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Impact of RET Teacher-Developed Curriculum Units on Classroom Experiences for Teachers and Students

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Abstract

This phenomenological study examined the impact of Research Experiences for Teachers (RET) teacher-developed curriculum on teaching styles and strategies at two RET sites with common Legacy Cycle training. The study was conducted to assess and document program-specific and National Science Foundation (NSF) goals related to classroom practices and outcomes. We set out to define how the RET program influenced teachers' teaching style and strategies and how teachers' new curriculum from the RET program affected students. Twenty-seven science and math teachers participated in interviews at the end of their summer research experience, and twenty of these teachers participated in interviews after teaching their Legacy Cycle module during the academic year. These interviews were coded for themes and subthemes relating to teachers' teaching styles and their effects on students. Teachers used real-world contexts within their Legacy Cycle curricula and thus began to teach in interdisciplinary ways, exposing students to engineering in the process. According to their teachers, students enjoyed learning with the Legacy Cycle curricula. They took a more active role in the classroom, leading them to be better able to apply their new knowledge. Using the Legacy Cycle as a pedagogical approach in an RET program leads to instructional materials that integrate teachers' research while maintaining use of state and national standards. Teachers perceived that student enjoyment of, and engagement in, the material increased, while also exposing them to engineering.

Keywords: research experiences, Legacy Cycle, phenomenology, professional development

Introduction

Teaching standards at the national and state level have moved or are moving to both inquiry-based science requirements and integration of engineering principles into math, science, and technology curricula. The development of scientific inquiry is considered to be the most effective way to create a society of scientifically literate citizens (National Research Council, 1996), and many national studies have demonstrated the need for improved scientific literacy in order to prepare students for science, technology, engineering, and mathematics (STEM) majors (Boundaoui, 2011). Effective professional development (PD) for teachers engages teachers, helps them to meet their teaching standards, helps them prepare their students for the real world, and helps them to build professional relationships in the field that they teach.

The purpose of this study is to examine the effectiveness of the NSF-funded Research Experience for Teachers (RET) Program (National Science Foundation [NSF], 2006) at two different sites as a PD program. While research on other RET programs and their outcomes has been reported, there is a wide variety of the types of experiences and required elements within the programs, which makes it difficult to compare and examine what is actually happening in the classrooms of the participants who develop curricular materials related to their research experience. The two sites examined in this study taught the Legacy Cycle and required that the participants write a Legacy Cycle unit following their research experience. The outcomes of their new curriculum, developed based on a sound pedagogical model, are examined in terms of the teachers' and students' experience in the classroom. The effect of the program on the teachers and their students is evaluated with detailed interviews using a phenomenology method. Due to the fact that there are few high schools with designated engineering classes, newly introduced engineering standards must be integrated into math and science classes. This study is focused on engineering because teachers have the responsibility of teaching engineering in these classes.

Background

Relevance to National and State Standards

National science standards (National Research Council, 1996) require teachers to teach using inquiry-based methods where students investigate authentic questions. This goal cannot be accomplished in a classroom that is focused on simply memorizing facts, without a linkage to a real world context. In order for students to gain a deeper understanding of science and mathematics, they must be taught by teachers who not only know the content well themselves (Garet, Porter, Desimone, Birman, & Yoon, 2001; Supovitz & Turner, 2000), but also how to teach these topics well (Brophy, Klein, Portsmore, & Rogers, 2008; Shulman, 1986). The Guiding Principles for Mathematics Curriculum and Assessment (National Council of Teachers of Mathematics [NCTM], 2009) emphasizes studying mathematical concepts in depth. The National Council of Teachers of Mathematics (NCTM) writes: "Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge. Learning mathematics with understanding is essential." Both sets of standards and guidelines emphasize the point that teachers must be able to do science and mathematics. They must be able to relate science and mathematics to the real world, in addition to just preparing students to take the next course in the sequence.

Much attention is also being given now to interdisciplinary studies within STEM. More schools are offering technology

and engineering classes, and more teachers are team teaching or simply making their core courses more interdisciplinary. States such as Massachusetts (Massachusetts Department of Education, 2006), Minnesota (Minnesota Department of Education, 2010), and Tennessee (Tennessee Department of Education, 2009) have already added engineering standards to the curriculum, either separately or as a part of their science standards. These new directions for STEM education require new pedagogical approaches and materials; professional development activities should address ways to help teachers develop these approaches and materials.

Desired Professional Development characteristics

Effective PD must afford teachers the opportunities to meet the goals set by the national standards. Teachers must be allowed to engage actively in meaningful discussion, planning, and practice. They must have the time to link what they have learned in their PD program to their specific classroom, curriculum, and standards (Garet et al., 2001; Little, 1993). Garet et al. found that time span and contact hours spent in a particular PD activity have a positive correlation with active learning and coherence, which includes alignment with standards and changes in teaching practice. If teachers are expected to translate what they are learning in PD, they must be given opportunity for that practice to become a natural part of the teacher's repertoire of professional skills (Fullan & Miles, 1992).

Teachers must also be allowed to become members of effective professional communities, where the network supports their continued growth over a longer period of time that extends beyond the PD activity (Dresner & Worley, 2006; Garet et al., 2001). This is particularly important when no or few other teachers at their school have had the same training and espouse the same beliefs about instruction.

The theoretical framework for this study is the research behind the idea that professional development activities should allow teachers the time to do scientific research and inquiry in order to lead their students in doing the same (Dresner & Worley, 2006). Professional development activities that revolve around a scientist-teacher collaboration have been suggested to be an effective model for allowing teachers the opportunity to do real science and mathematics. According to Loucks-Horsley, Henson, Love, & Stiles (1998), key characteristics of these programs include common goals of all participants, teachers taking on the role as content expert, and strong collaborations among the partners (Loucks-Horsley et al, 1998). Studies have shown that these types of collaborations lead to an improvement in teachers' views of inquiry and their confidence in teaching inquiry-based lessons improves (Caton, Brewer, & Brown, 2000; Odom, 2001). Teachers must receive opportunities to be trained in laboratory skills and hands-on learning and they must do this in the context

of deep science content with multiple opportunities to practice what they are learning (Jeanpierre, Oberhauser, & Freeman, 2005). Teachers who have received such training are much more likely to engage their students in hands-on learning – just as they have learned it themselves, avoiding cook-book labs (Loucks-Horsley et al., 1998; Wenglinsky, 2000).

