettle

During this portion of the legacy cycle, students will complete projects and presentations to assess their thinking. This also gives them a chance to try out any ideas that they had. This part of the legacy cycle will take approximately one week to complete.

I: Students will complete a peer lecture/mini-research project assignment at this point in the legacy cycle. In this assignment, students are responsible for researching a topic and presenting their findings to the class. The students will gather information on the types of metals commonly used to make the turbine blades in an aircraft engine. They will research the type of metal used and describe what characteristics make it useful. Students will then research methods of treating metals to make them more heat resistant. I will give them keywords such as pack cementation and chemical vapor deposition. Students will use resources such as TEL to gather information. They may also use any information from their journals that they find useful. In conclusion, they must prepare a one-page paper to hand in and will also present their findings to the class (limited to 5 minutes per student).

II: In the second portion of Test Your Mettle, students will go to lab and do an electroplating activity. Electroplating is a process whereby a thin coat of metal is applied to a material. The process involves placing the material to be coated in a solution containing ions of the metal and then passing an electric current through the system, which causes the ions to adhere to the material. This process is much more feasible in a high school laboratory setting because the equipment is affordable as compared to the materials needed to do pack cementation. Students will do multiple runs to check for consistency and repeatability. Mass is added to a sample when it is electroplated. Students will record the mass of the samples before and after the process to determine mass gain. Students will write up lab reports to show their results.

Go Public

In this part of the legacy cycle, students will have the opportunity to present their findings with their peers, parents, and members of the community.

I: All students will be responsible for turning in an accident report. This accident report will be summative of the entire legacy cycle. Using their journals, lecture notes, multiple perspectives, and research, students will answer the challenge question and present it in the form of an official accident report. The report will include the probable cause of the airliner accident, as well as recommendations for alternative metals. Students will also discuss methods of coating metals to make them more heat resistant.

II: This part of "Go Public" is not required for every student. All freshmen will participate in a science fair project during the spring semester. If students choose, they may build their science fair project around their work from this legacy cycle. With the electroplating equipment, students should have access to materials that they need. Again, students are not required to present their research from this legacy cycle in the science fair. They may choose their own topic, but may find it easier to build on the research they have already completed. The science fair will be a very public event. I hope to have an entire evening devoted to it where members of the community can come and see what the students are doing.

TN State Standards Addressed in Legacy Cycle

1. CLE 3202.Inq.3 Use appropriate tools and technology to collect precise and accurate data.
2. CLE 3202.Inq.4 Apply qualitative and quantitative measures to analyze data and draw conclusions that are free of bias.
3. CLE 3202.Inq.5 Compare experimental evidence and conclusions with those drawn by others about the same testable question.
4. CLE 3202.T/E.1 Explore the impact of technology on social, political, and economic systems.
5. CLE 3202.T/E.2 Differentiate among elements of the engineering design cycle: design constraints, model building, testing, evaluating, modifying, and retesting.
6. CLE 3202.T/E.3 Explain the relationship between the properties of a material and the use of the material in the application of a technology.
7. CLE3202.1.1 Explore matter in terms of its physical and chemical properties.
8. CLE3202.1.2 Describe the structure and arrangement of atomic particles.
9. CLE3202.1.5 Evaluate pure substances and mixtures (alloys).
10. CLE3202.2.3 Examine the applications and effects of heat energy.
11. CLE3202.4.3 Demonstrate the relationship among work, power, and machines.

12. 3202.Inq.2 Conduct scientific investigations that include testable questions, verifiable hypotheses, and appropriate variables to explore new phenomena or verify the experimental results of others.
13. 3202.Inq.3 Select appropriate tools and technology to collect precise and accurate quantitative and qualitative data.
14. 3202.Inq.5 Compare or combine experimental evidence from two or more investigations.
15. 3202.Math.9 Make decisions about units, scales, and measurement tools that are appropriate for problem situations involving measurement.
16. 3202.3.6 Collect data to construct, analyze, and interpret graphs for experiments that involve distance, speed, velocity, and time.

Appendix B – Legacy Cycle (Creep, Stress, Strain)

Challenge # 1
Engineers use different tests to determine the life of materials that are used for components in manufacturing and structural invention. Based on these tests engineers can then predict the life of these materials as well as give insight into failures that may occur on structures and materials. Your first challenge is to research tests that are associated with **creep**, **stress** and **strain**. Who uses these principles and what are they useful for.

Generate Ideas
Use computers to research these three principles.

Multiple perspectives
- www.instron.co.uk/wa/resourcecenter/glossary.aspx
- www.wmtr.com/Content/WhatisaCreepTest.htm
- steel.keytometals.com/articles/art43.htm
- http://www.civeng.carleton.ca/Exhibits/Quebec_Bridge/intro.html
- http://www.tms.org/pubs/journals/JOM/0112/Eagar/Eagar-0112.html
- http://www.concordesst.com/
- http://www.nasa.gov/columbia/foia/index.html
- Lecture from RetainUs project

Test Your Mettle
Student groups will find an example of where creep, stress or strain testing was used and prepare a group analysis.

Go Public
Student groups will then present their findings to their peers and demonstrate their knowledge.

Challenge # 2
Aluminum foil is an example of a material that is used everyday. Your challenge is to investigate the properties of aluminum foil and then based on what you have learned about creep, stress and strain, you and your group will develop tests to investigate the properties of aluminum foil.

Generate Ideas
- What properties can you test?
- Physical
- Chemical

Multiple Perspectives
- Discovery Channel – Season one, episode one – How Aluminum foil is made.
- lifehackery.com – 30 common uses for aluminum foil.
- earth911.com – what happens to aluminum foil in the land fills.
- Lecture on metals and properties of metals.
- Lecture on metal recycling.

Test Your Mettle
Here you will perform your experiments. You will need to keep track of your measurements and results. Once you have finished your experiments, you will then produce graphs that represent your experimental data.

Your group will also be given graphs and a scenario. Your group will then make an engineering determination of the scenario and prepare your report.

Go Public
Your group will present your analysis report to the other groups and give your findings. Part of your "Go Public" will be your group's response and feedback to the other groups analysis.

<u>TN State Standards Addressed in Legacy Cycle</u>

1. CLE 3202.Inq.2 – Design and conduct scientific investigations to explore new phenomena, verify previous results, test how well a theory predicts, and compare opposing theories.
2. CLE 3202.Inq.3 – Use appropriate tools and technology to collect precise and accurate data.
3. CLE 3202.Inq.4 – Apply qualitative and quantitative measures to analyze data and draw conclusions that are free of bias.
4. CLE 3202.Inq.5 – Compare experimental evidence and conclusions with those drawn by others about the same testable question.
5. CLE 3202.T/E.3 – Explain the relationship between the properties of a material and the use of the material in the application of a technology.
6. CLE 3202.Math.2 – Utilize appropriate mathematical equations and processes to solve basic physics problems.
7. CLE 3202.1.1 – Explore matter in terms of its physical and chemical properties.
8. CLE 3202.1.2 – Describe the structure and arrangement of atomic particles.
9. CLE 3202.1.4 – Investigate chemical and physical changes.