Learning by Making:
STEM Success for Mendocino County

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Learning by Making will develop a two-year science-driven computational-thinking based integrated STEM curriculum (Priority 3) that will improve mathematical and science proficiency for high-needs rural students (Priority 8).

A. Significance

Sonoma State University (SSU), in partnership with the Mendocino County Office of Education (MCOE), requests funding to develop a novel, integrated high-school curriculum for Science Technology Engineering and Mathematics (STEM) that uses computational thinking to focus on real world problem solving (Davison, Miller and Metheny 1995) including Disciplinary Core Ideas and Scientific and Engineering Design Practices in the Next Generation Science Standards (NGSS, 2013) and Mathematical Practices in the Common Core Mathematical Standards (CCMS, 2012).

Eligibility:

As institutional host of ten TRIO programs, SSU has a record of improving the achievement, attainment, and retention of economically disadvantaged students. In particular, SSU's Academic Talent Search (ATS) and Upward Bound annually serve 1,400 low-income and/or first-generation college-bound students in Sonoma and Lake Counties by partnering with secondary schools and their districts. Through an array of outreach services, workshops and informational events, these programs have significantly increased the numbers of students who complete high school and enroll in postsecondary programs after high school. Student outcomes are reported yearly to the U.S. Department of Education via Annual Performance Reports (APR). In the 2011/12 APR, SSU's ATS program demonstrated that 96.4% of its high school graduates enrolled in college, compared to an average postsecondary enrollment rate of minority (25.3% to 50.9%) and Economically Disadvantaged (ED, 21.3% to 38.9%) students at target schools (*www.cde.ca.gov* "Dataquest"). (See ATS program performance results at *http://www2.ed.gov/programs/triotalent/grantee-level.html*.)

SSU, an institution of higher education that meets the i3 statutory eligibility requirements as a Nonprofit Organization, will build on its success of collaborating with Local Educational Agencies (LEAs) to develop a partnership with Mendocino County Office of Education, a Rural LEA, to de-

velop successful innovative approaches to teaching STEM courses. SSU will provide the expertise of its Education and Public Outreach (E/PO) group, directed by Prof. Lynn Cominsky, which has developed widely used STEM curricula, trained teachers nationwide and started local after-school STEM programs using robotics and other engaging hands-on STEM activities. Partners from the private sector include Brian Silverman, President of the Playful Invention Company, and one of the early developers of the Logo language, and Garrett Jernigan, Ph. D. Both Silverman and Jernigan have advised other SSU projects that are currently in initial development phases and that are using Logo to control hardware sensors in the laboratory, and both have committed to contribute in-kind services to the project that together comprise more than 50% of the required match.

Rural Community with High-Need Students:

Mendocino County (MC) is a vast-sized northern California county with high rates of family poverty and low rates of college completion. Between 55% - 100% of students in each target middle school participate in the Free & Reduced Lunch Program (FRLP). According to U.S. Census Quick-Facts (2011) as few as 22.1% of county residents have attained a baccalaureate level of education, compared to the statewide average of 30.2% and national average of 28.2%. County students also demonstrate low rates of rigorous course-taking in high school. In 2012, only 25.8% of MC students graduated with courses required for enrollment in California public universities, compared to the 38.3% state average. Our proposed integrated STEM curriculum will be piloted with six MC California high schools that have demonstrated high needs as shown in Table 1:

Table 1: Partner High-Needs Secondary Schools in Mendocino County, California

	Number of students in grades 9-12	% Economically Disadvantaged (All grades, 2013)	% Free and Reduced Lunch Program (2012)	Rural LEA Low Income Program Eligibility
Anderson Valley	181	75	57.4	SRSA†
Fort Bragg	566	58	61.8	RLIS‡
Point Arena	173	74	65.0	SRSA†
Round Valley*	136	95	99.5	SRSA†
Ukiah*	1932	54	60.2	RLIS‡
Willits*	670	56	62.6	RLIS‡

†SRSA: Small Rural School Achievement Program

‡RLIS: Rural and Low Income School Program

*In Program Improvement

Novel Approach:

Our project, *Learning by Making*, goes beyond traditional project-based learning (PBL) curricula through a fusion of mathematical skill building and Logo-based computational thinking applied to real-world scientific problems where solutions are constructed by teachers and students working together. This type of learning experience is often referred to as "constructionism" (Papert 1999). The motivation of rural students will be increased as "teachers find ways to support students' interests and connect lessons to students' lives" (Hardre and Reeve 2003) thereby increasing students' self-efficacy and perceptions of their own competence. This, in turn, increases their persistence in continuing their education (Wang 2013).

