AC 2010-739: LEGACY CYCLE AS A VEHICLE FOR TRANSFERENCE OF RESEARCH TO THE CLASSROOM

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Legacy Cycle as a Vehicle for Transference of Research to the Classroom

Abstract

As engineers and educators, we seek the most viable methods through which we can translate research into practice. This paper describes how we have used Legacy Cycle modules[6] within the scope of a National Science Foundation (NSF) funded outreach program, *Research Experience for Teachers in Manufacturing for Competitiveness in the US (RETainUS)*. The six-week RET summer experience immerses high school mathematics and science teachers into the design and processes of engineering research. Teachers conduct their research alongside engineering students (undergraduate and graduate) with supervision from engineering faculty in various disciplines (mechanical, chemical, etc.). Of central importance to the project team is how to foster the translation of that research into practice, specifically into the high school mathematics and science curriculum. This paper explores the viability and flexibility of the Legacy Cycle as a vehicle to (1) train teachers to be researchers, and (2) as a planning and implementation model teachers can use to take engineering concepts and research into their classrooms.

RETainUS is designed so that teachers "become" researchers in the sense that they conduct literature reviews, develop research question(s), design (collaboratively with mentors/peers) their study, and report their results. Initiating teachers into the research process in the first week of the RET experience is key. In this paper, we describe how we use a Legacy Cycle approach to train the teachers in the research process. The inquiry approach inherent in a Legacy Cycle provides teachers the flexibility to research topics and develop their interests, yet the structure of the Cycle keeps the teachers focused and progressing towards the final goal/product: their research question. Using the Legacy Cycle early in the RET experience also showcases how a Cycle unfolds when implemented. This is important since each teacher is expected to develop a Legacy Cycle aligned to state curriculum standards that integrates engineering concepts and research learned as a result of their participation in the project. Their Legacy Cycle then serves as a vehicle through which their research is translated into the classroom.

This paper addresses how we have used the Legacy Cycle model to achieve project goals. We highlight the unique features of a Legacy Cycle approach and how those features contribute to the successful initiation of teachers into the research process, and to the successful translation of research into practice. Examples of the generated Legacy Cycles from the first year of the RETainUS program will be presented and distinctive features of these examples will be used to further explain the use and impact of the Legacy Cycle as a vehicle for transference of research into the classroom.

Legacy Cycle as a Vehicle for Transference of Research to the Classroom

Several national reports have emphasized the critical need for increased attention to developing a mathematically and technically competent workforce.[11,12] Many agree that high-quality mathematics and science education in the K–12 period is absolutely necessary to achieve the goal of creating a mathematically and scientifically literate public. Multitudes of initiatives exist to support K–12 science, technology, engineering, and mathematics (STEM) education. In traditional National Science Foundation-Math and Science Partnership (NSF-MSP) programs, the discipline specific STEM faculty have contributed to the MSP by delivering content to pre-service and in-service mathematics and science teachers as opposed to interacting with the teachers in a more sustained fashion.[10] The program for high school teachers described in this paper immersed teachers in the engineering research and design process, while simultaneously teaching the teachers how to design and implement the Legacy Cycle.

Acknowledging that "engineering research" and "engineering design" processes have distinct characteristics—in *design* engineers typically create solutions within a set of constraints, whereas *research* may be considered as creating new knowledge—the teachers were afforded the unique opportunity to explore those distinctions during the program. Several teachers participated in the design and implementation of engineering apparatus that were in turn used in addressing their research questions. Another teacher designed and supervised the implementation of an engineering measurement system from the low cost materials available in the laboratory for developing the stress-strain curve for hydro-gels reinforced with nano-particles.[16]

The National Research Council publication, *How People Learn: Brain, Mind, Experience, and School,*[3] describes best practices for supporting students as they develop flexible knowledge. One outcome of the "How People Learn" (HPL) research is the Legacy Cycle; a challenge driven pedagogical sequence that inherently embraces the principles of effective instructional design. The authors of HPL define four "centerednesses" of successful learning environments: Knowledge-centered, learner-centered, assessment-centered, and community centered.[3] Students in the STEM sciences need to learn how to adapt concepts across a variety of circumstances. The Legacy Cycle taps into the four teaching principles providing a template for students to create knowledge, use knowledge, and reflect on the entire process of learning. The characteristics of each of the centerednesses are as follows:

<u>Knowledge-centered</u>: This environment recognizes the need for students to not only acquire specific facts, but to gain a deep understanding of the field. Teachers who embrace a knowledge-centered environment help students make connections that relate the facts to the field, as well as how the field fits into the students' entire knowledge base.[3]

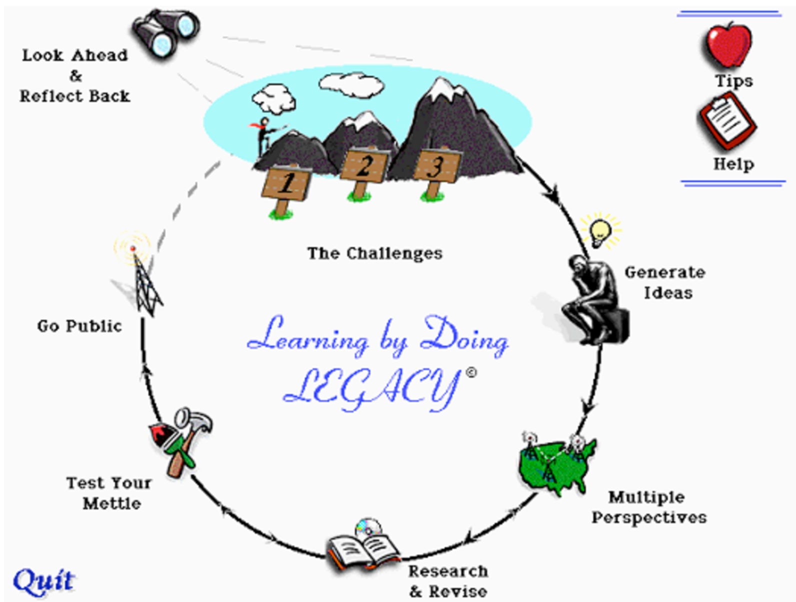
<u>Learner-centered</u>: The learner-centered environment acknowledges two principles for effective learning. Firstly, effective teachers understand that information students bring to the classroom will greatly impact how the students learn new material. Teachers must develop tools to discover and utilize students' prior knowledge and perceptions.[15] Secondly, learner-centered environments provide opportunities for students to think about thinking, engaging them in the process of metacognition.