Teachers must be required to demonstrate competence in a tangible and assessable way (Jeanpierre et al., 2005). The end product of a research or professional development experience must be a product that is held to some level of accountability. Related to this is the need for professional development providers to have high expectations for learning and the capability to facilitate multi-faceted experiences (Jeanpierre et al., 2005; Weiss & Hartle, 1997). Teachers must be expected to extend the content knowledge in a deep, meaningful way and not just at the surface level. Scientist mentors must communicate the value of the work that the teachers are doing to them as well. Thompson and Zeuli (1999) and Rogers et al. (2007) argue that this extension of content knowledge cannot merely be an addition of knowledge, but must rather be transformative and force teachers to experience a cognitive dissonance that challenges both their content knowledge and their professional content knowledge (PCK). These transformative experiences should be taken into consideration within PD programs.

National Teacher Professional Development Opportunity: NSF-sponsored Research Experience for Teachers

The National Science Foundation (NSF) sponsors a program called Research Experiences for Teachers (RET). The National Science Foundation has as its goals for the RET program (National Science Foundation, 2006):

The Directorate for Engineering (ENG), Research Experiences for Teachers (RET) in Engineering program supports the active involvement of K-12 teachers and community college faculty in engineering research in order to bring knowledge of engineering and technological innovation into their classrooms. The goal is to help build long-term collaborative partnerships between K-12 science, technology, engineering, and mathematics (STEM) teachers, community college faculty, and the NSF university research community by involving the teachers in engineering research and helping them translate their research experiences and new knowledge of engineering into classroom activities.

In 2007, the NSF hired an outside firm to conduct a review of the participants from 2001–2006 nationwide (Russell & Hancock, 2006). At that time the research experiences of the teachers tended to be more observational rather than actually conducting the research themselves.

Over time, the teachers participated in an increasing number of teaching workshops and developed more curriculum materials themselves. A mere 14% of survey respondents said that there was a great deal of follow-up in the academic year, while 34% said there was little to none. These results led to programmatic change in 2007, requiring more substantive follow-up, a stronger match between research and classroom activities, and encouragement of multi-year participants.

The NSF funds many RET programs across the United States. This section provides a summary of published outcomes and deliverables and is not meant to be an exhaustive list of all of the RET programs (Autenrieth, Butler-Purry, Page, Hurtado, & Welch, 2009; Benson, Medders, & Cass, 2010; Conrad, Conrad, & Auerbach, 2007; Kapila, 2010; Klein, 2009; Klein-Gardner, 2010; Ogden & Ogen, 2007; Trenor, Yu, Grant, & Salem, 2009; Wenglinsky & Silverstein, 2006; Zollars, Orlich, & Thomson, 2007). (See Table 1.) The NSF's expectations for these programs are that they will lead to effective classroom materials that integrate engineering into the STEM disciplines. It is critical that these programs provide a coherent program that links the research experience with the classroom materials that are being developed.

There are many reports in the literature of the success of RET programs. The programs listed in Table 1 are those found to report on a required curriculum component of the RET program and some that reported outcomes of the RET program as a whole. Programs that did not report on any aspect of a curriculum component were not included in this table. Many STEM teachers in these programs have been afforded the opportunity to 'do' real science and engineering, and as a result, teachers self-report an increase in understanding engineering and a willingness to discuss it with their students. Teachers in these studies often design some sort of lesson to use in their classroom based on their research experiences. However, some teachers have written materials on curriculum they are not required to cover in their standards, which is considered a shortcoming in terms of curriculum design. Other programs have teachers design only a single lesson, rather than an extensive period of study that utilizes their research as a basis, which limits the impact of the research experience on student learning. Few studies report the design of any sort of interdisciplinary curriculum. These studies do not indicate the strength or frequency of the real world examples in the instructional materials they develop, nor do they discuss the pedagogy behind the style of materials that is developed.

Legacy Cycle: Theoretical Framework and Use

The Legacy Cycle is a challenge-based curriculum design based on the research on How People Learn or

Table 1
Summary of selected RET programs, the types of classroom activities developed as outcomes, and findings on effectiveness of these activities

Location and Research Focus Area	Classroom Activities	Findings
Columbia University (Wenglinisky & Silverstein, 2006)	Constructivist based curriculum	Teacher participants now feel that they have a better understand of students' difficulties in the laboratory and inquiry-based setting because they have experienced their own difficulties. Their students are also more likely to participate in extracurricular activities related to science.
University of Arizona - Environmental Engineering (Ogden & Ogen, 2007)	Inquiry based curriculum	Lessons need to be put into larger units to be effective.
Georgia Tech (Conrad et al., 2007)	Real-life engineering examples	Discussed engineering as a career and some teachers brought their class to visit labs.
Polytechnic Institute of NYU (Kapila, 2010)	Lessons and activities for their classrooms based on their research	Their teachers report, 'They now had the experience of what it means to "do" as well as learn science'.
Washington State University (Zollars et al., 2007)	Multi-class period modules	No findings reported.
Texas A&M University (Autenrieth et al., 2009)	Developed longer projects	Participants' experiences led them to plan to promote engineering to their students in an end of program survey. Survey data also indicate that the teachers were planning to enrich their teaching with practical applications that their engineering research provided. Several teachers reported that they were willing to contact TAMU faculty to facilitate guest speakers, etc., and to encourage students to apply to TAMU engineering. Their survey data also indicated that most teachers were able to 'implement some sort of engineering-oriented activity into their classroom curriculum'. Some teachers experienced barriers that prevented implementation such as scope and sequencing, time constraints due to standards, and limitations because of the need for equipment or materials.
University of Houston (Trenor et al., 2009)	Legacy Cycle	Teachers in this study reported an increase in plans to encourage students to study engineering and to bring more engineering into their classrooms through guest speakers, field trips, etc.
Clemson University (Benson et al., 2010; Cribbs, Wade, Benson, & Switzer, 2010)	Legacy Cycle	Teachers increased their understanding of science and scientific inquiry and were functioning at high cognitive levels in the research environment. Teaching inquiry-based modules in classrooms increased students' value of their STEM courses and changed teachers' instructional practices.
Vanderbilt University – Bioengineering (Klein-Gardner, 2010; Klein, 2009)	Legacy Cycle	Teachers increased their understanding of the nature of science and increase the likelihood that they will teach about it in their classrooms.