The Logo programming language, which was developed at MIT in the 1970s, has been extensively used over the past four decades by thousands of teachers worldwide, primarily in grades K-8 (Papert 1999). Specifically designed for education and to foster computational thinking, Logo programming activities can be used to solve problems in all fields of STEM (Einhorn 2011). In this project Logo will be used by high-school students to undertake personally-relevant standards-aligned investigations in earth science, biology, chemistry and physics. Logo lends itself naturally to modeling and simulations, and to communicating graphical information (Logo Foundation 2011). Unlike most other computer languages (such as Java, Python or C) Logo is easy to learn and is extensible, i.e., it consists of a dictionary of words that are then combined into other words. SSU staff will work with Logo development specialists to design a simple network that supports data transfer from experimental sensors. A prototype experiment is shown in Figure 1 below.

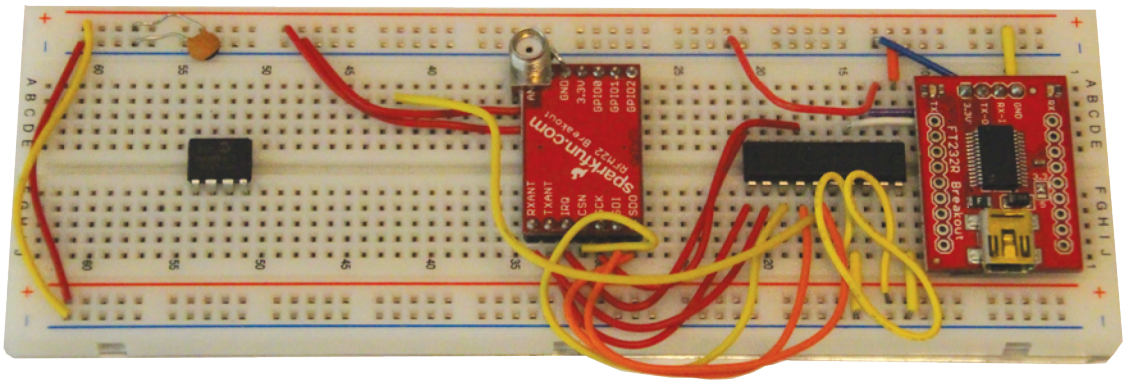


Fig. 1 Logo breadboard that students could use to add sensor hardware.

The students will write Logo words to read the sensors and obtain data, and can then easily combine these words to perform individualized experiments, analyzing and interpreting data while using mathematics and engaging in computational thinking without the difficulties usually encountered in learning how to program complex languages. Many of the student-designed investigations will use sensors to obtain data, while others will focus on simulation and modeling. As recommended in the NGSS Scientific and Engineering Design Practices framework, students will also develop and use models, construct explanations and arguments from experimental evidence, and report and communicate their results to their peers and their instructors.

The use of models is also an important Standard for Mathematical Practice in the CCMS which recommends that students "apply the mathematics they know to solve problems arising in everyday life, society, and the workplace." The CCMS also recommends "the strategic use of technology.. to assist students in forming and testing conjectures, creating graphs and data displays and determining and assessing lines of fit for data" as well as performing geometric constructions (see CCMS Appendix A). Using technology has been shown to provide benefits in the process of integrating science and mathematics content (see review by Pang and Good 2000) including the facilitation of collaboration among users, and the application of students' knowledge to practical tasks.

The integration of the NGSS Scientific and Engineering Design Practices and CCMS Standards for Mathematical Practice into our proposed high-school curriculum will be conducted by our project team using a modification of the successful PBL-approach discussed by Powers and DeWaters (2004): we will introduce a statement of a reality-oriented problem as a motivator early in each semester. The mathematics needed to frame the problem, as well as to model and analyze the data will be integrated with the science content and the technology, thereby increasing the students' mastery of mathematics (Judson and Sawada 2000) at earlier grade levels.