<u>Assessment-centered</u>: An assessment-centered environment allows students to scrutinize their learning, identify weaknesses, and make appropriate adjustments. Assessment-centered teachers design both formative and summative assessment tools to provide students with constant feedback.[3]

Community-centered: Community centered environments allow students to situate their knowledge in real-world scenarios. Students are given opportunities to explore how concepts affect the community (school, city, nation, world), and vice-versa.[3]

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*).[5]

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



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.[7] 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.[5]

The RETainUS program was designed to connect the four "centerednesses" of HPL design to the Legacy Cycle. This articulation is fully described later in the paper.

The Legacy Cycle has been used effectively in multiple disciplines and in K–12 as well as undergraduate classrooms. Klein and Geist[3] successfully implemented a Legacy Cycle centered-on the concept of torque in rural, suburban, and urban high school physics classrooms. In a controlled study, the authors found that students who participated in the Legacy Cycle had a deeper understanding of the concept of torque and were able to transfer the knowledge to novel physics problems. Brophy[4] examined the use of Legacy Cycle learning materials in introductory bioengineering classes and found the design principles to be highly effective at engaging students in the engineering process. Roselli and Brophy[14] and Pandy, Petrosino, Austin and Barr[13] redesigned traditional biomechanics courses using the Legacy Cycle and HPL principles. Students in the HPL research group altered their learning from memorizing formulas, to understanding how to categorize and choose information to solve more complex engineering questions. An added benefit to the introduction of the Legacy Cycle to the biomechanics courses was an increase in student satisfaction with the course as measured by instructor and course evaluation tools.

To date, the Legacy Cycle has been used as a structure for developing curriculum modules or as structure for managing and organizing instructional practice. Our applications of the Legacy Cycle build on these ideas, but also extend the application of the Legacy Cycle to Research Immersion Experiences (RIEs) for K–12 teachers.

Research Experience for Teachers (RET)

> "This has been the best professional development program I have ever been involved in. I usually participate in a summer program every year and this is by far the most beneficial and useful as far as using it in my classroom. I have actually taken what I learned this summer and have shared that with my students. The grant provided equipment specific to my legacy cycle instead of giving all the participants a generic set of equipment and as a result, I was able to easily implement the legacy cycle" (RET teacher reflection).

In Summer 2009, two mathematics teachers and seven science teachers from six local high schools participated in a six-week Research Experience for Teachers (RET project) funded by the National Science Foundation (NSF). The teachers designed and conducted engineering research with technical mentorship from Chemical Engineering, Mechanical Engineering, Materials Science, and Industrial Engineering faculty at Tennessee Tech University. In most cases, two teachers worked with one technical mentor. A Mathematics Educator also assisted the teachers in navigating the "engineering terrain" and by serving as a "translator" between the engineering faculty and the teachers. A faculty member from Nursing used her expertise to coach the teachers in instructional design specific to the development of a Legacy Cycle (curriculum module). The expectations of the RET experience were high, but teachers had ample support to accomplish the goals in the timeframe allotted.

Two applications of the Legacy Cycle were integral to the teachers' RET experience: (1) the Legacy Cycle was used by engineering faculty as a vehicle to train the teachers to be researchers, and (2) each participant teacher developed and implemented a Legacy Cycle that featured the engineering concepts and research they had learned as participants in the project. Both Legacy Cycle applications are discussed in subsequent pages.

Legacy Cycle as Vehicle for Training Teachers to be Researchers

Embedding the introduction to research into a Legacy Cycle format began by recognizing the commonalities between the learning that RET participants would be undertaking as novice engineering researchers and the requisite curriculum design skills that they would be expected to demonstrate as they took their summer experience back into the classroom via a learning module. The design of the Week One introduction to research is based on prior work with a Research Experience for Undergraduates (REU) program at TTU. As the project staff prepared for the first summer offering of the RET, we noted the potential strength of reformulating the existing Week One structure into a visible framework using the Legacy Cycle. We had observed that the intense schedule of the Week One introduction (Research Immersion Experience—RIE) provided multiple challenges, a primary one being how to ensure the participants could generate their own meaningful research question and draft research plan in a week's time. Thus, aligning this challenge with the pinnacle phase one of the Legacy Cycle model was straightforward. Table 1 below presents the six phases of the Legacy Cycle[6] with a general description of the phase in Column 2 and specific activities designed to guide the learning process during the Week One RIE.

Table 1. Introduction to Research Legacy Cycle

Legacy Cycle Phases	General Description	Specific Activities for Introduction to Research
Challenge	question or critical need that engages the learner and requires them to look at their own current knowledge and preconceptions	RET participants are challenged to produce a "research question" and "research plan" that will guide their summer work.
Generate Ideas	an activity that causes learners to display and compile their current knowledge/ideas/perceptions	*Activity 1*: "What is research?" *Activity 2*: TPS "What is research in engineering? "
Multiple Perspectives	two or more resources that provide information related to the topic of the challenge	*Resources*: supplied books and technical articles *Mini-lectures*: Concepts and definitions – research and development, measurement, reliability, validity, evidence, clarity, significance *Activity 3*: participants consider and compare word pairs "research" and "development", "theory" and "practice", "science" and "engineering". *Activity 4*: TPS "Why conduct research?"
Research and Revise	activities that learner's engage in to help revise their original ideas based on new information	*Activity 5:* Poster – State the research question. *Activity 6:* Walk the Wall – read and respond to peers' posters. Provide

		feedback on clarity and significance of the question. *Activity 7:* Read and study the Chapter 3 of "Craft of Research" to better refine their question. *Activity 8*: Meet with technical mentors and visit engineering labs and graduate students to learn more about their topics. *Activity 9*: Revise the research question *Activity 10*: Add to the poster – what kinds of measurements will be made (and methods used) to collect the evidence needed to answer the question? *Mini-lectures*: Project management, SMART goals, planning (Gantt chart), research project checklist
Test Your Mettle	Formative assessments that enable learners to evaluate the depth of their learning (iterative exchange between this step and Research and Revise)	*Activity 11*: Update the Poster - The participants update their posted research question based on conversations with the technical mentor and with their peers. They are also required to further address the anticipated processes for measurements and data analysis, and to include project goals and planning. Project staff roam the room and prompt additions to the posters.
Go Public	Final conclusion(s) that learners display	*Activity 12*: 15 minute oral presentations to the peer RET participants, technical mentors, and project staff via electronic slide show. Respond to audience questions.