HPL (Bransford, Brown, & Cockings, 2000). HPL focuses on the principles of Knowledge Centeredness, Student Centeredness Assessment Centeredness, and Community Centeredness. Any effective curriculum must at its core teach students a defined body of knowledge. This body of knowledge is determined at the K-12 level by state and national standards. Teachers may also strategically add areas of focus within their curriculum to create knowledge at different levels of importance: enduring understandings, things that are important to know or do, or things that are worth being familiar with (Wiggins & McTighe, 2005). Student-centered instruction considers what students bring into the classroom from many aspects—prior knowledge, misconceptions, personal issues, etc. Effective instruction also takes into account how students best learn the material to be taught. Assessment-centeredness overlaps with both knowledge-centered and assessment-centered instruction. Teachers must implement effective formative and summative assessments that assess the areas determined to be most important and compare these to measurable goals. Community-centered instruction can take on two aspects. The classroom itself must have a culture of community learning, with students learning from each other and the teacher. A teacher must also help bring students into a

desired larger community such as scientists or engineers or even just STEM-literate citizens. Effective teachers will also take advantage of the community in which they live, bringing in outside resources into their classroom.

The Legacy Cycle consists of six distinct stages: The Challenge Questions, Generate Ideas, Multiple Perspectives, Research and Revise, Test Your Mettle and Go Public (Klein & Harris, 2007; Schwartz, Brophy, Lin, & Bransford, 1999). The Challenge Question sets the stage for the entire module, giving the students a real-world problem and motivation to learn the rest of the unit. The challenge question should be relevant to the students' lives. Generate Ideas has the students share initial ideas on the challenge question, both what they know about the topic and what they think they will need to find out in order to answer the challenge question. This stage of the cycle may also be used to help students focus in on key aspects of the Challenge Question and narrow the focus of the problem. Multiple Perspectives is a chance for the students to hear from an expert in the field. This could be in the form of a short statement, video clip of an interview or as a guest speaker. The outside opinion is not meant to tell the students the answer to the challenge question, but to lead them in the right direction and consider issues that they previously overlooked. Research and Revise

is where the bulk of the module is spent and where most of the content knowledge is taught. Instruction should include a variety of teaching methods that are best suited for both the students and the content to be mastered. Test Your Mettle represents the formative assessment stage and is completed as the teacher progresses through the concepts; therefore, switching between Research and Revise and Test Your Mettle is appropriate and useful. Often times, teachers want to assess the students' understanding before moving on the next topic. The use of formative assessment should be seamless within the learning of the Research and Revise topics. The final stage of the cycle is Go Public. In this stage students summarize what they have learned, perhaps giving a presentation and definitely answering the Challenge Question. It is this summative assessment that must be compared to the learning goals and standards for the unit.

Similarities may be noted between the 5E learning cycle (Bybee et al., 2006) and the Legacy Cycle. Both cycles begin with student engagement; the Legacy Cycle beginning with its Challenge Question and Generate Ideas and the 5 Es with the Engagement step. Both cycles utilize the 5 Es step of Exploration and Explanation, with the Legacy Cycle completing this in the Research and Revise step. The 5 Es cycle continues with Elaboration; in the Legacy Cycle this is most likely accomplished during the latter parts of the Research and Revise stage. Both Explanation and Exploration may also be accomplished during the Legacy Cycle's Test Your Mettle formative feedback stage. Finally, Evaluation from the 5 Es is accomplished during both the Test Your Mettle and Go Public stages. The 5 Es and the Legacy Cycle do differ in some regards though.

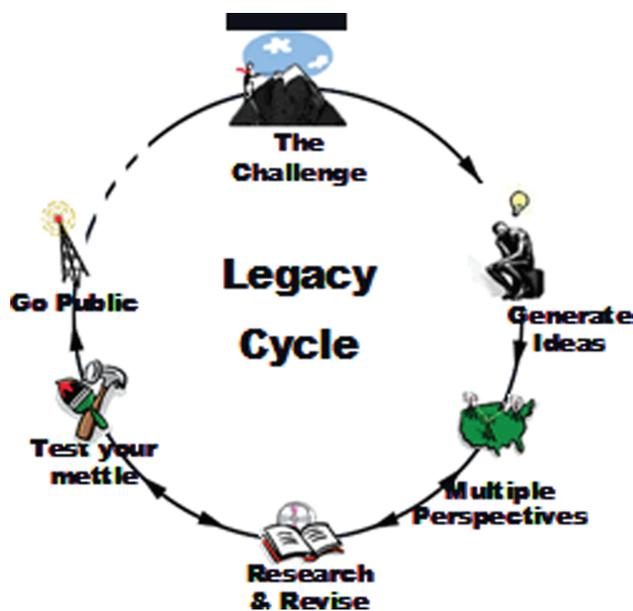


Figure 1. STAR Legacy Cycle Diagram. This figure illustrates the six distinct stages of the Legacy Cycle (Klein & Harris, 2007; Schwartz et al., 1999).

The Legacy Cycle is more explicit about the use of formative assessment and its iterative role between the Research and Revise stage and the Test Your Mettle stage. The Challenge Question stage of the Legacy Cycle is perhaps a more explicit form of the Engagement stage, with learners being guided towards solving a particular problem. The Multiple Perspectives stage of the Legacy Cycle is unique from the 5 Es in that it explicitly involves the perspectives of others, both within and beyond the classroom walls.

The Legacy Cycle was utilized by the NSF-funded VaNTH Engineering Research Center for Bioengineering Educational Technologies at both the K-12 (Cordray, Harris, & Klein, 2009; Klein & Geist, 2007; Klein & Sherwood, 2005a, 2005b; Klein, Brophy, Aston, & Paschal, 2010; Olds, Harrell, & Valente, 2006) and university levels (Brophy, 2003; Cordray et al., 2009; Greenberg, Smith, & Newman, 2003; Pandey, Petrosino, Austin, & Barr, 2004; Roselli & Brophy, 2006; Troy & Linsenmeier, 2003). The developed curricular materials were shown to be effective both in teaching content knowledge as well as in improving students' ability to transfer their ideas to new applications (near-transfer or adaptive expertise). Adaptive expertise makes use of innovation and is directly opposite of 'inert' knowledge that more traditional teaching methods produce (Bereiter & Scardamalia, 1985; Gick & Holyoak, 1980; Martin, Rivale, & Diller, 2007; Perfetto, Bransford, & Franks, 1983; Whitehead, 1929). HPL and the Legacy Cycle also readily support the elements recommended for retention of under-represented students in the STEM disciplines (Altschuld & White, 2006).

