MSP Targeted Partnership for Science Learning through Engineering Design (SLED)

1. Vision, Goals and Outcomes

Landmark national reports (NAE, 2004; NAS/NAE, 2007; NSB, 2007; NSB, 2008) and international assessments such as TIMMS and PISA (IEA, 2007; OECD, 2006) have raised serious concerns about the state of science, technology, engineering, and mathematics (STEM) education in the U.S. and its implications for global competitiveness. A chief finding is that students are often disinterested in science because the subjects are often taught in an isolated, disjointed fashion that makes it difficult for students to see connections among concepts and to the real world (Abell & Lederman, 2007). This problem is exacerbated by a dearth of well-prepared teachers, teachers' lack of science and mathematics content knowledge (particularly at the elementary level), limited science instructional time, and lack of effective teacher professional development in science and mathematics (Abel & Lederman, 2007; Fulp, 2002; van Driel, Beijaard, Verloop, 2001; van Driel, Verloop, de Vos, 1998). Such teacher issues are especially acute in rural and urban schools (Business Higher Education Forum, 2007; NSB, 2006).

Quality K-12 classroom science learning depends on equipping inservice and preservice teachers with a proficient knowledge base in science content, high-quality pedagogy, and effective methods for recognizing and supporting student learning (Abell & Lederman, 2007; Appleton, 2007; Haigh & Rehfeld, 1995; Koriala & Bowman, 2003; Lonning & DeFranco, 1994). However, it is also becoming increasing important for teachers to effectively blend disciplines (Lederman & Niess, 1997) and integrate math and science as a means of building student understanding of and appreciation for both content areas (AAAS, 1989; Frykholm & Glasson, 2005; NCTM, 1989; NRC, 1996).

The STEM education community has responded in recent years with well-documented problem- and project-centered approaches that allow students to learn content from multiple disciplines in the context of authentic problems (Carlson & Sullivan, 1999; Hmelo-Silver, 2004; Kolodner, et al., 2003; Krajcik, et al., 1998). One project-based approach in particular, the engineering design process, has been heralded by science education researchers as a strong mechanism to facilitate integrated curriculum and instruction (Fortus, Dershimer, Krajcik, & Marx, 2004; Hill & Anning, 2001; McRobbie, Stein, & Ginn, 2001; Roth, 1996). Like real world scientific inquiry, design activities focus on ill-defined problems that allow students to make decisions, reason through their designs, utilize and learn new scientific concepts, and construct new knowledge relevant to their own lives (Bucciarelli, 1994; Harel, 1991; Harel & Papert, 1991; Kafai, 1994; Koldner, et al., 2003; Roth, 1997). Engineering design encourages students to construct refinable solutions to real problems using inquiry and cooperative learning processes that allow students to explore for new understandings and to relate those understandings to other concepts (Mooney & Laubach; 2002). At the middle school level, an engineering design approach for teaching science concepts has led to superior performance in knowledge gains in core science concepts, engagement, and retention when compared to a scripted inquiry approach (Mehalik, Doppelt, & Schuun, 2008).

However, while empirical research validates the use of engineering design at the middle and high school levels, such efforts are still almost nonexistent for the elementary school classroom. This is a significant gap particularly in light of these grades being the critical juncture for student interest in science and a point where girls, in particular, "turn off" to science and mathematics (Abell & Lederman, 2007; Hurley, 2001, 2003; Lederman & Niess, 1997; Miller & Metheny, 1995; Roth, 1996, 1997). Studies indicate that elementary and intermediate school teachers (defined as grades 1-6 and 3-6, respectively) continue to teach science in isolation, and, furthermore, grapple with barriers such as insufficient subject matter knowledge about how to integrate disciplines, inadequate instructional time, and limited access to or awareness of curriculum resources that blend disciplines (Abell & Lederman, 2007; McBride & Silverman, 1991; Meier, Nicole, & Cobbs, 1998). This is even more pronounced in rural and low-SES schools where a high percentage of schools are not involved in any type of curriculum integration (Arredondo & Rucinski, 1996; Czerniak, 2007).

To address this identified gap in the portfolio of integrated science learning pedagogy, we propose an innovative math-science targeted partnership that will answer the question: Given the necessary tools and resources, cross-disciplinary support, and instructional time, could elementary/intermediate teachers work as a community of practice and effectively improve elementary school students' science achievement through a standards-based, design-oriented, integrated curriculum built around the use of the ***engineering design process***? We will utilize situated learning to uncover, evaluate, and explain how elementary and intermediate school teachers teach through engineering design and how students begin to conceptualize science and design as a result of exposure to the novel curricular materials.

1.1 Partnership Vision and Goals

Our ***vision*** for the Targeted Math-Science Partnership of *Science Learning through Engineering Design (*SLED) is to increase grade 3-6 student learning of science, as measured by statewide science assessments and other means, by developing Indiana's first integrated, engineering design-based approach to elementary/intermediate school science education. Our partnership will go beyond the fundamental practice of bringing engineering to the elementary schools (Cunningham et al, 2008; Rogers & Portsmore, 2004) and will instead devise innovative, design- and standards-based curriculum; invent design-informed science instructional methods; and implement ongoing assessments to inform the project at the pre- and in-service teacher education levels in central Indiana.

Our SLED ***goals*** are to:

1. Create a partnership of university engineers and scientists, teacher educators, school teachers, school administrators, and community partners to improve science education in grades 3-6 through the integration of engineering design in science teaching and learning.
2. Enhance the quality and quantity, and diversity of in-service and pre-service teachers prepared to utilize engineering design as a means to teach science through authentic, inquiry-based, multi-disciplinary, design projects.
3. Adapt, refine, and test existing project- and design-based curricular materials/tasks, and where necessary develop new ones, to support the teaching of elementary science through authentic, inquiry-based, multi-disciplinary, design projects.
4. Generate evidence-based outcomes that contribute to our understanding of how teachers teach science through the engineering design process and how young students effectively learn science concepts through design-based activities.

The SLED project will address the Indiana Academic Science Standards (IASS) (INDOE, 2009) new core standard entitled "The Design Process" that requires K-12 students to: "1) identify the goal of a design for a real-world problem; 2) select and use materials to develop a solution that will meet the goal; 3) draw and plan the solution in a notebook; 4) create the solution; 5) evaluate and test how well the solution meets the goal; and 6) document the solution with drawings including labels" (J. Hicks, Center for Curriculum & Instructional Leadership, Indiana Department of Education, personal communication, May 1, 2009). This IASS addition will require Indiana K-12 teachers to have the knowledge, skills, and resources necessary to teach science through engineering design. The SLED project will create an effective model for science teacher professional development for education stakeholders in Indiana (i.e. school administrators, teachers, and teacher educators) and a more systematic trajectory for merging design and inquiry curriculum in Indiana schools. We anticipate strong opportunities to inform a revision of the mandated Indiana Statewide Testing for Educational Progress (ISTEP) for first-time measurement of what students know in relation to this new design process core standard.