The schedule for the Week One RIE is in Table 2, showing that the "formal" instruction time allocated for *Basics of Research* is limited to five hours; a two-hour instructional block on Day 2 and a three-hour instructional block on Day 3. The participants are encouraged to begin using a journal for reflective writing throughout Week One and to continue its use as the lab journal throughout the six-week program. During the formal instruction times, an active learning exercise called the Think-Pair-Share (TPS)[9] was used. Participants responded to a TPS query first by thinking and writing a response in their journal, then briefly discussing their thoughts with a partner and finally sharing commonalities and discrepancies with group dialog. A useful tool for monitoring learning progress was a "public" item called the Poster. At the end of Day 2, each participant is given a 24" x 30" self-stick poster sheet to hang on the wall of the common room and required at various times over the next few days to add content to the poster. Much of their learning was visible through edits they made and they were encouraged to provide feedback for their peers by "walking the wall" and engaging their fellow participants in conversation about the content on their posters. Various written resources were provided to the participants and introduced via the activities and mini-lectures. These included: (1) topic journal articles selected by the technical mentor for background reading, (2) individual copy of the book, *The Craft of Research*,[2] (3) a group reference copy of *Getting it Right: R&D Methods for Science and Engineering*,[1] (4) mini-lecture handouts, and (5) a research project checklist.[8]

Table 2. Schedule for Week One

Days	Times	Description
Day One – Monday	8 am – 10am	Introductions and Orientation
	10 am – noon	Campus Tour
	Noon – 1pm	Lunch
	1pm – 4pm	Technical Mentor Presentations
Day Two - Tuesday	8am – noon	Technical Mentor Presentations
	Noon – 1pm	Lunch
	1pm - 3pm	Research Basics I
	3pm – 4pm	Library Research Tools
Day Three - Wednesday	8am – noon	Work with technical mentors
	Noon – 1pm	Lunch
	1pm – 4pm	Research Basics II
Day Four - Thursday	8 am – noon	Work with technical mentors
	Noon – 1pm	Lunch
	1pm – 4pm	Prepare presentations
	4pm – 5pm	Conversation and Feedback
Day Five - Friday	8am – noon	Individual Presentations
	Noon – 3pm	Picnic Lunch at Park

Observations on Use of Legacy Cycle for Introduction to Research

The observations offered in this section are informal. The instructional elements of the RET program were not designed to capture data to provide formal assessment.

Activities 1–4: In response to the first TPS, not surprisingly, discussion revealed that many of the descriptors were phrases classically associated with the scientific method (hypothesis, experiment, data analysis, results, etc). The second TPS was used in anticipation of some of the conceptual and linguistic barriers regarding engineering the teachers might be experiencing throughout Week One and during the summer. Given that one of the RET project goals was to provide more awareness about what engineering is in relation to science, the teachers responses provided useful starting points for conversations between project staff and RET participants. Further discussion occurred during Activity 3 where the mini-lecture had supplied a view of research as "a process that acquires new knowledge" and development as "a process that applies new knowledge to create new device or effects" [1] and a simple graphic had provided a quick glimpse of the spectrum of connection between basic science and engineering. This encouraged the participants to observe where their summer work may fit on such a continuum. The fourth activity encouraged the participants to expand on their prior understanding of research to go beyond the initial question of “what is it?” to “why do we do it.”

Activity 5: This first pass at crafting a research question was based on the participants’ current understanding of the topic they’ve been assigned. If they found the task too ambiguous (and most did!), they were encouraged to paraphrase what they know about the topics they just heard about from the technical mentors during the Day One Afternoon Session and Day Two Morning Session.

It must be noted that this single activity was highly stressful. The participants were very vocal in their uncertainty. They felt they needed to know much more about their topic prior to forming a question. They demonstrated a reluctance to put anything on paper. Staff coaching during this activity was very important. The participants were encouraged to just “put something” on paper as a means to start the process, and were reminded they could edit it at any time in the following days as they learned more. Part of the intent here was to foster the awareness of the iterative nature of research. Additionally, it became clear that since engineering is often viewed as application of science, and since some of the topics that participants were working on would be more on the “development” side and thus the work they would be engaging in would not necessarily be led by a research “question” but rather a design process, there was much uncertainty about what they were to do in that case. They were caught in the semantics of how to craft a “question” when they felt they really needed to make a “statement” calling for a solution that met a certain requirement, i.e. engineering design specifications. Future delivery of the Week One training needs to take this into account and offer samples of how to deal with this troubling feature.

In a few cases, participants explicitly stated they wished someone would tell them what to write. They desired structured steps with finite limits on what they must do and began to express strong doubt about whether they could deliver anything meaningful in six-weeks given their perception of what they know and don’t know and what is expected of them. The open-ended nature of research as an inquiry process was clearly outside their zone of comfort.

Activity 6: “Walking the wall” reassured the group that everyone was experiencing the same concerns regarding the crafting of a research question in such a short time frame. The support they offered one another was a strong benefit of this activity. The depth of conversations regarding how the summer would work immediately increased.

Activity 7: The overnight reading assignment opened them up to the fact that a process did exist for purposefully refining an interest in a topic into a useful research question. Using the steps provided in the reference, they could focus their energy on moving from a topic of interest to a refined research question that was significant.

Activities 8–11: These activities expanded on the basic model of the previous activities. There was a natural iteration and refinement process at work as evidenced in the crossed out pen writing on the posters. The group bonding that formed during the peer feedback and conversations was one of the noticeable highlights of this approach to group training in research. Because the actual topics in some cases related closely to one another, pairs of participants found support in one another; while the diversity of projects meant that each participant was able to learn peripherally about multiple engineering perspectives by listening to one another report informally during the group discussion times.

Activity 12: The presentations made at the end of Week One served as the "Go Public" phase of the Legacy Cycle for Introduction to Research. Another concern of the participants was how detailed these presentations needed to be. The project staff were slightly surprised by the level of stress evident in some of the participants and had to work to alleviate this during the late afternoon of Day Four. With the emphasis on the individual participants as the "lead" researcher for their topic, it had not been considered that the teachers would not have confidence in preparing their own presentation of research question and plan. Here again, staff needed to be ready to coach the process one-on-one. It is worth noting that one of the participants who on Day Two was pretty sure they wanted to walk away from the experience, had rallied and was providing peer coaching. Indeed, this individual provided one of the clearest questions and the most detailed plan of the nine participants.

Wrap-up: The various informal dialogs throughout the week between the project staff and the participants tended to reinforce the cyclic nature of the inquiry process that guides research and is exemplified by the Legacy Cycle. Thus, by the end of the week, the participants were well aware of the process that they had been experiencing as an Introduction to Research and recognized that it was a compressed version of how a Legacy Cycle could be played out in a classroom setting. While the process itself was very intense and did not often lend time for reflective awareness of how participants could use the Week One experience to model and guide their design of classroom activities at the end of the summer to take their research experience back into the classroom, the potential was high to reinforce the dialog in future offerings of this training model. In actuality, while they may not have had time to become explicitly aware of the Legacy Cycle model in action during Week One, some participants were indeed thinking about it in following weeks, as indicated during weekly Coffee Hour talks.