Research Questions

Literature on RET programs points to the need for longer instructional units that are standards-based, interdisciplinary, and having a clearly identifiable pedagogical basis. Drawing upon the effective professional development literature, we hypothesized that the teaching style and strategies of the teachers in these two RET programs would become more research-based and interdisciplinary in nature. We believed that the unique combination of research experience and Legacy Cycle training would allow teachers to integrate engineering into design- and inquiry-based instructional materials in a way that was appropriate for their classrooms and at the same time, met curriculum standards. Furthermore, national standards dictate the use of scientific inquiry and a growing number of states dictate the use of embedded engineering within science classes. Teachers must have the opportunity to do real inquiry and design before they expect their students to do so. We hypothesized that students would become both more interested in engineering as well as adaptive experts in the studied field due to their activities within the Legacy

Cycle curricula. Based on this background, this study focuses on the following research questions:

- How does the RET program influence a teacher's teaching style and strategies?
- How does the teacher's new RET-based curriculum affect his or her perceptions of outcomes for students?

Methodology

Research Framework

This study utilizes the research framework of phenomenology. This type of research focuses on describing and interpreting an experience or 'phenomenon' as it is perceived by the people who experience it (Ary, Jacobs, & Sorensen, 2010). This research method seeks to answer questions about the "essence" of an experience, or the ways that people who experience it relate to it and give it meaning (Manen, 2011). Semi-structured interviews and journals gathered from multiple participants are the primary data source in this type of research. Questions explored include what has been experienced (textual description) and what context(s) influenced the experience (structural description). The phenomenological analysis includes creation of a composite description of the overall essence of the experience.

Overview of the Programs

The two RET programs studied in this manuscript were very similar. Both lasted six weeks in total, beginning with an opening workshop that introduced participants to the Legacy Cycle. One exemplary Legacy Cycle module written by one author of this manuscript was presented, and participants were trained on how to write their own Legacy Cycle units. Both programs spent time discussing the expectations of research and the RET program. Both programs worked to develop a sense of community and collegiality amongst the participants through weekly meetings and workshops (although one program offered more structured instructional workshops on technical research skills than the other). This same program also offered more information to teachers on assessing their teaching modules. After five weeks in the lab, both programs brought their participants back together to write their individual Legacy Cycle modules to be implemented during the following school year. A more detailed description of each program is provided here.

Structure of the Vanderbilt University RET Program

The Vanderbilt University Bioengineering RET Program, a six-week non-residential program, began in the summer of 2004 and has continued through 2012. Reflective of the

NSF's goals, Vanderbilt University's RET program's specific goals are to educate teachers about the engineering educational research taking place at Vanderbilt University, give teachers a broad overview of bioengineering, engage the teachers in meaningful research experiences, help teachers take their research experiences back to their high school science classrooms, disseminate instructional materials created by the RET participants, and create long-lasting relationships between the university and the participants. Currently this program serves eighteen teachers each summer, almost entirely high school teachers, from all of the STEM disciplines. STEM teachers are recruited from public, private, and parochial schools in a four county region in middle Tennessee. Applicants must submit a statement of interest as well as a letter of support from their school. The candidate's statement of interest is of the utmost importance. The candidate must have a strong motivation for participation in every aspect of the program and be able to articulate this motivation successfully. Successful candidates went beyond saying that they wanted to participate in the program and that the program would help bring real-world examples to their classrooms. Any unique characteristics of the candidate's background should be brought to light, particularly if he or she either motivate a need for participation or make the candidate more qualified. If the candidate's school has any special programs in engineering or STEM, while not necessary, this should be explained and related to the RET program in both the candidate's and recommender's letters. The recommender must also write a motivating letter that is unique to each applicant. It is desired to see the school's commitment to the teacher, his or her participation in the RET program, and having the teacher bring back what he or she learns in the RET program to both the students and other teachers. In addition to the qualifications of each applicant, a balance amongst the four major counties that the RET program serves is desired as well as a balance among the subjects that the RET participants teach. The acceptance rate each summer is 20–25%. Beginning in the summer of 2008, teachers were required to apply in pairs from their schools and to commit to two years of participation. As a result, the program has a mix of first, second, and occasionally third year participants.

Prior to arrival on campus for the six-week program, each teacher is paired with a research mentor and research project of their choosing. The research mentor is responsible for preparing the teacher adequately for both knowledge-based and safety aspects of his or her laboratory.

The summer program begins with a three-day workshop in which the teachers are exposed to the broad field of bioengineering. The teachers also participate as a student in a Legacy Cycle based module from the VIBES K12 curriculum (Klein, 2006) and prepare for their research placement. The teachers then spend twenty-three days in their assigned research laboratory completing the project with which they were paired (with teacher and sometimes

professor mentor input). Training in laboratory and research skills is crucial for effective PD. Most teachers are fully integrated into the lab for the summer, both participating in lab group meetings and spending informal time with the members of the group to become full members of a professional community where they are held to the high expectations of the group and become more fully aware of the value of the research they are conducting. The last three days of the RET program are spent in a workshop format with the goal being the creation of a curriculum unit that is based on the teacher's research experience but appropriate for the standards-based high school classroom as dictated by the literature of effective PD. Each of these units is designed using the Legacy Cycle format which has been described earlier. These units are intended to be substitute units for the way the teacher traditionally taught the topic, so as not to add content that there is no time to cover, and also allows the teacher to introduce engineering to their students. Each of these units is held to a high standard as it will eventually be submitted for possible publication on the TeachEngineering digital library. Teachers are encouraged to bring scientific inquiry and engineering design into their classrooms after having the opportunity to develop these skills and improve their own confidence during their research placement.