1.2 Targeted Partnership

The targeted partnership of *Science Learning through Engineering Design* includes Purdue University's colleges of Engineering, Science, Technology, and Education working directly with elementary and intermediate school teachers and their students in four Indiana school districts: Taylor Community School Corporation, Plymouth School Corporation, Lafayette School Corporation, and Tippecanoe School Corporation. We based this strategic partnership on several key factors: 1) rural and small community schools face disproportionate difficulties recruiting and retaining qualified teachers (Barley & Brigham, 2008); 2) the participating schools have a keen interest in engineering design as a vehicle for science learning because of reform efforts and/or curriculum integration needs in these districts; and 3) Purdue University is well-known as a national leader in engineering and engineering education and thus is well-positioned to lead this initiative. All of the core partners shared in project planning, are committed to the project's goals, and take responsibility for implementation and oversight of project activities.

The project builds on established collaborations among the university and school partners. Two of the partner school districts—Lafayette School Corporation (LSC) and Tippecanoe School Corporation (TSC)—sit in close proximity to the Purdue campus, are part of the teacher education Professional Development Schools (PDS) network, and each semester host teacher education students for early field experiences and student teaching. During the 2007-08, LSC hosted 451 early field placements and 88 student teachers, and TSC hosted 902 early field placements and 105 student teachers. By leveraging the large placement of Purdue graduates in LSC and TSC, we can more seamlessly pilot teacher and student interventions and validate methods prior to implementation in the rural setting of Taylor Community School Corporation (TSCS) and Plymouth School Corporation (PSC).

Taylor and Plymouth schools, because of their distance from Purdue, rarely host early field experiences but do occasionally host student teachers; in addition, they are part of a recently developed Rural Schools Network designed to support Indiana's rural schools and to collaborate with Purdue on the Woodrow Wilson Indiana Teaching Fellowship program, a transition-to-teaching program focused on preparing STEM teachers for high-need Indiana schools. More than 31% of elementary and secondary public schools nationwide are in rural locations (Beeson & Strange, 2003), and over half of Indiana school districts have fewer than 2000 students. These small schools experience unique challenges including having the least likely student body to attend college (NCES, 2000) and having a documented history of struggling to attract and retain teachers that requires relying heavily on teachers to teach more than one subject area (Schwartzbeck et al., 2003). SLED's focus on implementing engineering design-based integrated curriculum into the unique rural school location can provide significant insights for meeting unique science-learning needs in underserved rural schools nationwide.

The genesis for this project arose from on-going school-based initiatives including INSPIRE, the Institute for P-12 Engineering Research and Learning (directed by SLED senior personnel Strobel), an NSF project entitled *Examining Engineering Perceptions, Aspiration, and Identity Among Young Girls* (directed by SLED Co-PI Capobianco), and pilot studies integrating engineering design in the elementary science teacher education (initiative by Capobianco and LSC). These initiatives have focused on introducing engineering design in elementary classrooms in school districts, including Lafayette and Tippecanoe. Based on the positive reactions to these initial implementation efforts, we created the partnership to explore scaling up this approach. Throughout the 2008-09 academic year, Purdue team members met with administrators and teachers from the partner schools to formulate the plan for the proposed project. What we have learned from our focus group interviews is that partnering teachers want to: 1) establish a collaborative partnership with Purdue University scientists and engineers; 2) experience a rigorous, integrated, design-based science curriculum that will help them design lessons and activities that will improve student performance in science; 3) learn how to utilize a newly introduced block schedule to maximize science learning and instruction; and 4) become skilled at using evidence-based outcomes to determine how students learn science through the engineering design process.

Purdue University

Purdue University, a land grant, research university with a strong reputation in STEM disciplinary expertise, serves as headquarters for the I-STEM (Indiana's new Science, Technology, Engineering, and Mathematics Resources Network) statewide initiative designed to support STEM education in K-12 schools. The four academic colleges participating in this initiative each bring key expertise: The College of Engineering is one of the largest in the United States and houses the innovative School of Engineering Education that supports key K-12 initiatives including INSPIRE and the NSF DRK-12 *Quality Cyber-Enabled, Engineering Education Professional Development to Support Teacher Change and Student Achievement*. The College of Technology supports a statewide technology assistance program and an award-winning technology education program for preparing middle and high school technology teachers, which includes *Project Lead the Way* certification. The College of Science supports one of the largest K-12 outreach programs of its kind in the nation. The College of Education annually enrolls about 800 teacher education students and serves nearly an equal number who are preparing to be secondary teachers and matriculate in their disciplinary departments. Through its teacher preparation efforts, the College of Education maintains close working relationships with many school systems in the state. The Discovery Learning Center at Purdue's interdisciplinary Discovery Park complex heads the *Indiana Interdisciplinary GK-12: Bringing Authentic Problem Solving in STEM to Rural Middle Schools* in a partnership that includes the Lafayette School Corporation.

K-12 Partners

Our K-12 partners are four Indiana school districts that represent rural and small community elementary school environments: Lafayette School Corporation, Taylor Community School Corporation, Plymouth School Corporation, and Tippecanoe School Corporation. Each K-12 partner has a unique and compelling context for the SLED initiatives.

The **Taylor Community School Corporation** is a rural school district with four schools—primary, intermediate, middle, and high—that enroll over a student body of 1446, of whom 83% are White, 6% are Multiracial, 5% are Black, 3% are Hispanic, 2% are Asian, and 1% are Native American. The free or reduced lunch programs include 35% of the students. Overall ISTEP math passing rate for 2008-2009 is 75.6%. TCSC has recently expanded its successful *Gateway to Technology* initiative to include *Project Lead the Way* in the high school. The demonstrated strong interest in integrative engineering and science from the high school students has led to the soon-to-be-adopted New Tech High School model of project-based learning infused with technology, teamwork, and critical thinking. Teachers and administrators will soon be in intensive professional development for a conversion process in 2010. The proposed SLED project will accelerate middle school student and teacher interest and capabilities in engineering design for integrative science learning and will build a stronger student pipeline into the New Tech High School model.

The **Plymouth School Corporation** is a rural school district in northern Indiana with an enrollment of 3486 in four elementary schools, 1 intermediate school, 1 junior high, and 1 high school. Nearly 22% of these students are minority with 16% Hispanics, and 48% of the students receive free or reduced lunch. The pass rate of the ISTEP math for 2008-2009 was 79.1%. Plymouth School Corporation is currently pursuing solutions to a self-assessed need for a more rigorous, standards-based science curriculum.