We recognize that implementing this type of framework represents a challenge. In the traditional classroom setting the emphasis has been on informational learning, e.g., the dissemination of knowledge by a teacher to the students, students reading textbooks, or browsing for information on the Internet. It is critical to our STEM curriculum development project that the teachers become

"intellectual agents" who learn alongside the students as they engage in purposeful research to solve problems that are relevant to their lives and/or that engage students' intellectual curiosity. The deepest learning will occur when scientific and engineering practices meet reality: if an activity is not successful, there will be additional obstacles to overcome solutions will have to be discussed, and modeled, by a community of engaged student-teacher teams, learning together (Papert 1999). Our project will therefore also provide rich learning experiences for a minimum of twenty MC science and mathematics teachers, who will be intellectually supported by professional development (PD) activities in a growing community of practice as we develop our two-year integrated STEM curriculum. (The community of practice will include at least half the science and mathematics teachers in our six partner schools.)

Contributions to STEM Education Theory, Knowledge, and Practices:

Since the NGSS and CCMS are intended to be adopted nationally, using the new Scientific and Engineering Design and Mathematical Practice standards as the bases of our proposed curriculum will ensure that the work that we do will have broad applicability. Our curriculum will be among the first to implement these new Practice standards in a cohesive and integrated manner. Comprehensive evaluation of our work will advance the theory, knowledge and practice for the integration of the new NGSS and CCMS Practice standards, as well as adding to the growing knowledge base defining the effectiveness of computational thinking within STEM courses. The need for empirical studies on integrated curricula in general, and of the effectiveness of technology-based integration programs on students' understanding of mathematics and science are long-standing issues (Pang and Good 2000). More recently, workshops sponsored by the National Research Council (2010, 2011) have explored the scope, nature and pedagogical aspects of computational thinking. It is clear from these reports that there is a great need for educational research into the role that computational thinking can play in improving STEM learning outcomes. In a recent review, Grover and Pea (2013) note that although "(s)ome strides have been made in the realm of defining curricula for nurturing computational competencies, and assessing their development, large gaps still exist that call out for empirical inquiries."

To ensure nation-wide applicability, our curriculum development process and teacher professional development will be formatively assessed, and the resulting STEM student learning outcomes and improvements in student achievement will be systematically studied and summatively assessed by external evaluators at WestEd (see Section E for details of the evaluation plan).

Improving on Outcomes:

In Table 2, we list the percentage of students in our partner high schools who have scored proficient or better in math and science (using the 2013 data from the California Subject Test (CST) *http://star.cde.ca.gov/star2013*). These data can be compared to the statewide averages of 51% in math and 60% in science. Only one of our partner schools (Anderson Valley) has student proficiency scores that are comparable to the state averages for both math and science. We also list the percentage of graduating students who have met the requirements for admission to the University of California (UC) or California State University (CSU) systems. According to the California Master Plan, the CSU system selects entrants from the top third (33%) of graduating California high school students, while the UC system selects from the top eighth (12.5%). The last two columns in Table 2 provide the expected improvement in standard mathematics and science CST scores for the students who are taking the new courses, as estimated in Section B.

Table 2: College eligibility and proficiency in math and science from standardized tests with expected outcomes

School	% 2012 grads eligible to apply to UC/CSU	% Students scoring proficient or better on math	% Students scoring proficient or better on science	Expected % Students scoring proficient or better on math*	Expected % Students scoring proficient or better on science*
Anderson Valley	8.50	45.5	45.5	60	60
Fort Bragg	22.7	24.2	53.4	39	69
Point Arena	9.5	7.6	20.7	23	35
Round Valley	2.7	0.0	17.5	18	32
Ukiah	19.8	22.5	44.2	38	59
Willits	53.9	24.3	32.3	39	47

** For students enrolled in both new courses*

At the present time within MC, each high school develops its own science curriculum, effectively preventing the MC teachers from forming a community of practice to share resources, expertise and details of successful classroom activities. Typically, most MC schools teach either earth science or biology in the ninth and tenth grades. Advanced science laboratory courses in chemistry and physics are regularly offered in the larger MC schools, but may not be taught in the smaller schools. Three years of mathematics are required for CSU/UC admission (and a fourth year of mathematics is recommended for UC admission), however only the larger MC schools are able to regularly offer courses such as trigonometry, pre-calculus or calculus. This is not unusual: small rural schools often are unable to offer advanced courses and are lacking in technology compared to larger schools (Khattri, Riley and Kane 1997).