Legacy Cycle as Vehicle for Embedding Engineering Concepts into Curriculum

As a culminating product of the RET experience, each project teacher was asked to develop a Legacy Cycle aligned with his/her curriculum standards that incorporated engineering research and concepts from their summer experience. As Project Staff, we saw the potential of the Legacy Cycle as a vehicle for transferring research into practice—in this way, we ensured that the teachers' summer experience was not limited to their own professional development, but was extended to their students as well. Our goal was to facilitate the teachers in engaging their students with mathematics and science content as it related to "real-world" engineering design and research. The teachers' struggles with Legacy Cycle development are discussed along with their successes. Examples of the teacher-developed Legacy Cycles are presented to highlight the distinctive features of the Legacy Cycle model that led to the successful transference of research into these K–12 classrooms.

Development of the Legacy Cycles proved challenging for the teachers. The Legacy Cycle was an unfamiliar approach to instructional design for the teachers. Early frustrations stemmed from difficulties in writing and focusing the Challenge Question. In parallel to their experiences with writing their research questions, the teachers often began with challenge questions that were far too broad and/or complex for their students to tackle. More challenging, however, was how to narrow the focus without losing the engineering emphasis. As mathematics and science specialists, it was natural for the teachers to gravitate towards topics they felt were difficult for students to grasp, or that were traditionally taught in non-engaging ways. Their goals were to use the inquiry that is interwoven throughout the Legacy Cycle model to motivate student learning. As project staff, we encouraged them in those pursuits—in doing so, however, the teachers found it difficult to simultaneously keep a focus on bringing the engineering concepts into the Cycle. This was particularly challenging for the mathematics and biology teachers. Those who taught physics, physical science, and chemistry also struggled with this aspect of the Legacy Cycle, but to a lesser extent than the other teachers.

The second greatest struggle for the teachers centered about the alignment of the Legacy Cycle with their curriculum standards. The teachers felt compelled to start with their curriculum standards and to then develop a Legacy Cycle that would teach that particular content. While a standards-driven approach to lesson planning is preferred, we observed that the teachers often compromised the quality and potential of their Legacy Cycle by being too limited by, or "too close to," their curriculum standards. We found no solution to this dilemma since starting with a Legacy Cycle and later "inserting" the standards it addresses, may indeed improve the quality of the Legacy Cycle itself, but it may not be applicable to their teaching if it fails to adequately address their curriculum standards. With the No Child Left Behind Act and teacher accountability at an all-time high, the teachers could not afford to "free themselves" to the development of a Legacy Cycle that did not address several standards in-depth, since several hours of instructional time would be taken to implement the Cycle.

Despite these early struggles, all of the RET teachers developed Legacy Cycles that were aligned with their curriculum standards, appropriate for high school students, and designed to highlight features of their engineering research from the RET experience. A brief overview of each Legacy Cycle is provided in Appendix A. Samples of student work and a complete Legacy Cycle are provided in Appendix B.

Legacy Cycles place students in the role of an investigator and require them to become researchers—giving them ownership in their learning. Students engaged in a legacy cycle are creating knowledge via investigation and experimentation that they develop and direct. This then places the teacher in uncertain territory since the students' questions and their research shape the direction of the learning. If students' questions result in the exploration of unanticipated (or unfamiliar) content for the teacher, then the Legacy Cycle serves as a "mirror for teacher practice." The teacher may have to confront limitations in their content knowledge and/or move into the role as learner alongside his/her students. We anticipated that navigating this terrain would be "risky" and "uncomfortable" for our teachers. We have been pleasantly surprised by the outcomes.

After implementation of the Legacy Cycles, the teachers were asked to write a reflective paper that highlighted both the positive and negative aspects of the implementation for both themselves and the students. Teacher quotes included in this paper are referenced according to the course in which the Legacy Cycle was implemented and the title of the Legacy Cycle (LC). The five teachers who implemented their Legacy Cycles in Fall 2009 unanimously reported positive learning outcomes for their students:

> My students enjoyed participating in the legacy cycle. They produced quality work and did well on their assessment…there were some excellent projects as well as some very basic projects… however, some lower performing students excelled at these types of activities and everyone was engaged and was very excited about doing the hands on activities (Physical Science; Sunscreen LC).
>
> I could not have asked for better results from my students! They were actively engaged through the entirety of the legacy cycle. Even students who typically are not focused and not motivated were highly motivated to produce quality work. I heard many positive comments. My students indicated that they had a more in depth understanding of the content because of the way the legacy cycle was designed. Ultimately, the overwhelming conclusion was that they were very proud of the fact that they took difficult work, understood it, and ultimately successfully completed a fantastic final project! In thirteen years of teaching, I have not received this level of quality work accompanied with the level of understanding the students have for the content they have mastered (Mathematics; Linear Programming LC).
>
> The legacy cycle proved extremely effective as a means for translating engineering concepts and research into my high school chemistry and physical world concepts classroom, as well as providing a highly engaging active learning experience for my students…I believe that the successful legacy cycle [as the first lesson of the school year] set the stage for an engaging and productive year for my students (Chemistry/Physical World Concepts; Concrete Tile LC).

The teachers also noted that the legacy cycle helped students to think differently about their career trajectories and to consider STEM fields they had not previously considered:

> Implementation of this legacy cycle in the classroom has had a profound impact on the student perspective of careers in science and engineering. I teach at a small, rural school...Opportunities for furthering education after high school are limited for these students as most of them come from low SES families and motivation to attend postsecondary schools is scarce. Opening the door with aspects of engineering and scientific inquiry has made students aware that there are more fields of study besides teaching, medicine and business (Physical World Concepts; Polymer LC).
>
> Some of my students would never have considered engineering before completing this legacy cycle because they didn't understand that what we did in our legacy cycle was engineering (Physical Science; Sunscreen LC).

> One female student openly admitted that engineering had never been considered as a career field for her and this project had changed her mind (Mathematics; Linear Programming LC).

Finally, several teachers commented on their experiences implementing the Legacy Cycle. Their comments portray implementation as a rewarding experience despite their initial concerns and lack of comfort.