The **Lafayette School Corporation** enrolls over 7380 students in grades K-12 in 8 elementary schools, 1 middle and 1 junior high school, and 1 high school with a graduation rate of 70%. This small city district is 64% White, 19% Hispanic, 11% Black, and 6% Multiracial. Fifty-eight percent of the students are on free or reduced lunch. LSC ISTEP math percent passing rate for 2008-2009 was 65.2% compared to the state average of 75%. A key concern for our LSC partner is a new STEM block learning initiative that will begin in school year 2010-2011 at Sunnyside Middle School for the approximately 60 5^{th} and 6^{th} grade students. The 100 minutes of block instruction will integrate math, science, engineering, and technology; however, LSC currently does not have integrated STEM curriculum available and currently lacks teacher development on how to use this time effectively and productively.

The **Tippecanoe School Corporation** is a local suburban district with an enrollment of 11,868 in 18 schools: 10 elementary, 6 middle, and 2 high. District ethnicity is 83% White, 8% Hispanic, 4% Multiracial, 3% Black, and 2% Asian, and 30% of all students receive free or reduced lunch. For 2008-2009, 76.2% of students passed the ISTEP math. The two high schools have recently added *Project Lead the Way* courses, and the corporation is expanding the program into the middle schools.

1.3 Building on Lessons Learned

Significant research programs in small group mathematical modeling, reforming undergraduate engineering education through integrative STEM coursework, and using authentic research experiences to teach science to undergraduates have created a portfolio of curriculum reform on the undergraduate level at Purdue. These lessons provide valuable points of testable extrapolation into the K-12 environment. In addition, the Discovery Learning Center's highly successful GK-12 project provides unique lessons in the pedagogy of using "scientists in residence" as design coaches in the middle school classrooms and in building close collaborative ties between STEM discipline faculty and educational experts.

Purdue researchers will build on longitudinal studies that examine factors contributing to engineering identity formation among young learners and teacher professional development in elementary engineering education. Evidence gathered shows elementary school students engaged in engineering learning activities tend to: 1) articulate deeper understandings and applications of the engineering design process after exposure to multiple design tasks; 2) confront their misconceptions of engineers and construct and retain new, more informed understandings; 3) demonstrate persistence in problem-solving through design yet grapple with limited transfer of learning from school to real-world science and other disciplines; and 4) express positive career aspirations and identity development as they progress from one engineering learning activity to another and from one grade to another. In addition, elementary school teachers struggle with: 1) developing and integrating engineering learning activities with other disciplines; 2) incorporating science concepts; and 3) assessing student learning of science through engineering learning activities. Our elementary and intermediate school initiatives will build on our pilot studies for integrating engineering design in elementary science teacher education by providing tested teacher development initiatives and revised assessment instruments.

1.4 Anticipated Outcomes

The project outcomes will include:

1. In-service professional development for 200 elementary/intermediate school teachers (~140 contact hours/teacher) and preparation of 100 pre-service teachers in the use of engineering design to teach science through authentic, inquiry-based, multi-disciplinary, design projects.
2. Improved science achievement of 5,000 students in grades 3-6 in the partner schools through exposure to engineering design-based curriculum and activities implemented by teachers.
3. A library of tested, design-based curricular materials to support teaching science in grades 3-6.
4. Creation of a cyber-infrastructure-enabled community of practice related to science education through engineering design that can disseminate grades 3-6 engineering design-based curriculum materials.
5. Research on the understanding of how teachers teach science through the engineering design process and how young students learn science through design-based activities (see research questions below).
6. Institutionalization of engineering design-based innovation through the development of an undergraduate engineering design-focused science methods course, a graduate course for in-service teachers and STEM graduate students, and the integration of engineering design-based curriculum in grades 3-6 of partner schools.

2. Research and Implementation Framework

Our research program draws on situated learning theory (Lave & Wenger, 1991) where learners become part of a community of practice through apprenticeship and advance from simple to more complex tasks until becoming full-fledged community participants. Learners must engage in authentic learning tasks that relate to their own experience and have similarities to what an experienced practitioner would undertake (Brown, et al., 1989; Bruner, 1996; Lave & Wenger 1991; McFarlane, 1997; Selinger, 2001). In SLED, inservice and preservice teachers will integrate curricular activities grounded in the engineering design process and the work of professional engineers (e.g., civil, environmental, or materials engineers) while simultaneously merging these concepts and skills with children's use of everyday technology (e.g., simple machines), children's ideas of current science issues and topics (e.g., water conservation and purification), and children's abilities to work collaboratively in a setting modeling the engineer's workplace. We hypothesize that authentic engineering learning tasks are more likely to hold the attention and interest of students and lead to deeper levels of science engagement (Fortus, et al., 2004; Roth, 1996; 1997; 1998) and advance teacher understanding of a broader range of engineering practice (e.g. protective equipment design, agriculture, environmental engineering, materials engineering). Students will gain and share new knowledge with others to form a productive community of practice.

2.1 Research Questions

We posit the following research questions relative to three domains of our initiative: 1) partnership; 2) teachers (inservice and preservice); and 3) students.

Table 1. Research Questions in Three Domains

Partnership	Teachers (inservice/preservice)	Students
1. What factors in the partnership support and impede teachers' development of engineering design in their classrooms? 2. How is administrative support of design-based curriculum and instruction achieved and sustained within and across partnering schools? 3. How do partnership-supported activities impact the scientists and engineers who participate? 4. How does the partnership support affect teachers' confidence levels in implementing engineering design-based instruction?	1. How do elementary/ intermediate school science teachers conceptualize design? 2. In what ways do elementary/intermediate school science teachers construct and implement design-based science tasks that capitalize on strengths of their existing curriculum and/or currently available curriculum resources? 3. What design-informed pedagogical methods do they employ? 4. How do teachers reflect on, develop, and sustain their design-informed methods? 5. What classroom-based challenges do teachers encounter and how do they solve them? 6. In what ways do teachers collaborate with one another and with other members of the community of practice to reflect on their challenges, ideas, and solutions? 7. What differences exist in teacher-identified challenges in implementing an engineering design challenge when comparing teachers of rural school settings with non-rural school settings?	1. How do elementary/intermediate school students conceptualize and learn design? 2. How do elementary/intermediate school students utilize and learn science when engaging in engineering design-based tasks? 3. What new science content knowledge do students construct when engaging in engineering design-based tasks? 4. How do students connect individual scientific concepts together in the context of an engineering design-based task and how enduring and accurate are these connections?