For example, one RET teacher worked in the Biomedical Modeling Lab (Miga, 2010), where she worked on materials testing of polyvinyl alcohol as a breast tumor phantom. This teacher then developed an Algebra I curriculum unit (McKelvey, 2010) that focuses on linear functions and utilizes materials testing, specifically stress, strain, and Young's modulus in an eleven hour long unit. Another RET teacher worked in the Organic Thin Films Laboratory (Jennings 2010), where she extracted photosystem I (PSI) from spinach leaves and adhered it to a gold monolayer on a silicon wafer. These wafers were then used to turn light energy into electrical energy that could power a calculator. The teacher and her collaborators' work was published in *Langmuir* (Faulkner, Lees, Ciesielski, Cliffel, & Jennings, 2008). She developed two related curricular units of about nine instructional hours each for her chemistry course, one on covalent bonding and one on formula writing and compound naming. A second teacher in this same lab in a following year took the results of the wet cell already developed and worked to design a dry cell that would produce similar results. Her chemistry unit focuses on the connection between photonic energy, photosynthesis, and electrochemical cells and is described more fully in *The Science Teacher* (Beard, Ciesielski, & Hijarzi, 2010). A fourth RET teacher worked in a medical imaging laboratory where she used a cabinet x-ray machine to develop a method for determining the bone mineral density of small animals by utilizing different phantoms and filters. This teacher's mathematics curriculum unit on logarithms, which focused on bone mineral density, can be

found on the teachengineering.org website (Shaffer & Johnston, 2010).

During the academic year, each teacher is responsible for teaching his or her newly developed instructional materials. As a part of a professional community on K-12 engineering education, the teachers all gather twice a year as well to discuss their experiences and provide encouragement and support for each other. The instructional materials are then updated to fix any problems or clarify any issues brought to light by the first implementation. The revised instructional materials are then submitted to the TeachEngineering.org digital library for review and possible publication.

Structure of the CAEFF RET Program

The goals of the Center for Advanced Engineering Fibers and Film's (CAEFF) EFF-X program were to familiarize teachers with the research process, educate them about polymer science and technology, and engage them in the transfer of knowledge from laboratory to classroom. During the summers of 2007, 2008 and 2009, 28 middle and high school teachers were selected from South Carolina and metro Atlanta school districts from a variety of disciplines in mathematics (algebra, geometry, calculus and statistics) and science (chemistry, biology, physical science and physics). Each teacher was placed with two mentors, a faculty advisor and a graduate student mentor, at one of two CAEFF partner institutions in South Carolina and Georgia (for Atlanta teachers). The six-week program included workshops on technical and scientific concepts pertaining to polymers and polymer processing, the development of teaching modules, and basic methods for assessing pedagogical innovations. The schedule for the teachers was roughly five weeks of laboratory research, with weekly seminars and workshops, culminating with a poster session at the final program. During the sixth and final week of the program, EFF-X interns mainly worked on teaching modules to connect their research findings to the curriculum. The final products for the EFF-X interns were a research poster in which they summarized their findings, and a teaching module that would be ready to implement in their classrooms. The teachers at both locations met weekly, either physically at each other's campuses, or through weekly teleconferences. This allowed the free exchange of ideas for teaching module development, and facilitated peer assistance in grappling with the difficulties of learning highly technical skills and concepts, and the frustrations of the research process itself.

Because of the nature of CAEFF research, the projects that EFF-X interns engaged in were highly interdisciplinary, and program goals were achieved through the integration of mathematics, science, and engineering. For example, mathematics and physics or physical science were integrated through a project that used MATLAB to create mathematical

models to simulate polymer processes. The EFF-X intern created a graphical user interface (GUI) that made the underlying program transparent to the user (her students). Programs written by the EFF-X intern were compiled into ‘executable’ programs, which can be used as stand-alone applications in the classroom. Similarly, research in materials characterization for biomedical materials development or bio-based polymers, which comprised approximately half of the EFF-X research projects, interconnected chemistry, physics, and biology. Examples of projects of this nature are “Lactide-Derived Copolymers for Film and Packaging” and “Capillary Action in Hollow Polymer Fibers.” Examples of teaching modules developed from these projects include “Statistical Analysis of Surface Energies of Materials” for an AP statistics class, and “Diffusion in Dialysis Membranes” for a high school physics class.

Teachers were recruited from both urban and rural school districts in South Carolina, and from metro Atlanta, Georgia. The two locations (CAEFF partner institutions) for the RET interns were two hours apart. During the first year, recruitment strategies included advertisements in a catalog of graduate courses at Clemson for in-service teachers that is sent to every middle and high school in South Carolina. The catalogs were also distributed at state teachers’ conferences, such as the South Carolina Science Council. Flyers with detailed program information were provided to science coordinators at the state level in South Carolina, and to the Atlanta Public School District Science Curriculum Coordinator, for distribution to appropriate district and school personnel. Similar strategies were employed the following two years of the program, with the added benefit of word-of-mouth and press releases about the previous year’s program achievements.

Study Participants

There were 30 participants between the two sites, with a fairly equal balance between male and female. They taught a wide range of STEM subjects, and their teaching experience ranged from 2 to 28 years. All teachers taught high school with the exception of two middle school teachers and one community college professor. Table 2 provides a thorough description of the participants at each of the two sites.

Interviews

Of the participants from the two sites (10 CAEFF, 17 VU), 27 participated in interviews in their last week in the program, and 20 participants also did another interview following the implementation of the curriculum. In the Vanderbilt RET program, the interviews during the last week of the program were conducted by the undergraduate student researchers who had been working with the teachers; in the CAEFF program, these interviews were conducted by the program director. Interviews began with questions about the teacher’s background, experiences, and motivation for participating in the program. The questions asked the teacher about the research experience itself as well as self-efficacy for scientific research and how prepared he or she felt to teach about engineering; for example, “What part of the program (activity, experience, person) did you learn the most from?” The interviews ended with a general formative assessment question about the program: “What suggestions for change would you make in the program, and why?” The interviews lasted 30 minutes to 1 hour, depending on the length of the

Table 2
Study Participants

	Vanderbilt University Participants	CAEFF Participants
Total number of participants	20	10
Gender	11 male 9 female	4 male 6 female
School Setting	Urban setting – 2 Suburban setting – 10 Rural setting – 8	Urban setting – 2 Suburban setting – 8
Race/Ethnicity	18 Caucasian 2 African-American	7 Caucasian 2 African-American 1 Asian-American
Subjects Taught	Physical science, Biological science, Chemistry, Physics, Technology, Computer Science, Mathematics, Middle school science, and one Community College professor of engineering technology	Geometry, Algebra, Physical Science, Biology, Calculus, and Probability and Statistics
Average years in the profession at the time of participation	13 (2–28)	10 (4–21)
Educational Background	15 teachers majored in a STEM discipline in college; 14 had a master’s degree (five in a STEM discipline, ten in education, and one with both)	10 had either a STEM or STEM education undergraduate degree; 4 had master’s degrees (three in education, one in technology); 1 had a PhD in engineering
Years in the RET program	1 st year – 17 2 nd year – 2 3 rd year – 1	1 st year – 10

responses. The interviews that took place after the teachers had taught their modules were shorter, and focused on their experiences in teaching their self-designed instructional materials; they were conducted by the directors of the RET sites. Teachers were asked about how effective they thought their modules were and about their students' reaction to them. They were also asked about opportunities that teaching their modules gave them to discuss engineering with their students. The interviews lasted approximately 30 minutes. All interviews were recorded and transcribed.