> Overall I feel that this has been a successful experience for me as a teacher as well as for my students. I had to step out of my comfort zone as far as my teaching style. It required a lot of preparation especially for the electrophoresis lab, but it was worth it when my students showed excitement about doing the activity (Physical Science; Sunscreen LC).

> Required sacrifice and commitment for this project far exceeded the amount of professional development expected of professional teachers. Six weeks during the summer was an immense amount of time to devote to research on a topic that was extremely overwhelming in the beginning of this project. After working with mentors and colleagues associated with RET I am convinced that introducing material in a Legacy cycle empowers students far beyond textbooks and traditional lab activities. Progress in self-esteem, increased confidence in student ability, and overall performance in the classroom are visible on day 1 of the legacy cycle. Although time is always an issue in a standards-based core subject when planning curriculum, benefits of the legacy cycle far outweigh the time it takes to complete. Understanding that a legacy cycle cannot feasibly be used with every standard and topic covered in a science classroom, it is a valuable tool to increase interest in science/engineering, student engagement, level of retention and overall achievement (Physical World Concepts; Polymer LC).

> This experience has had a profound impact on the way I approach integrating engineering concepts into a high school mathematics classroom. I used to simply hope that a word problem might exist at the end of the lesson to maybe demonstrate to my students that there are engineering applications to the mathematics that we learn. Professionally, now I am able to give these examples from the experiences I have had. It has also given me the courage to be a presenter for a regional partnership group of teachers on how to effectively integrate engineering through the venue of a legacy cycle…Personally, I have challenged myself to finish an in-depth research project in engineering! I feel like I have come full circle as my father was an engineer and now I understand many of the things I saw him doing when I was a child (Mathematics; Linear Programming LC).

> I believe that implementation of the Legacy Cycle teaching strategy makes me a more effective teacher and brings me more personal satisfaction than a traditional lesson planning format. I plan to use the Legacy Cycle with future classes (Chemistry/Physical World Concepts; Concrete Tile LC).

> This is the first time I have ever seen my professional development impact my students immediately. The RET experience has given me a new outlook on teaching. I think all teachers should constantly learn new ways of presenting material to avoid becoming stagnant. I also feel the RET experience helped me professionally by engaging with other teachers who care about their students and want to help them be excited about learning and encourage them not only to do well in school but to further their education. The three major components of this project seemed very scary and completing them boosted my self-confidence (Physical Science; Sunscreen LC).

One teacher's comment captures the overall comments/reflections of the teachers, "Helping my students boost their self-confidence is the best reward for my work in the RET program" (Physical Science; Sunscreen LC). Given the effort and work required, and given the teachers' initial reservations about implementing a Legacy Cycle (Could their students do it? Would it be worth the instructional time it cost? Do I have the skills/knowledge necessary to manage it effectively so that the experience is productive for my students? etc.), we are satisfied that the teachers' reflections speak volumes about the power of the Legacy Cycle approach as a method to transfer research into practice. The Legacy Cycle model reaps benefits for student learning, student motivation and consideration of career trajectories, and teacher confidence and effectiveness. In addition to the successes reported by the teachers, project staff observed teachers and students as these legacy cycles were implemented. We witnessed the excitement and engagement of the students, and the mirrored excitement of the teachers as they observed their students creating knowledge and engaging with their curriculum standards in ways that had not previously done. This was perhaps as rewarding for us as for them.

Relating the RETainUS Program to HPL Theory and Legacy Cycle Design

The RETainUS program was designed to connect the four "centerednesses" (knowledge-, learner-, assessment-, and community-centeredness) of HPL design to the Legacy Cycle. To make these connections more explicit, we offer the following description.

In designing their Legacy Cycles, RET participants were required to develop a challenge question by aligning course standards with the concepts learned during the six-week research experience. This activity tapped into the *knowledge-centered* environment since the teachers were acquiring new knowledge and determining how to fit this knowledge into their current course paradigms. Some of the participants struggled to fit the complex engineering concepts into their curriculum, but by the end of the program all of the teachers successfully addressed several (10–15) STEM curriculum standards in each of their Legacy Cycles.

Most of the RET participants came to the RETainUS program with a deficit of knowledge concerning the engineering design process as well as the underlying fundamental concepts of the engineering disciplines in which they were immersed. The teachers experienced the aggravation and pressure of developing a product without prior understanding. They had not studied composite materials or the intricacies of nanotechnology, yet they were expected to design an instructional unit on these concepts. Through this experience the participants gained an appreciation for the value of the *learner-centered* environment. When they designed their own legacy cycles they became highly cognizant of the need for starting with the students' level of understanding. The teachers were very successful at designing activities to *Generate Ideas* to make certain they correctly identified areas of weakness in fundamental concepts. The participants also designed creative *Multiple Perspectives* to address these expected weaknesses.

The RET participants experienced the *Research and Revise* portion of the Legacy Cycle directly by performing authentic research in the engineering labs. They endured the process of systematic trial and error by developing a Legacy Cycle and then changing and modifying the unit as they became more proficient in the research lab. This process helped them understand the importance of an *assessment-centered* environment. Frequent formative evaluation was necessary for the teachers to master new content and incorporate that content into their evolving Legacy Cycles. Their final products would have been far less engaging if the teachers had not received constructive criticism throughout the six-week period.

The most apparent connection among the RETainUS program, the Legacy Cycle, and HPL theory was evident in the *Test Your Mettle* and *Go Public* portions. The foremost goal of the RETainUS program was to provide real-world engineering experiences for STEM teachers in K–12 classrooms so they could, in turn, convey the world of engineering to their community of students. The teachers used their newfound knowledge of "in the trenches" engineering research and instructional design to develop Legacy Cycles. The participants experienced a *community-centered* environment as they learned how the research they conducted fit into the "real world" (nanotechnology and sunscreens) and they passed this situated learning on to their students in the form of Legacy Cycles.

Summary

In the RET experience, the Legacy Cycle was applied in two ways: (1) the Legacy Cycle was used by engineering faculty as a vehicle to train the teachers to be researchers, and (2) each participant teacher developed and implemented a Legacy Cycle that featured the engineering concepts and research they had learned as participants in the project. In these ways, teachers experienced a legacy cycle both as students (learning to conduct research) and as instructional designers and facilitators (when they implemented it in their classrooms). This "insider" knowledge provided the teachers with insight into the levels of discomfort experienced by their students when learning in a way that was atypical for a mathematics or science class. Because students "design" their own direction for learning, there is initial concern about what they are "supposed to be doing" and "how to do it." This mirrored the experience of the teachers in the Week One RIE when they struggled to write a research question and develop their research design. In a more significant way, the Legacy Cycle mirrors engineering as a field. It can be argued that engineering differs from "science" due to elements of design that are often developed and adapted within the experience—engineers often have difficulty explaining what they do; you have to experience it. Some RET experiences are structured such that teachers do not have an "authentic" engineering experience—we argue, however, that using the Legacy Cycle to train the teachers in research and design, and in turn, asking the teachers to develop their own Legacy Cycles can provide a more authentic engineering experience—teachers are using the tool they will be creating. The Legacy Cycle also provided a way for teachers and students to see how engineering could be a “fit” for anyone. The benefits for the teachers and their students far outweighed the struggles and discomfort.