The SLED research team will employ a mixed-methods approach and collect quantitative and qualitative data concurrently throughout the project. In addition student performance data on Indiana Statewide Testing for Educational Progress (ISTEP), the research team will collect data using: 1) pre- and post- *Instructional Engineering Knowledge Assessments* (adapted from Fortus, et al., 2004); 2) pre- and post-*Surveys of Enacted Curriculum* (Blank, Porter, & Smithson, 2001) among inservice teachers; 3) pre- and post- *Doing Science Self-efficacy Instrument* (Lee & Strobel, submitted) among in-service teachers; 4) pre- and post- *Concern-Based Adoption Instrument* on integrating engineering into elementary classrooms (adapted from Hord, Rutherford, Huling-Austin, & Hall, 1987); 5) student and teacher participant semi-structured *interviews* to determine the role of authentic design and situated learning on scientific understanding and motivational factor; 6) follow-up *questionnaire* with preservice teachers; 7) direct *classroom observations* to ensure the collection of process data on students' and teachers' engagement with engineering design; and 8) *supporting documents* (i.e. lesson plans, implementation plans, students' drafts and design artifacts as collected through design notebooks, action research reports). Analysis and interpretation of qualitative data will involve the use of grounded theory (Strauss & Corbin, 1998) and document and content analysis, respectively (Hodder, 1994; Krippendorff, 2004) while quantitative data (e.g. knowledge assessments) will involve construction of data sets appropriate for software such as SPSS and Winsteps Rasch (Linacre, 2003; Popham, 1993) and the application of common statistical tests (t-test, ANOVA).

We will employ regression analysis to predict and construct relationships between factors and will give attention to gender and ethnicity differences across grades and individual cases within grade levels. We will take a unified approach joining intensive case-study analysis with statistical analysis that will include single- and multiple-case studies with the unit of analysis including individual teachers at each grade level, students within individual classrooms as well as comparative cases across individual schools (rural vs. small town; rural vs. rural) (Yin, 2003). In this nested research design, statistical analyses will guide case selection for in-depth research; provide direction for more focused student, teacher, and school case studies and comparisons; and be used to provide additional tests of hypotheses generated from small-N research (Lieberman, 2005). Qualitative analysis will guide instrument refinement and variable development to be tested across the larger population. Triangulation of all data sources will ensure confirmation and validity of emerging findings and provide a holistic understanding of student engagement in and understanding of science by design (Miles & Huberman, 2000). Products will include evidence-based outcomes generated from quantitative data analysis of student performance on knowledge assessments, teacher input on SECs, and student, teacher, and school case studies.

2.2 Implementing a Strategic Action Plan

Our project will have four interrelated components: 1) collaboration with STEM disciplinary faculty and grades 3-6 teachers to adapt and develop engineering design-based tasks; 2) an inservice teacher professional development program to equip grades 3-6 teachers in partnering schools to use engineering design as a tool for teaching science through authentic, inquiry-based, multi-disciplinary, design units; 3) a preservice teacher education program to prepare future elementary school teachers to teach science using the engineering design process; and 4) research that will investigate how grades 3-6 teachers teach science through the engineering design process and how students learn through design-based activities.

1. ***Portfolio of engineering design-based tasks***. Teachers will adapt, refine, and test existing project- and design-based curricular materials/tasks, and where necessary develop new ones, in collaboration with STEM disciplinary faculty to foster grades 3-6 student learning in science. Tasks will align with both the National Science Education Standards (NRC, 1994) and the Indiana Science Academic Standards (ISAS, 2009) and have common characteristics from existing design-based models including: Design-Based Science (Fortus, et al., 2004), the Center for Highly Interactive Classrooms, Curriculum and Computing in Education at the University of Michigan (Krajcik, et al, 2002), and Learning by Design © (Kolodner, et al., 2003). Five key task attributes parallel inquiry-based process skills and practices in the scientific world: 1) problems are either ill-defined or defined loosely such that students can impose their own problem frames; 2) students experience a sufficient level of uncertainty and ambiguity in finding solutions; 3) learning is driven by students' current state of knowledge; 4) students work in collaboration with other students and experience themselves as part of a community in which specific practices and resources are shared and scientific and technological knowledge are socially constructed; and 5) students can draw on the expertise of more knowledgeable others, including peers, teachers, or outside experts (Beneson, 2001; Fortus, et al., 2004; Lewis, 2002; Roth, 1998).

   These engineering design-based tasks differ from existing science curricular activities in that the problems students explore require more complex, student decision-driven responses than typical teacher-guided scientific inquiries, and the problems require students to work with constraints and develop testable and workable solutions. Each task follows a cycle of problem identification, plan development, model construction, testing, feedback and optimization (Figure 1) that is illustrated in the Mitten/Glove task exemplar.

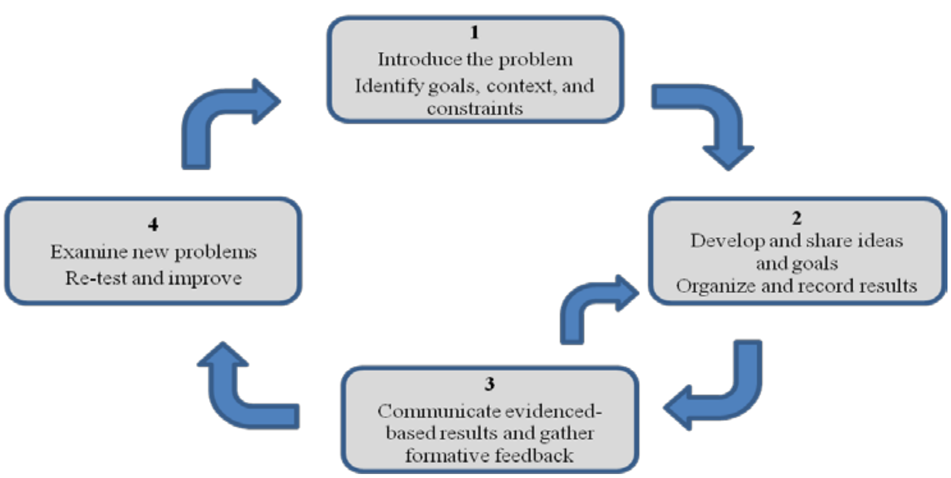


Figure 1. Design-based learning cycle (adapted from Fortus, et al, 2004)

Mitten/Glove Task – Grade 4

Learning objectives: After this task, 4th grade students should be able to:

- Recognize that some materials are good conductors of heat while others are insulators.
- Recognize that different materials gain and lose thermal energy at different rates.
- Evaluate materials to determine their use as either conductors or insulators and their respective gain or lose of thermal energy.
- Apply their understanding of thermal energy, heat transfer and properties of materials to design mitten/glove.
- Estimate and measure the area of a students' hand and determine average hand size for class.
- Relate examples of engineered products that use a material's heat capacity and heat transfer.