The transcripts from these 47 interviews were read twice to identify emerging themes related to the research questions. An initial list of themes and subthemes was consolidated and organized into 20 themes and 103 subthemes by the first and a second researcher. Using NVivo8 (QSR International, Cambridge, MA), the interviews were coded by one of the researchers by subthemes only. Additional subthemes appeared in the coding of the first few transcripts, which were added, and the first few interviews were re-coded. The second researcher then also coded four interviews (two post-summer and two-post modules, with one interview being from each site in each case) and compared the coding to the first researcher. The first researcher coded more interviews than the second, and was thus more familiar with all parts of the interview that needed to be coded; thus, discrepancies between the two researchers' codings were typically resolved in researcher one's favor. Codes were negotiated iteratively until all disagreements were resolved and 100% agreement was achieved on selected comparative interviews. That said, a few discrepancies had to be discussed and resolved that required researcher one to review all interviews and make coding adjustments. No additional subthemes were added at this point.

Results

There were 20 total subthemes that appeared in the interview with high frequency: 9 subthemes related to

teachers' methods and style and 11 subthemes related to teachers' perceptions of the effect of the RET experience on their students. The threshold point for the number of interviews needed to determine high frequency of occurrence was ten interviews. This number was selected because a gap existed in the number of subthemes between 10 sources and 6 or fewer sources, clearly not significant subthemes. The subthemes which appeared in high frequency, 10 or more, are reported and analyzed below.

The nine significant themes based on the teachers' methods are shown in Table 3. The eleven significant themes related to the effect of the new curriculum on the students are shown in Table 4.

In the post-summer interview, the questions were more focused on the teachers' research experience and less on their translation of their experience to the classroom because they had not yet taught their new curriculum. The research experience itself is not the focus of this study. This is the reason for relatively few appearances of the subthemes in the post-summer interviews.

Analysis of Teaching Styles and Strategies

The first research question, "How does the RET program influence teaching style and strategies for program participants?", produced many answers. First of all, the simple use of the Legacy Cycle as a way of structuring lessons was new for first time participants. It was through the use of the Legacy Cycle that teachers brought other changes to their teaching style both within the Legacy Cycle and to their overall teaching style and strategies. The responses to this research question fell into two major themes: (1) Teachers taught using a real-world context and thus began to teach in an interdisciplinary way, exposing students to the field of engineering in the process; and (2) Teachers were able to make day to day changes in their lessons and still meet their teaching standards because the Legacy Cycle is flexible. The nine subthemes listed in

Table 3

Significant themes based on the teachers' methods and teaching style. Number of sources refers to the number of teachers interviewed who referenced this theme at least once. Total number of references is the total times that theme was referenced. Some teachers referenced a theme more than once.

Subtheme	Sources post summer (n = 27)	Sources post module (n = 20)	Total number references post summer	Total number of references post module
Teacher uses a real-world context for teaching concepts	7	18	8	19
Teacher began to teach in an interdisciplinary way	2	16	2	17
The interdisciplinary teaching includes liberal arts subjects	–	10	–	11
Teacher looked for more types of resources (video clips, field trips, guest speakers, current news, etc)	9	9	10	10
Teacher exposes students to engineering topics for the first time	4	16	6	24
Teacher talks about engineering as a college major	–	10	–	10
Teacher sparks interest in engineering and research	4	14	5	17
The Legacy Cycle is flexible and teacher was able to make modifications	5	18	6	24
Teacher continues to cover teaching standards with new method	3	16	3	17

Table 4

Significant themes related to the effect the RET-based curriculum had on the students. Number of sources refers to the number of teachers interviewed. All results represent teacher-reported perceptions, rather than directly reported student data who referenced this theme at least once Total number of references is the total times that theme was referenced. Some teachers referenced a theme more than once.

Subtheme	Sources post-summer (n = 27)	Sources post-module (n = 20)	Total number references post-summer	Total number of references post-module
Students enjoy the Legacy Cycle	–	21	–	30
Students like the course material better when taught with the Legacy Cycle	–	15	–	15
The more the students participate in the Legacy Cycle, the more they like the Legacy Cycle	–	10	–	11
Students do more hands-on activities	4	8	5	10
Students follow the engineering design process	3	15	3	18
Students become independent learners and thinkers	4	11	5	16
Students have ownership and responsibility of their own learning and are invested in the class	4	11	4	22
Students can apply the concepts to a new situation better when taught with the Legacy Cycle than with traditional teaching methods	–	11	–	11
Students are encouraged to pursue engineering as a college major	10	3	10	4
Students understand the breadth of engineering	–	14	–	18
Students are motivated to learn about engineering topics	–	12	–	12

Table 3 fall into one of these two categories and are discussed below.

Teachers Use a Real-World Context to Teach in an Interdisciplinary Way, Often Including Engineering and Liberal Arts Subjects

When utilizing the Legacy Cycle, teachers must present their students with a challenge question as the context and motivation for the entire module. Teachers use a real-world context in their teaching through challenge questions that draw from actual problems or occurrences (7 sources post-summer, 18 sources post-module). The real-world context helps students understand the application of the material they are learning and thus may be more motivated to learn about the topic. Examples of contexts ranged from rollercoaster simulations to pharmaceutical drug uses. One teacher commented that they used “a challenge question about a drug, whether it be suitable for treating, in this case a dog, and that was their challenge question and it led to a discussion.” This real-world context facilitates the integration of many disciplines into one lesson plan in a single-subject class. Indeed, two teachers at the end of the summer and sixteen teachers after teaching their module referenced that they have begun teaching in an interdisciplinary way. One teacher commented that she taught “physics and biology and chemistry all within an 8–10 day period.” Another teacher described her class in this way: “We started talking about the science of everything more so than just the technology sometimes and what’s going on and how everything’s related to everything. And so, and then as the math things pop up you know, it gives you a chance to teach math along the way as well.” It makes intuitive sense that real-world contexts would require interdisciplinary teaching; the real-world does not have problems that can be answered by one subject, such as chemistry or physics alone, but a combination of many subjects allows real scientists and engineers to solve

real-world problems. This real-world context and interdisciplinary method most likely would not have come from a less structured curriculum format.