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Appendix A: Brief Overview of the Teacher-developed Legacy Cycles

(1) Chemistry and Physical World Concepts legacy cycle (implemented with 141 students) that featured student-centered research into concrete properties and applications, student design and preparation of concrete tile samples, and student development and implementation of a method for testing the strength of their own and classmates' tiles;

(2) Mathematics (Algebra 2 and Precalculus) legacy cycle (implemented with 32 students) that featured an exploration of linear programming, the simplex method, and very basic genetic algorithms to demonstrate the various roles optimization can play in the engineering work force. Students presented solutions to a complex three-variable scenario to assess knowledge gained;

(3) Chemistry legacy cycle (implemented with 90 students) that featured a particular characterization of a Nafion membrane performed by a classic acid-base titration with one "twist": the acid base titration was only effective after a thorough double-displacement reaction that proceeds according to the activity series. The students characterized the membrane and then promoted the sale and distribution of their membrane based on their findings via a competitive advertisement;

(4) Physical Science legacy cycle (implemented with 35 students) that featured the structure and characteristics of nanoparticles, the pros and cons of their use in products (in particular, their use in sunscreen), and an electricity lab in which the students made series and parallel circuits and conducted a "dye electrophoresis" lab (the size of the particles determined how far they moved);

(5) Chemistry and Physical World Concepts legacy cycle (implemented with 21 honors students) that featured a study of polymers and their physical and chemical properties as well as the design and construction of a testing device that measured the amount of force it took to fracture these polymers. Students tested polymers with their device and determined tensile strength and well as elongation strain and tensile modulus;

(6) Biology 1 and Human Anatomy legacy cycle (to be implemented in Spring 2010) that features using calorimetry of biomass, in the form of alfalfa, to understand the amount of energy in biomass. Students use the information gathered from the experiments to help them find an alternative fuel source to power fictitious boats off of a desert island;

(7) Physical Science legacy cycle (to be implemented in Spring 2010) that features a study of metals and ways to increase those metals' ability to withstand high ambient temperatures (in the context of an airplane crash investigation);

(8) Physical Science legacy cycle (to be implemented in Spring 2010) that features a study of creep, stress, and strain tests and how to apply these tests to investigate the properties of aluminum foil;

(9) Mathematics (Algebra 2) legacy cycle (to be implemented in Spring 2010) that features the relevance of the complex number system in chemical engineering by focusing on polymer electrolyte membrane fuel cells.

Appendix B: Concrete Legacy Cycle

Background:

This Legacy Cycle was implemented with approximately 145 students. The students were predominantly 10th graders of Caucasian descent. Classes were made up of approximately equal numbers of male and female students and included many students with a variety of learning challenges, including students considered at risk due to low socioeconomic status, English language learners, special education students, and students that have had limited success in previous educational settings.

The legacy cycle is expected to be used in grades 9–12, but could be modified for use in grades 6–8 as well. Students are not expected to bring extensive prior knowledge to the project, although students are expected to be familiar with concrete applications such as sidewalks and possibly countertops and backsplashes.

The legacy cycle challenged students to design strong and attractive concrete tiles such as those used in a countertop. It featured student-centered research into concrete properties and applications, student design and preparation of concrete tile samples, and student development and implementation of a method for testing the strength of their own and classmates' tiles. Students were assessed both informally and formally through a graded WebQuest, analysis of posters, and independent judging of their final products based on outlined criteria chosen by the students themselves. Details of the Legacy Cycle as implemented are included below along with photo samples of student work.

The Legacy Cycle covered Tennessee curriculum standards for Chemistry I and Physical World Concepts that address the Embedded Inquiry and Embedded Technology and Engineering strands. Detailed learning expectations, state performance indicators, and checks for understanding are provided after the student work samples.

Concrete Legacy Cycle

Day 1: Challenge Question

You have been hired to make concrete tiles for a countertop. You need the tiles to be both strong and attractive.

- How will you make the tiles?
- How can you determine the strength of the tiles?

Day 1: Generate Ideas

- Students will be asked to Think-Write-Pair-Share what they "Know" and "Need to Know" to answer the questions.

        - Teacher will record ideas under "Know" and "Need to Know" columns on a transparency to be saved for later.
- Students will determine the grading scheme for the project.
    - What percentage of the grade should be based on strength?
        - Create a strength rubric.
    - What percentage of the grade should be based on attractiveness?
        - Create an attractiveness rubric.
    - Should effort be a part of the grade?
        - If yes, create an effort rubric.
    - Who will conduct the rubric-based assessment?
        - Students themselves
        - Teacher
        - Independent judges (other teachers, etc.)
- Students will be asked to begin considering how to determine tile strength.
- Students will be asked to begin considering how to determine tile attractiveness.

Day 2: Multiple Perspectives

- Students-teacher discussion of "good" tests versus "bad" tests based on the scientific method of investigation.
- Interviews with concrete experts- video or live
    - Researcher
    - Construction worker
    - Construction core teacher
- Video on Portland cement from Portland Cement Association (if available)

Days 3 – 6: Research and Revise

(Day 3) Concrete WebQuest (Appendix D)
(Day 4) Tour of facilities and equipment available to students
Assign or choose groups of 3 – 5 students
Mixing Concrete Lab (Appendix E)
NOTE: Mixing concrete lab should be conducted on a Friday to allow tiles to cure.
(Day 5) Review of ASTM testing methods
Review "Know" and "Need to Know" lists from Day 1
Address remaining "Need to Know" items if necessary
Begin brainstorming strength testing method
(Day 6) Develop and test strength testing method using tiles made in the Mixing Concrete Lab

Day 6 – 7: Test Your Mettle

(Day 6) Begin work on poster with guidelines (Appendix F)
(Day 7) Strength testing method due, finish poster

Day 8: Research and Revise

- Plan final tile manufacture; make final tiles (both strong and attractive)
  NOTE: Tiles should be made on a Friday to allow tiles to cure.

Day 9: Go Public

- Presentation of poster and demonstration of strength testing method for class.
- Class as a whole will determine the method that will be used for judging the work of the class according to the rubric previously developed.