Science concepts:

Conductor:	A material through which energy (electrical, thermal or sound) can be easily transferred.
Heat:	A form of energy associated with the motion of atoms or molecules, and capable of being transmitted through solid and fluid media by conduction, through fluid media by convection, and through empty space by radiation.
Heat capacity:	The amount of heat required to raise the temperature of one mole or one gram of a substance by one degree Celsius without a change of phase (from solid to liquid, or liquid to gas, etc.)
Heat transfer:	The transfer of thermal energy between bodies due to a difference in their temperatures.
Insulator:	A material through which energy (electrical, thermal or sound) cannot be easily transferred.

Stage 1: *Introduce the problem and elicit students' ideas*

The task begins with a driving question: "How can we improve the design of gloves and mittens?" Teachers instruct students to identify the limits of existing gloves and mitten designs based on their prior experiences. The teacher leads a whole-class discussion about the advantages and disadvantages of gloves vs. mittens, which is a key understanding, since engineering design is often a compromise of trade-offs.

Stage 2: *Develop and share ideas via whole class discussion*

Students explore existing mitten/glove designs through testing and investigation activities of: 1) product dissection that allows students to explore the internal and external materials of mittens and gloves; 2) studying material surface textures for gripping ability; and 3) studying glove/mitten pattern shapes to understand universal fit and comfort. This stage includes teacher-directed class discussions involving how some materials keep you warmer or cooler than others (i.e. insulators vs. conductors). The teacher also presents the concepts of dimensioning, waterproofing, permeability, heat, heat transfer, heat capacity, as well as cost.

Stage 3: *Create, test, and communicate results*

Students use newly acquired knowledge on scientific and engineering concepts to brainstorm individually and cooperatively to generate multiple design sketches. Students share their ideas at four levels: individual, pairs, groups or teams of four, and the entire class. Each team mutually agrees upon one design and then creates and tests the design versus glove/mitten performance expectations. Students work collaboratively to design scientific investigations based on their glove and mitten design ideas. Students' investigations are based on probing questions about their design, such as: "What kinds of experiments can we do to determine if this glove design is a good one?" Technology, including digital thermometers, allows students to collect, record, and graph surface temperatures of existing gloves and mitten designs, and timers could allow students to assess the time it takes for moisture to penetrate glove/mitten materials. Using design notebooks, students record their investigations, design thinking, and design sketches. Students create a prototype of the chosen design and further test the prototype for performance analysis.

After each team has constructed its designs, they rejoin as a class to communicate the results of their initial prototypes through a poster or pin-up session. Students gather formative feedback from other teams and determine whether or not to re-test and/or improve on their designs and to learn from designs proposed by other students. The teacher's primary objective during this stage is to encourage students to examine the data gathered from testing and make evidence-based claims about their prototypes. Additionally, the teacher further helps students explain and justify their designs by revisiting relevant scientific concepts (e. g. heat transfer) discussed earlier in the process.

Stage 4: *Retest and improve*

In the last stage, students make final modifications to their prototypes. The teacher also poses a new problem that students solve by applying what they have learned. In the Mitten/Glove Task, students may explore the redesign of mittens or gloves used in the home (cooking, landscape/gardening) and/or other artifacts (e.g. slippers)

The Mitten/Glove task is one of several tasks included in SLED's Scope and Sequence (Table 2) that will provide guidance on how to introduce the essential understandings, scientific knowledge, inquiry- and design-based skills to SLED teachers and students in a sequential and meaningful manner. Each design task will have indicators that allow student classification of novice, apprentice, proficient, and mastery levels based on a student's ability to identify goals/context/constraints; articulate scientific concepts; organize/record results; communicate evidence-based results; apply scientific concepts; and test/retest and improve. The Mitten/Glove task also has aspects that enable us to introduce how the engineering design process can help advance and improve circumstances, which is key to helping students understand that engineering is fundamentally dedicated to improving people's lives.

Table 2. Examples of design tasks from SLED Scope and Sequence

Grade level	***Learning Objective****	***Anticipated outcomes*** *Students should develop scientific conceptual understanding of:*	***Examples of NSES & IASS***
3	Identify challenges and issues related to existing bike racks and design an alternative way to carry books.	Properties of matter Structures and forces acting on them Materials engineering and design	Properties of objects and materials Motions and force
3	Evaluate, design, and build a better candy bag.	Volume Strength of materials Structures and forces acting on them Materials engineering and design	Properties of objects and materials Properties and changes of properties in matter
4	Design and build your own irrigation system out of everyday items.	Volume Strength of materials Structures and forces acting on them Civil engineering and design Teamwork	Properties of objects and materials Motions and force
5	Design and construct a package that contains and protects a living plant to be mailed to students studying plants in a neighboring school	Seed germination Plant growth Packaging engineering and design Teamwork	Explain that in any particular environment, some kinds of plants and animals survive well, some not as well, and some cannot survive at all
6	Evaluate pros and cons of incorporating a hand recognition biometric technology into a new security system for a museum and provide design recommendations.	Classification Human body systems Biometrics technology Engineering product planning and design Meeting the needs of society Teamwork	Abilities necessary to do scientific inquiry Abilities of technological design Science and technology and local challenges
6	Explore structural, economic, and environmental factors that must be evaluated when planning to move a lighthouse or other building	Structural engineering and design Erosion Structures and forces acting on them	Describe how waves, wind, water, and glacial ice shape and reshape the Earth's land surface by erosion and depositing

* Adapted from NSDL's *Teach Engineering Resources for K*-12; Boston Museum of Science *Engineering is Elementary*; IEEE's *TryEngineering.org*; KidWind Project; *Stuff That Works* curriculum (Benenson & Neujahr, 2002)

2. ***SLED Inservice Teacher Program.*** The SLED Inservice Teacher Program will consist of four professional development activities. These activities include: a Summer Institute; Follow-up Sessions; Cyber-enabled infrastructure; and Collaborative Action Research Network (CARN).