When solving problems, engineers typically take information from many disciplines. Thus when teachers teach in an interdisciplinary way, they are again, teaching thought processes central to engineering practice (Sheppard, Colby, Macatangay, & Sullivan, 2006). When teachers are branching out of their subjects, they are also looking for new teaching resources. Eight teachers post-summer and eight teachers post-module said that they have begun to use more resources, namely field trips, guest speakers, news clips, and videos. One teacher brought her students back to the lab she worked in and had her mentor show her students, “about the pathology as she does the histology section and then possibly [go on] a tour” of her lab. Another teacher explained that her class “looked at a couple of TV news interviews for a company up in Iowa that is making milk cartons out of biodegradable polymer that is made from corn starch.” The new resources increase the teachers’ abilities to teach both with a real-world context and also in an interdisciplinary manner.

All of the participating teachers teach STEM classes, yet a common theme that emerged from the interviews (10 post-module) was that liberal arts subjects, such as writing and economics, were also integrated into the science or math classroom. One teacher explained that his students, “had to write about whether the drug would have been successful or not. They had to write brief essays.” The students had to make judgments based on what they had learned in the module and put their knowledge into writing, both of which are important jobs of engineers (National Academy of Engineering [NAE], 2004). Explaining the science in non-science terms is also an important skill for a practicing engineer. One teacher explained that her students “did an activity where they had to write like they were an electron and they were traveling through a circuit and so

that incorporated a little bit with English because they aren't used to writing in their science classes." Economic analysis was also integrated in to the many science and math classrooms. One teacher explains that she told her students to include the cost of lab materials as a factor when designing a lab as part of her module. Economic considerations and cost analysis is another important element of engineering projects. While writing and cost analysis are not typical STEM classroom topics, teachers are able to integrate other disciplines and skills into STEM topics with the Legacy Cycle.

The challenge questions created by the teachers sometimes asked students to create a design or to make a recommendation on a problem, which required the thought process of an engineer. Thus in the process of solving these real world problems, the students are exposed to engineering topics (4 post-summer, 16 post-module). One teacher explained that she gave her students "terminology that they have never heard before, such as modulus and tensile strength and things like that." These are engineering terms that the students would not have been exposed to within the traditional curriculum.

In addition to exposing students to engineering topics, teachers also took this opportunity to talk about engineering as a college major. Ten teachers mentioned talking about the possibility of engineering as a major with their students. Using the opportunity to discuss their summer research, teachers also sparked an interest in engineering and research (4 sources post-summer, 14 post-module). One teacher commented, "I want them to have some exposure to it so that it could be a choice for them in college."

The Legacy Cycle is Flexible, Allowing Teachers to Make Modifications to their Lessons and Still Meet Curriculum Standards

Within the Legacy Cycle, teachers can move back and forth between the Research and Revise stage and the Test Your Mettle stage many times within a single cycle. Also, if students do not understand a certain topic or concept, the cycle allows the teacher to pause and review any background information before moving forward with the planned lesson. Thus teachers can make modifications as they are teaching, as referenced by five teachers post-summer (and post Legacy Cycle training) and eighteen teachers post-module. Teachers can also make modifications in order for the module to be appropriate to a different class. For a lower class, one teacher "scaled back just a little bit on ... how far in detail" she went with the same material. The flexibility of the Legacy Cycle allows teachers to not only design it to fit their students, but it also allows them to meet their curriculum standards still. Three teachers post-summer and sixteen teachers post-module said that they were still able to meet their standards using the Legacy Cycle and some teachers even

commented that the Legacy Cycle goes beyond their standards. As one teacher commented, "There's a lot of standards that are covered" in just one module. Another teacher observed that the modules "are going above and beyond what the standards call for."

Analysis of Student Effects

Responses to the research question "How does the new curriculum affect the students?" fell in to the major themes of (1) Students enjoyed the learning with the Legacy Cycle, (2) Students take a more active role in the classroom and thus can apply knowledge better, and (3) Students are exposed to the field of engineering. It is important to remember that these results are teacher-reported perceptions of student gains, rather than direct measures of student progress. The 11 subthemes listed in Table 4 fall into one of these themes and are discussed below.

Students Enjoyed Learning with the Legacy Cycle

All participants in the RET Program implemented Legacy Cycle modules in their classrooms. Twenty-one teachers referenced the fact that their student enjoyed the Legacy Cycle. One teacher states that it was her students' "favorite part of the year." Another teacher stated of her students, they "absolutely enjoy it and I get feedback. I also do evaluations, personal evaluations at the end of the year that are over the course and last year, not these students but with my students that I did the Legacy Cycle with last year, that was their favorite part ..." It is also clear that students enjoyed learning the same course material better when taught in the Legacy Cycle format than with traditional teaching methods (15 sources). One teacher observed that "students really did like it. I think for your more hands on kind of students I think that yes, that they would definitely, it makes them like the course material better." When students are enjoying themselves and having fun interacting with other students in the classroom, they have a positive association with the material that they are learning and have a higher intrinsic value for it (Eccles & Wigfield, 2002). Ten teachers also mentioned that the more the students participate in Legacy Cycle based curricula, the more that they are comfortable with the new teaching method and the more they enjoy the Legacy Cycle. One teacher said, "When you teach [with the Legacy Cycle, the students] begin trying to find the application in other situations that they might hear about on the news or something." The students absorb the knowledge when it is presented with the Legacy Cycle in a real-world context that they can apply to new situations more easily than they can with traditional teaching methods. This finding correlates with those of the VaNTH ERC (Cordray et al., 2009) where adaptive expertise was improved through use of the Legacy Cycle method.