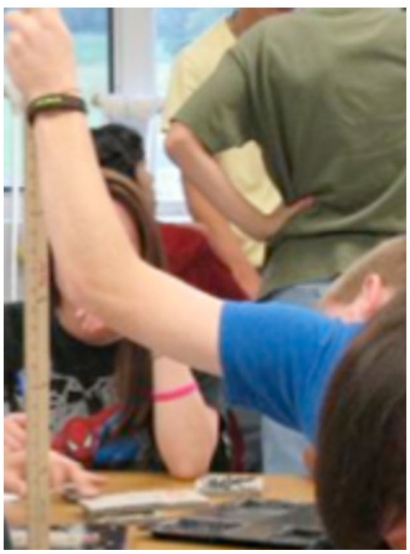
Day 10: Go Public

- Groups will present tiles for judging based on criteria chosen by class.

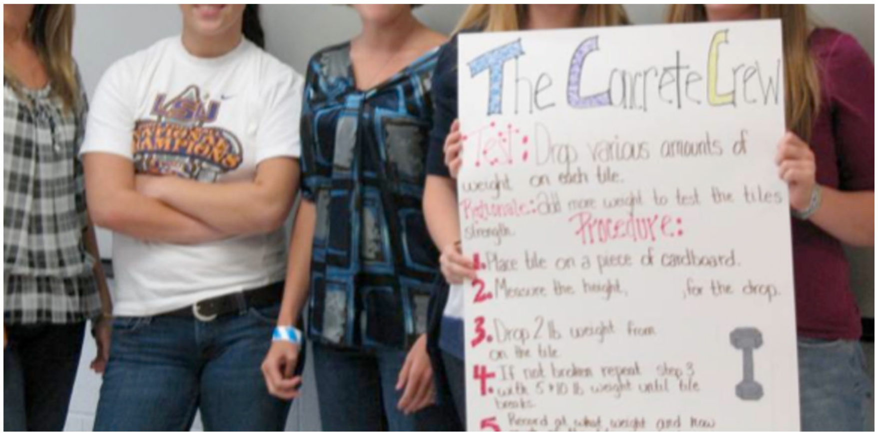
<u>Samples of Student Work</u>

(Note: Students' faces have been hidden for safety reasons)

Making Tiles

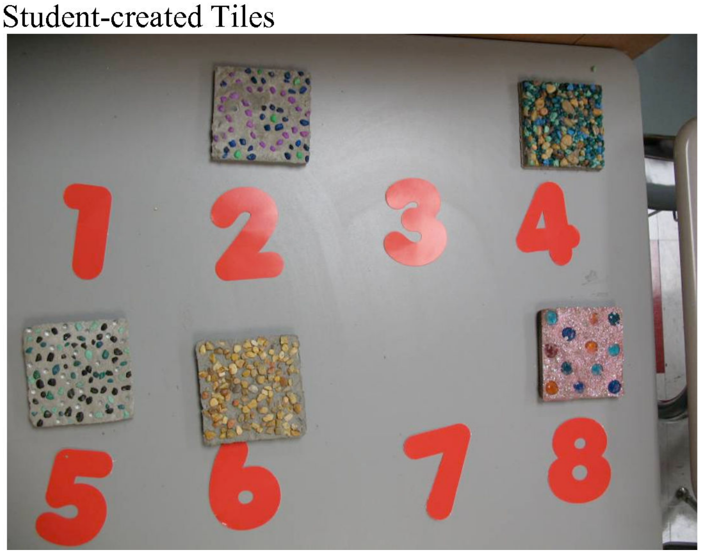


Presenting their Plan for Strength Testing



Student-created Apparatus for Testing Tile Strength

Student-created Tiles



Curriculum Standards Addressed in Concrete Legacy Cycle

Physical World Concepts: Embedded Inquiry

Conceptual Strand
Understandings about scientific inquiry and the ability to conduct inquiry are essential for living in the 21st century.

<u>Course Level Expectations</u>
CLE 3237.Inq.1 Recognize that science is a progressive endeavor that reevaluates and extends what is already accepted.
CLE 3237.Inq.2 Design and conduct scientific investigations to explore new phenomena, verify previous results, test how well a theory predicts, and compare opposing theories.
CLE 3237.Inq.4 Apply qualitative and quantitative measures to analyze data and draw conclusions that are free of bias.
CLE 3237.Inq.5 Compare experimental evidence and conclusions with those drawn by others about the same testable question.
CLE 3237.Inq.6 Communicate and defend scientific findings.

<u>Checks for Understanding</u>
CFU 3237.Inq.1 Develop a testable question for a scientific investigation.
CFU 3237.Inq.2 Develop an experimental design for testing a hypothesis.
CFU 3237.Inq.4 Perform an experiment to test a prediction.
CFU 3237.Inq.7 Analyze and interpret the results of an experiment.
CFU 3237.Inq.10 Analyze experimental results and identify possible sources of experimental error.

Physical World Concepts: Embedded Technology & Engineering

Conceptual Strand
Society benefits when engineers apply scientific discoveries to design materials and processes that develop into enabling technologies.

<u>Course Level Expectations</u>
CLE 3237.T/E.2 Differentiate among elements of the engineering design cycle: design constraints, model building, testing, evaluating, modifying, and retesting.
CLE 3237.T/E.4 Describe the dynamic interplay among science, technology, and engineering within living, earth-space, and physical systems.

<u>Checks For Understanding</u>
CLE 3237.T/E.1 Explore the impact of technology on social, political, and economic systems.
CLE 3237.T/E.2 Differentiate among elements of the engineering design cycle: design constraints, model building, testing, evaluating, modifying, and retesting.
CLE 3237.T/E.3 Explain the relationship between the properties of a material and the use of the material in the application of a technology.

CFU 3237.T/E.5 Design a series of multi-view drawings that can be used by other students to construct an adaptive design and test its effectiveness.

Chemistry I: Embedded Inquiry

Conceptual Strand
Understandings about scientific inquiry and the ability to conduct inquiry are essential for living in the 21st century.

Course Level Expectations
CLE 3221.Inq.1 Recognize that science is a progressive endeavor that reevaluates and extends what is already accepted.
CLE 3221.Inq.2 Design and conduct scientific investigations to explore new phenomena, verify previous results, test how well a theory predicts, and compare opposing theories.
CLE 3221.Inq.4 Apply qualitative and quantitative measures to analyze data and draw conclusions that are free of bias.
CLE 3221.Inq.5 Compare experimental evidence and conclusions with those drawn by others.
CLE 3221.Inq.6 Communicate and defend scientific findings.