- The SLED Summer Institute will entail two weeks (~70 hours) of engaging teachers in challenging curricula design to develop their understanding of the engineering design process, science content knowledge, and the pedagogies needed to teach science through authentic, inquiry-based, multi-disciplinary design units. In addition to design-based science units created and tested by Purdue scientists, engineers, and teacher educators in our project implementation, we will introduce additional engineering design-based curriculum resources including activities generated by the National Science Digital Library's *Teach Engineering Resources for K*-12; the Boston Museum of Science *Engineering is Elementary*, *Stuff That Works* curriculum (Benenson & Neujahr, 2002), and *Learning by Design* ™ (Hmelo, Holton, & Kolodner, 2000; Kolodner et al., 1998, 2003, Kolodner, Gray, & Fasse, 2003). With assistance from Purdue disciplinary faculty, teachers will compose design-, standards-based science lessons, map and integrate these lessons within their existing curriculum and develop an action plan for integrating at least two multi-week, design-based, thematic units in the subsequent school year. SLED design teams will include one Purdue scientist or engineer, at least two grade-level school teachers, and one teacher educator. Team members will work collaboratively to develop, test, and assess newly generated curriculum. The summer institute will focus initially on a pilot offering for grades 5/6 teachers at the local LSC and TSC schools. We will ramp up the summer institute cohorts as outlined in the project timeline in section 2.4 and will eventually invite additional rural Indiana schools to partner with us in year 5.
- SLED teachers will attend at least four follow-up sessions (~30 hours total) throughout the academic/school year to extend their understanding of the engineering design process; reflect on implementation efforts; and revise, monitor, and adjust teacher practice accordingly. Examples of follow-up sessions may include: shadowing experiences with professional engineers; research experiences with university scientists and engineers; reflective collaborative action research sessions with partnering schools and university teacher educators; and community engineering-design nights for sharing school/project activities.
- We will leverage the extremely successful Purdue "hub" cyberinfrastructure to build a SLED community of practice. While best known through the NSF-funded nanoHUB that has experienced 66.5 million web-server hits (Klimmeck et al, 2008), the underlying HUBzero™ technology will provide instant web browser availability of seminars, tutorials, podcasts, animations, and publications and will catalyze a virtual community of educators, researchers and science education stakeholders. The SLED hub will provide community-building features such as: *online presentations* with voice and animation available 24/7; a self-serve mechanism for users to *upload their own tools, presentations, and other materials* that includes content screening and automatic appearance on the "What's New" page; *ratings and citations* that lets the community judge the quality of the posting, combines with web statistics to rank resources, and allows registered users to post citations that reference the resource in literature so the community can see the work built upon that resource; *content tagging* that allows effective resource searching; *news and events*; and multiple *user support* mechanisms. HUBzero™ technology provides excellent quantitative assessment of resource downloads and tracking of curriculum refinements. We will link the SLED hub to the MSP Learning Network for greater national collaboration on the use of engineering design for integrating science and mathematics education.
- Teachers will meet quarterly over the academic year to systematically engage in collaborative conversations, gather new ideas, and evaluate their attempts at integrating the design process in practice (Capobianco, 2006, 2007; Capobianco & Feldman, 2008). Teachers will engage in at least one cycle of action research in the fall by planning, acting, observing, and reflecting on their attempts and in a second cycle of action research in the spring when implementing their second proposed engineering unit (Carr & Kemmis, 1986; Kemmis & McTaggert, 1988). Teacher-researchers will "report out" their research through the cyber infrastructure, face-to-face follow

up sessions, and conference presentations. At the end of each project year, we will identify two teacher-researchers from CARN as design coaches who will serve as school- and district-based CARN facilitators and assist in summer institutes and school-based follow-up sessions. Each subsequent year, we will select additional design coaches. By project end, we will have produced four generations of teacher-researchers/design coaches capable of providing continuous refinement of resources for integrating the engineering design process.

3. ***SLED Preservice Teacher Program.*** Our three key teacher preparation components will include: an integrated, design-focused undergraduate science methods course; a collaborative field experience with SLED teachers and faculty; and a SLED Summer Institute.
   - *EDCI 365 -Learning to Teach Science through Design in the Elementary School* will be a design-focused and integrated undergraduate science methods course for elementary education majors one semester away from student teaching that will emphasize the development of deep-level understanding of the subject material across life, physical, earth and atmospheric, and environmental. The course will be developed and taught by faculty who are actively engaged in research in science, engineering, and technology and in the teaching and learning of science. Approximately 20 preservice teachers each year will learn: 1) how elementary school children learn science using relevant learning theories in science education; 2) how to teach science through inquiry and design and parallels between the two approaches; 3) how to assess children's science learning through the engineering design process; and 4) how to create design- and standards-based elementary school science lesson plans.
   - *SLED field experience* happens early and continuously, is carefully scaffolded to ensure student success, and is closely supervised with ongoing feedback by the methods instructor, SLED faculty and partner teachers. We will pair preservice teachers enrolled in EDCI 365 with SLED inservice teachers in LSC and TSC who will integrate their respective design-based science lessons from the summer institute. SLED preservice teachers will complete a total of 16 contact hours in the SLED classrooms, prepare lessons, enact lessons, engage in collaborative conversations with the SLED inservice mentors about their attempts, assess student learning, and a create summative portfolio for design-based science instruction.
   - Five to ten pre-selected SLED preservice teachers will participate in the *SLED Summer Institute* with inservice teachers and university faculty partners. We will select preservice teachers who have: 1) completed and passed EDCI 365 within one academic year prior to summer program; 2) demonstrated high interest in teaching science through the engineering design process; and 3) demonstrated commitment to the summer program.

2.3 Partnership Collaboration

The local LSC and TSC schools will provide access to classrooms and teachers in order to pilot and validate SLED research and educational models. Taylor and Plymouth schools will also provide classroom access and teacher development opportunities that will allow SLED to assess engineering-design based learning outcomes in the rural setting.

Purdue University will offer project leadership, preservice and inservice teacher professional development, curriculum development expertise, and assessment oversight. In addition, Purdue will draw on its strong STEM resources for disciplinary expertise and authentic design projects in areas of chemistry, earth and atmospheric science, biotechnology, biology, technology, engineering (materials, civil, electrical and computer, biomedical, and environmental and ecological). The unique engineering education expertise at Purdue will provide strong leadership for pedagogically informed collaborations between STEM discipline faculty and education faculty.