Wang (2013) presents evidence that improving math achievement by 10th grade has been shown to have a significant and positive effect on choosing STEM in college. He also shows that the "largest impact on STEM entrance, (and) intent to major in STEM is directly affected by 12th-grade math achievement, exposure to math and science courses, and math self-efficacy beliefs." It therefore follows that the documented poor math proficiency performance coupled with the lack of a four-year college preparatory math and science curriculum at smaller rural schools effectively precludes future STEM career choices for many rural students. By piloting two years of computational thinking laboratory-based STEM curriculum at each school we will a) enable all MC schools to offer a progression of laboratory science courses that meet or exceed the UC/CSU requirements; b) increase the students' mathematical proficiency through integration with computational thinking (Harel 1988, Judson and Sawada 2000) and c) provide a rich professional development experience for the mathematics and science educators that will enable them to effectively deliver this curriculum as part of a community of practice.

Forming a community of practice with the widely separated rural teachers participating in our program will be optimized by pairing planned face-to-face PD sessions with the use of online communications technology such as Wikis and regular online group meetings (as recommended by Sheey 2008 and referenced therein).

B. Project Design

In this section, we define our project goals and measurable outcomes, provide an overview of our proposed novel STEM curriculum including the details of the project activities planned to achieve these goals within the context of our logic model, and identify potential risks to project success and mitigation strategies.

Project Goals and Metrics:

The major goals for this project are summarized in Table 3. For each goal we also provide an associated metric to be evaluated and the planned method(s) of evaluation.

Table 3: Project Goals, Metrics and Evaluation Methods

Project Goal	Metric	Method of Evaluation
Develop college preparatory two-year integrated STEM curriculum that focuses on computational thinking and scientific and engineering design practices.	The two courses will be accepted as elective credit for the "G" requirement in the state of California.	Courses will be evaluated by the UC and CSU systems through the a-g On-line Update website.
Train at least one science and one mathematics teacher in each school to successfully deliver the curriculum.	Teachers will demonstrate competence to oversee student project designs, including troubleshooting the hardware and software.	WestEd evaluators will observe in-class performance of teachers at each school.
Offer two-year curriculum to high-needs students at each school.	Number of high-needs students who enroll in the new courses at each school.	WestEd evaluators will quantify the number of enrolled high-needs students at each school.
Improve math and science proficiency for students enrolled in new courses at each school.	CST summary test data in mathematics and science.	WestEd will compare CST test data for cohort of students enrolled in new courses to similar students who have not taken the new courses.

Our proposed program has a strong theoretical basis, as individual elements of our program are supported by documented evidence of effectiveness. As shown in the logic model below, integrated STEM curricula will be developed by SSU education specialists in partnership with MC science and mathematics teachers and private partners that are experts in Logo. After *Learning by Making*, students will demonstrate increased proficiency in science and mathematics and will therefore be

better prepared for college STEM studies. STEM educational programs using Logo have succeeded in improving student learning in the United States (e.g., St. Paul, Minnesota, Kozberg and Tempel 1999), and in countries around the world (e.g. Costa Rica, Fonseca 1993). Combining Logo and mathematics has also been demonstrated to improve the mathematics performance of fourth-grade students (Harel 1988). The integration of mathematics into a science-driven curriculum via technology has been shown to produce positive effects on (middle-school) student learning (e.g., Judson and Sawada 2000). Engineering curricula have been successfully implemented as vehicles for K-12 science and mathematics integration (Schaefer, Sullivan and Yowell 2003) and have had success in teaching chemistry (Apedoe et al. 2008). Student success in 10th -12th grade mathematics, along with exposure to additional math and science courses increases the likelihood that students will choose STEM majors in college resulting in an increase in STEM professionals from high-needs groups (Wang 2013).