Checks for Understanding
CFU 3221.Inq.2 Identify an answerable question and formulate a hypothesis to guide a scientific investigation.
CFU 3221.Inq.3 Design a simple experiment including appropriate controls.
CFU 3221.Inq.4 Perform and understand laboratory procedures directed at testing hypothesis.
CFU 3221.Inq.5 Select appropriate tools and technology to collect precise and accurate quantitative and qualitative data.
CFU 3221.Inq.6 Correctly read a thermometer, balance, metric ruler, graduated cylinder, pipette, and burette.
CFU 3221.Inq.8 Export data into the appropriate form of data presentation (e.g., equation, table, graph, or diagram).
CFU 3221.Inq.13 Analyze experimental results and identify possible sources of bias or experimental error.
CFU 3221.Inq.14 Recognize, analyze, and evaluate alternative explanations for the same set of observations.
CFU 3221.Inq.15 Design a model based on the correct hypothesis that can be used for further investigation.

State Performance Indicators
SPI 3221 Inq.2 Analyze the components of a properly designed scientific investigation.
SPI 3221 Inq.5 Defend a conclusion based on scientific evidence.
SPI 3221 Inq.6 Determine why a conclusion is free of bias.
SPI 3221 Inq.7 Compare conclusions that offer different, but acceptable explanations for the same set of experimental data.

Chemistry I: Embedded Technology & Engineering

Conceptual Strand
Society benefits when engineers apply scientific discoveries to design materials and processes that develop into enabling technologies.

Course Level Expectations
CLE 3221.T/E.1 Explore the impact of technology on social, political, and economic systems.
CLE 3221.T/E.2 Differentiate among elements of the engineering design cycle: design constraints, model building, testing, evaluating, modifying, and retesting.
CLE 3221.T/E.3 Explain the relationship between the properties of a material and the use of the material in the application of a technology.
CLE 3221.T/E.4 Describe the dynamic interplay among science, technology, and engineering within living, earth-space, and physical systems.

Checks for Understanding
CFU 3221.1 Select appropriate tools to conduct a scientific inquiry.
CFU 3221.2 Apply the engineering design process to construct a prototype that meets developmentally appropriate specifications.
CFU 3221.5 Design a series of multi-view drawings that can be used by other students to construct an adaptive design and test its effectiveness.

State Performance Indicators
SPI 3221.T/E.1 Distinguish among tools and procedures best suited to conduct a specified scientific inquiry.
SPI 3221.T/E.2 Evaluate a protocol to determine the degree to which an engineering design process was successfully applied.

Concrete WebQuest- Answer on your own paper!

Point your browser to the Concrete Pond Quiz at
http://www.cement.org/basics/concretebasics_pondquiz.asp

1. *What was your score?*

Point your browser to http://planetgreen.discovery.com/home-garden/gword-concrete-recycling.html

2. *What are some properties of concrete shown or discussed in this video?*

Point your browser to http://www.cement.org/basics/concretebasics_concretebasics.asp

3. *What are the components of concrete?*

4. *What is the key to achieving a strong, durable concrete?*

Point your browser to http://simple.wiktionary.org/wiki/proportion

5. *What does "proportion" mean in your own words?*

Point your browser to
http://www.waybuilder.net/sweethaven/BldgConst/Building01/default.asp?iNum=0501

Read the section titled "CONSTITUENTS OF CONCRETE."

6. *What are aggregates?*

7. *What is hydration?*

Read the sections titled "STRENGTH OF CONCRETE" and "DURABILITY OF CONCRETE."

8. *What is the most important factor controlling the strength of concrete?*

9. *What is mentioned in these sections that you could change in your own tile?*

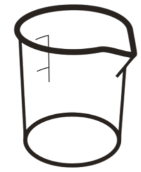
10. *What are some of your ideas about how you will make strong tiles?*

Do a Google search for "Concrete Tile." Look at some examples of tile for sale on at least two websites.

11. *What are some of your ideas about how you will make attractive tiles?*

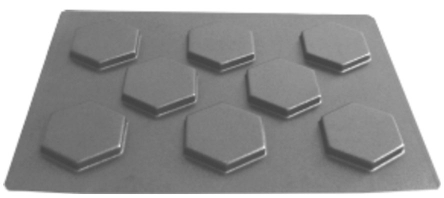
Mixing Concrete Lab

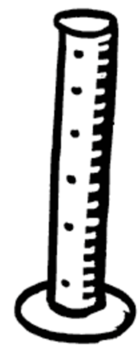
CAUTION: Avoid touching any of the chemicals with your bare hands. Wash your hands with soap and water before leaving the lab.



1. Use a spatula to handle the concrete.
2. Use a balance to measure the mass of an empty beaker. Mass of empty beaker: ____________________ grams
3. Add up the mass of the empty beaker + 450 grams.

   Mass of empty beaker +450: ___________________ grams.
   Set the balance to read this.
4. Measure concrete into the beaker until it is balanced. You now have 450 grams of concrete mix in the plastic beaker.
5. Use a graduated cylinder to measure 80 mL of water.
6. Add the water to the beaker with the concrete mix.
7. Mix thoroughly with the spatula.





8. **Lightly** spray your mold with cooking spray and wipe with a paper towel to spread the spray evenly in your mold.
9. Using the spatula carefully fill two of the square spaces in your mold with the concrete mixture. Pack it down using the spatula. Good packing is important! You can use the spatula to smooth the top if desired.
10. Make two more sets of tiles. Use aggregates of your choice in the second and third mixes. Record the aggregate you used and the amount of each aggregate used on the back of this paper. Choose your aggregates carefully based on what you know about strong concrete and what the class has decided about attractiveness.
11. Scrape any leftover mixture from the beaker into the trash and wipe out the beaker with a paper towel. Wipe the spatula with a paper towel. Wash the beaker, the spatula and your hands.

Concrete Strength Testing Poster Guidelines

IDEA AND RATIONALE

- In 10 words or less, describe what your group thinks is the best way to test tile strength. This is your IDEA.
- In 10 words or less, why do you think your idea is a good idea? This is your RATIONALE.
- Put these on your poster. Have Mrs. Thurber check your poster for these when you are done.

METHOD

- Using a bulleted or numbered list, describe exactly how your test should be carried out. A classmate should be able to read your list and conduct your test without your help. This is your METHOD.
- Put this on your poster. Have Mrs. Thurber check your poster for this when you are done.

PICTURE

- Your poster should have at least one picture showing how your test is set up and carried out.
- Put this on your poster. Have Mrs. Thurber check your poster for this when you are done.