2.4 Project Timeline

Program initiatives of the five-year SLED project will unfold as follows:

Program Initiatives	Year One	Year Two	Year Three	Year Four	Year Five

SLED Administration					
Partnership Leadership Team Mtg					
Partnership Steering Committee					
External Advisory Board Meeting					
STEM faculty retreat					
HUB Cyberinfrastructure					
Initiate HUBZero™ platform					
Populate hub with resources					
Track usage and quantitative stats					
Inservice Teacher Professional Development - SLED Summer Institute					
Development of materials					
Cohort 1: gr 5/6 (local pilot)					
Cohort 2: gr 5/6 & preservice					
Cohort 3: gr 5/6 & preservice					
Cohort 4: gr 3/4 & preservice					
Cohort 5: gr 3/4 , preservice, & new rural partners					
Follow-up Sessions					
CARN					
Preservice Teacher Education Program					
EDCI 365					
SLED field experience					
Summer Institute					
Research Program					
Development of assessments					
Administer IEKA pre assessment					
Administer IEKA post assessment					
Administer pre SEC survey					
Administer post SEC survey					
Conduct student interviews					
Conduct teacher interviews					
Conduct classroom observations					
Analyze data					
Produce supporting documents					
Evaluation and Assessment					
Partner interviews					
Survey of enacted curriculum					
Teacher interviews and surveys					
Teacher data collection					
Classroom observations					
ISTEP					
Student IEKAs					
Dissemination and Sustainability					
Link w/MSP Learning Network					
Dissemination					
DLC affiliated community					

3. Evaluation Plan

Indiana University's Center for Evaluation and Education Policy (CEEP) will conduct an ongoing evaluation of SLED. With a three million dollar operating budget and more than four decades of experience in evaluation planning and execution, CEEP's staff of over 60 (including Ph.D.-level senior staff) has expertise to conduct rigorous STEM education program evaluations on the international, national, regional and local levels. CEEP will provide measurable criteria and outcome-oriented data for necessary programmatic adjustments throughout the project period and at its conclusion.

3.1 Objectives and Evaluation

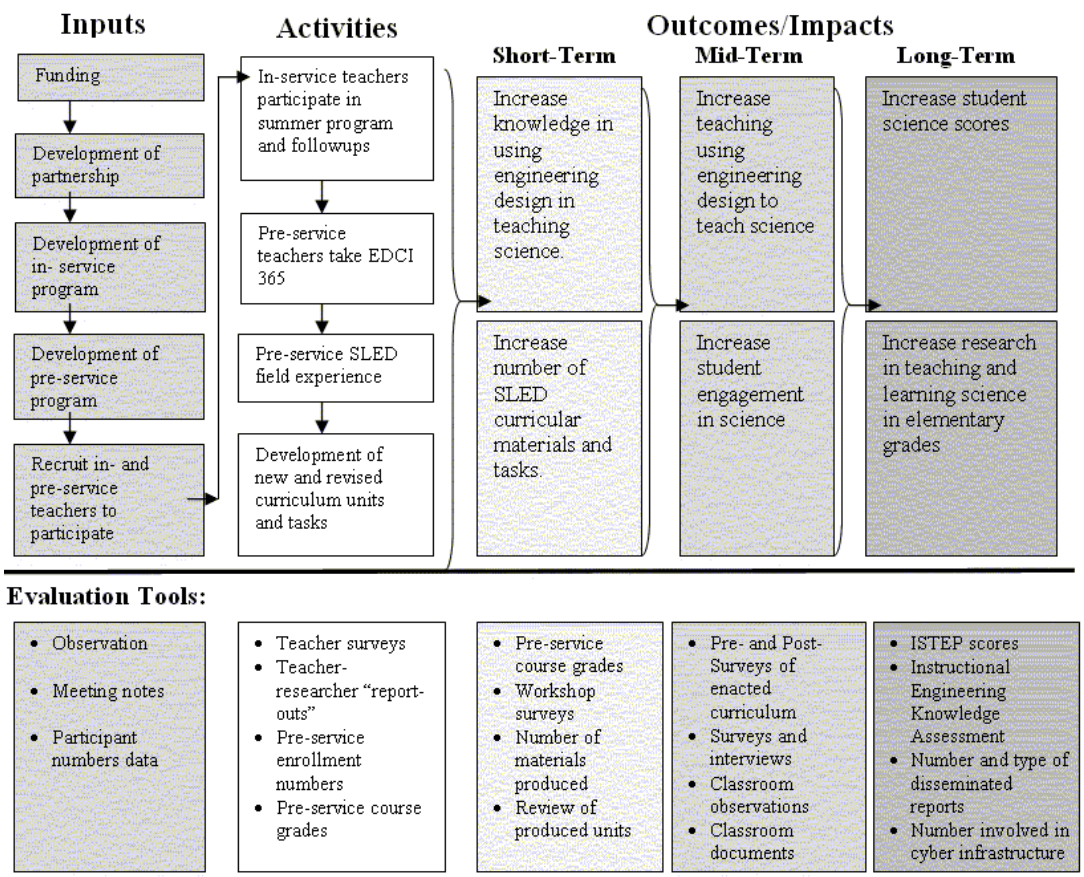
The four main goals of SLED program—development of a partnership; enhanced quality and quantity of teachers prepared to utilize engineering designs; creation of new and adapted preexisting curricular materials and tasks; and the increase of student science knowledge—align with evaluation questions and measurable outcomes in the chart below as well as corresponding benchmarks that can be found in the supplementary documents.

Goal	Evaluation Questions	Evaluation Instrument

Partnership	To what extent has a partnership been established? To what extent do all partners participate? How can the partnership be improved? What additional help/support may the partners require to be successful?	-Observation, -Project meeting notes -Partner surveys and interviews
Teacher Preparation	Are in-service and pre-service teachers enrolling in summer institutes? Do both groups feel prepared and well-equipped to teach using this method? To what extent do both groups able to implement this method into their curriculum? What additional support/resources could teachers use to make this method successful?	-Pre- and Post-Surveys of Enacted Curriculum -Surveys and interviews -Classroom observations -Classroom documents
Curricular Materials/ Tasks	Are materials and curriculums developed in a timely manner for teacher use? To what extent do teachers find the provided materials useful? Do the materials translate to classroom use? To what extent are the appropriate and useful for grade 3-6 students	-Teacher surveys -Teacher-Research quarterly meeting notes and observations -Teacher-researcher "report outs"
Student Science Knowledge	To what extent are teachers consistently using the curriculum and materials? (treatment fidelity) To what extent are students following and engaging in these methods? What methods are working and what are not as effective? To what extent are student grades improving as a result of using these curricula and materials?	-Classroom observations -Classroom documents -Pre- and Post-Instructional Engineering Knowledge Assessments -ISTEP

3.2 Evaluation Methodologies

CEEP will focus on the program activities (formative) and proposed outcomes (summative) on an ongoing basis and will monitor and measure to provide feedback to Co-PI Weaver on a regular basis. The evaluation scheme will rely on the systematic collection and analysis of impact and implementation data as outlined in the program evaluation logic model below.



4. Partnership Management and Governance Plan

We will employ a three-tiered structure to manage and govern the project: a SLED Partnership Leadership Team, a SLED Partnership Steering Committee, and a SLED External Advisory Board.

Roles and Responsibilities

The **SLED Partnership Leadership Team** will directly oversee SLED and will meet monthly to manage project implementation. Bowman and Capobianco will lead the team and will meet on a weekly basis with the fulltime project manager who will be responsible for day-to-day project management.