Students Take a More Active Role in the Classroom and Can Apply Knowledge Later

The new curriculum implemented by the teachers following their lab experiences allowed students to have a more active role in the classroom while the teachers take on a less active role. This is characteristic of the Legacy Cycle with its learner-centered focus that builds upon the tenets of *How People Learn* (Bransford et al., 2000). Immediately following the teachers' research experience, four teachers anticipated having more hands-on activities. Eight teachers referenced having more hands-on activities in the post module interviews. The teachers reported that the effect on the students of their more active roles is immense. When students are actively participating in the lesson, they are more engaged and more focused and thus have a better understanding of the material overall. One teacher said, "I would like to do a teaching module where I have my students derive their own formulas and kind of work on the volume of various objects in a hands-on approach." Another teacher said his students "actually did conservation of energy on a pogo stick to where calculating the amount of ... energy stored within the spring versus how high they could go and so they really liked that."

As part of the new hands-on activities, many teachers (3 post-summer, 15 post-module) had their students follow the engineering design process. The process includes learning engineering skills, making designs and modifications to those designs, testing the designs and finally reporting and presenting the results. One teacher explains, "[My students] came up with and created a design idea for a battery that could run off spinach and they had to describe their reasoning behind the design." The designs were not just for made-up situations, they were for real problems, so the students were very much acting like engineers. With more active participation, the students become independent learners and thinkers (4 post-summer, 11 post-module). When the students have a more active role, they have to think for themselves. When students must think for themselves they have to become innovative, which is a crucial skill for success in STEM fields. One teacher said that it is neat to "give students an opportunity to do some investigation, give them time to analyze the data collected and you just guide them through the process and give them plenty of time and opportunity to explore ... that will stir up their interest so this is personal." This type of flexibility is possible with the Legacy Cycle because of its combined knowledge-centered and learner-centered approach.

In the process of learning on their own and becoming more active, the students are taking ownership and responsibility of their learning (4 post-summer, 11 post-module). Many teachers required group projects and presentations for the first time in their math or science classes. When the students share their learning with their peers, they are taking ownership of it. A teacher said that she allowed her students to "take ownership of [the

material] and be proud of the things that they've done and accomplished." Another teacher observed that she was able to "give students an opportunity to do some investigation, give them time to analyze the data collected and you just guide them through the process and give them plenty of time and opportunity to explore, to kind of guide them through so that the interest that the personal discovery and finding of some solutions, some new findings, that will stir up their interest so this is personal." When a student is responsible for his or her own learning, he or she learns the material better and he or she will remember it longer (Bransford et al., 2000). Eleven teachers referenced that the students can apply the concepts learned in class to new situations better with the Legacy Cycle than if they had been taught the same material with a traditional teaching method. One teacher said her students "were better able to think on their own or take that knowledge for later use instead of just having it for the test and then moving on. They were able to continue to have that because they had experience having developed that knowledge on their own."

Students are Exposed to the Field of Engineering

The teachers gain new knowledge of the field of engineering from their time in the engineering labs and from hearing engineers give presentations on their current lab work. They then share this knowledge with their students. This might be through the engineering content of their lessons, or by simply talking about their lab experience with their students. This is the first time that many of the students have been formally exposed to the field of engineering. In the process, the teachers encouraged their students to pursue engineering as a college major (10 post-summer, 3 post-module). One teacher at the CAEFF site commented that the module "was a great tool because I got to talk about what Clemson had to offer and the different program and how it's more available to students." As a result of the exposure, students understand the breadth of the field of engineering, as referenced by 13 teachers. This not only means that they are more aware of the different types of engineering, but the breadth of people involved, and some of the stereotypes and myths about engineering were cleared. Students who have no concept of the true work of an engineer may never develop interest in the field, or might not choose to pursue engineering as a college major. When students were "looking at really some of the different topics that went with [engineering], some of the different people that are biomedical engineers, they were able to get a different view of what engineering is, hopefully break the stereotypes." Now that these students have been exposed to the field and have a better understanding of the different types of engineers, and the interest in engineering has been sparked, they may be more likely to pursue a college major in engineering. Their interest in engineering both from discussion and class

lessons related to engineering have motivated students to learn engineering topics (12 post-module). The students may be more likely to take classes related to engineering for the remainder of high school. Again, this motivation to learn about engineering topics may continue into college, where they will be more likely to choose engineering as a college major. These findings are supported by research related to the Social Cognitive Career Theory (SCCT) (Lent & Brown, 2003). SCCT posits that there is a relationship between contextual variables (such as those provided by introducing engineering in the classroom) and certain aspects of motivation such as self-efficacy, and, indirectly, interest and goals.

Conclusions

This phenomenological study shows that the NSF RET program is an effective professional development experience for teachers in terms of increasing their confidence in using a learning cycle as the basis for instructional design. The Legacy Cycle is an effective means for teachers participating in authentic research experiences to integrate their research into their classroom. A major goal of the NSF RET program is for teachers to translate their science and engineering research experiences into classroom activities. The majority of the literature of the RET programs shows that this goal is difficult, unless the RET program provides sufficient time for instructional material development, encouragement to create actual curriculum units, and training in pedagogical skills that facilitate the integration of real-world contexts into standards-based teaching. Teachers in our programs used real-world contexts in their instructional approaches and thus began to teach in an interdisciplinary way, exposing students to the field of engineering in the process. This is considered to be a key component of quality professional development. Teachers were able to make day to day changes in their lessons and still meet their curriculum standards because of the flexibility of the Legacy Cycle. Students in these classrooms enjoyed learning with the Legacy Cycle, according to their teachers' perceptions. Students took a more active role in the classroom, leading them to be able to apply their new knowledge better. Students were also exposed to the field of engineering in their K-12 education.

For engineering educators at the high school level, these results imply that RET programs are an effective way to gain exposure to engineering in a way that facilitates effectively integrating it into the classroom, and that the Legacy Cycle is a very effective means of doing so. For those who deliver professional development experiences for STEM teachers, the PD program described here is an effective way to effectively integrate engineering into the classroom, with positive perceived effects on the students.

While our results are promising, there are some limitations to the study. The interviewers may have affected

the qualitative results because of their familiarity with the teachers, which may have a biasing effect on the outcomes. In addition, the structured nature of the questions asked during interviews naturally led to some of the themes that emerged. More open-ended questions may have led to more and different themes. Additional studies on future RET programs, both at these two sites and others, may help to increase the "generalizability" of these results with additional participants. In addition, other types of data, such as direct observations of students, and other frameworks, such as student motivation or attitudes towards STEM topics, would further the body of knowledge about outcomes of authentic contexts and the use of inquiry- and challenge-based instructional methods.

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