As delineated in the Partnership Leadership Team (PLT) table in the Supplementary Documentation, each team member provides critical intellectual input and is fully engaged to realize the SLED vision, goals, and outcomes. As director, Dr. Bowman, an internationally known researcher in materials science and engineering and a leader in STEM education at both the university and pre-university level, will be responsible for overall project leadership and integration of engineering concepts into curriculum and professional development initiatives. Co-PIs Capobianco and Weaver will provide extensive expertise in science education, action research for engineering education, innovative instructional materials and methods, instructional technologies, authentic science practice in education, and STEM learning theories. Dr. Capobianco will coordinate teacher professional development and CARN. Dr. Weaver will build a partnership with the Purdue Discovery Learning Center and will be responsible for overseeing project evaluation practices and the use formative project assessments from independent evaluator Dr. Courtney Brown to inform project refinements.

Our K-12 partners will be represented by Dr. John Layton (Co-PI) of the Lafayette School Corporation, David Notary of the Tippecanoe School Corporation, John Magers of Taylor Community Schools, and Dr. Dan Tyree of Plymouth School Corporation. These team members will coordinate the implementation of the inservice initiatives and will provide leadership for sustainable classroom reform.

Additional Purdue team members include Dr. Todd Kelley, Dr. Johannes Strobel, and Dr. James Lehman. Dr. Kelley will provide technology education expertise and will collaborate developing and implementing engineering design challenges and curriculum, the SLED methods course, summer institutes, and research on student learning. As director of INSPIRE, Dr. Strobel has extensive expertise in the cognitive science of engineering education and will provide strong leadership for research on student learning and collaboration in the development and implementation of engineering design challenges and the summer institutes. He will also help implement and research the hub-based virtual community initiatives for SLED. As head of Purdue's Department of Curriculum and Instruction, Dr. Lehman will lead sustainable implementation and research for our inservice professional development and provide expertise in cyberinfrastructure-based learning for SLED hub implementation.

A **Partnership Steering Committee** will engage a larger base of project stakeholders and will meet quarterly to assess progress, review plans, and recommend project adjustments. This committee will consist of members of the Partnership Leadership Team plus two to three representative teachers and/or administrators from each participating school district, participating scientists and engineers, community representatives, and graduate students involved in the project implementation

The **SLED External Advisory Board** will consist of Indiana Department of Education's Science Curriculum Specialist Jennifer Hicks and Technology Education Specialist Michael Fitzgerald as well as science and math education experts from higher education and national engineering faculty who have expertise in implementing engineering design in elementary science teaching and learning (see Supplementary Documents). The External Advisory Board will meet annually with the PLT to review progress and provide input on project vision, dissemination, national collaborations, and sustainability.

Engaging STEM Partners

The disciplinary partner table in our Supplementary Documents provides details on the specific roles and intellectual contributions of our strong contingent of ten STEM disciplinary faculty members at Purdue who represent areas of chemistry, earth and atmospheric science, biotechnology, biology, technology, and engineering (materials, civil, electrical and computer, biomedical, and environmental and ecological).

5. Institutional Change and Sustainability
To ensure sustainability of the ideas, resources, and work generated by SLED's partnership, we will:

1. Institute Indiana's first ***elementary science teacher education methods course*** that will serve as a hallmark for preparing the next generation of elementary science educators to teach science through design.
2. Develop a ***local, new teacher SLED induction program*** whereby SLED teachers will serve as mentors for student teachers and early career science and math elementary school teachers.
3. Convert the ***SLED Summer Institute into a graduate level course*** for all STEM and education graduate students interested in pursuing research on student learning, best practices, assessment, and teacher professional development in engineering design based instruction.
4. Designate and centralize all SLED STEM faculty affiliates and graduate students as named ***Discovery Learning Center Faculty and Graduate Student Affiliates*** who will serve as research and K-12 ambassadors for other STEM faculty interested in pursuing engineering design-based science inquiry and education.
5. Employ Purdue's hub cyberinfrastructure as an ***interactive national and state repository of all best practices, curricular resources, and assessments*** that will support student learning of science through the engineering design process.

6. Results from Prior NSF-Support
As summarized in section "<u>1.3 Building on Lessons Learned,</u>" the SLED project builds on significant previous research in STEM curriculum, engineering education, and math and science education reform.

Small Group Mathematical Modeling (SGMM) Approaches to Improved Gender Equity in Engineering (**NSF HRD #0120794; $948,340; 2001-2007)** Co-PIs: Bowman and Capobianco. Developed contextual problems for first-year engineering students to address retention of underrepresented students, instituted curriculum reform as evidenced by use of model-eliciting activities in the College of Engineering courses, and launched Mathematical Modeling in Engineering Education Conference. Ten publications in scholarly journals such as the *Journal of Women and Minorities in Science and Engineering*; *Journal of Engineering Education*; and *Journal of STEM Education*; over 24 conference presentations; and Zawojewski, J. S., Diefes-Dux, H. & Bowman, K. (Eds.). *Models and modeling in engineering education: Designing experiences for all students* in preparation.

Department Level Reform (DLR): Reforming Engineering Education: Multidisciplinary Engineering (**NSF EEC #0431906; $999,000; 2004-2008)**. Co-PI: Bowman. Developed new multidisciplinary engineering undergraduate program in the School of Engineering Education at Purdue Focused core curriculum on multidisciplinary themes, integrating research and teaching, and emphasizing team skills. Innovative courses cut across traditional discipline boundaries. (Bowman, 2006; Imbrie et al, 2005)

The Center for Authentic Science Practice in Education (CASPiE) **(NSF CHE 04-18902; $2,988,043; 8/15/04-7/31/10).** PI: Weaver**.** Designed to address major barriers to providing research experiences for first and second year undergraduate science students by: providing students with access to authentic research experiences as part of the mainstream curriculum; providing access to advanced instrumentation for undergraduate research experiences; helping faculty enhance research experiences. Developed a laboratory course sequence and online network of instruments that provides access to advanced research-level instrumentation for CASPiE students. (Weaver et al., in press; 2006; 2008; Hoch, 2009; Majewski, 2009; Russell, 2008; 2009; Choi, 2007; Russell, in press; Bentley, et al., submitted)

Quality Cyber-Enabled, Engineering Education Professional Development to Support Teacher Change and Student Achievement **(NSF DRK-12 #0822261; $1,269,008; 2008-2010)** Co-PI: Strobel.
Uses the study of engineering to advance the problem solving and critical thinking ability of students and investigates how early exposure to engineering principles may increase student interest in STEM fields. INSPIRE program implements activities and tests impact on learning and teaching. Includes face-to-face workshops with elementary school teachers and extends community of practice through video-based mentoring. Project uses the *Engineering is Elementary* and model-eliciting mathematics materials.