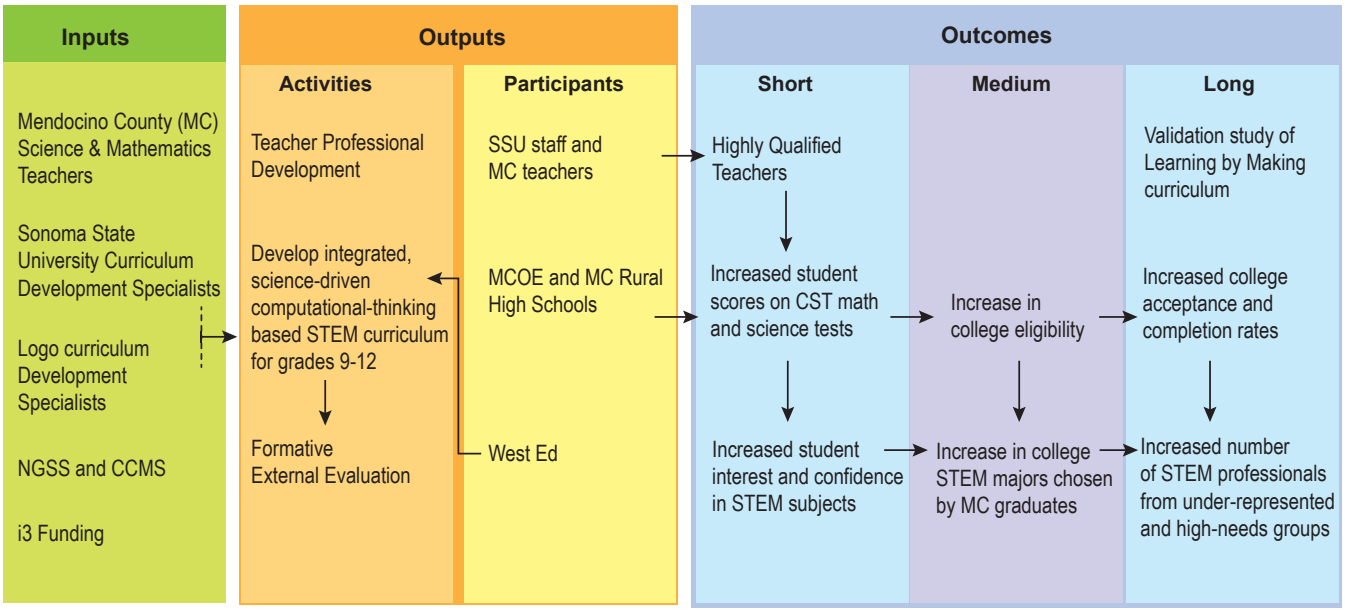
Using the results of Harel (1988), we can estimate the expected improvement in mathematical proficiency for our students. In this study, the students who participated in the combined Logo and mathematics course showed increases in mathematical proficiency averaging 20%, nearly twice that of students who had not taken the course (but had only taken standard courses). Based on this study, we apply an attainable but ambitious estimate of 15% (roughly halfway between the baseline increase and the highest recorded outcome) to produce the expected improvements listed in Table 2 above. Since our courses will also include science content (for which there is no equivalent study), we use increases in mathematical proficiency as a proxy for the expected increases in science proficiency, adopting the same 15% improvement goal.

Teachers will be trained to use the curricula, software and hardware in their classroom through PD by SSU staff and Logo specialists, using PD standards as described by Loucks-Horsley, et al. (2010). This training is critical to ensuring the competence of teachers, who are not typically experts in computational thinking (Grover and Pea 2013). WestEd will evaluate the PD sessions, as well as observe the teachers' practice to help ensure that the teachers are highly qualified to deliver

the curriculum. WestEd will also provide formative evaluation activities during curriculum development, providing early testing and feedback to ensure the curricula are appropriate for classroom use, will conduct extensive summative evaluations of each unit's effectiveness, and will do the comparison studies to quantify the gains in proficiency by the students who are enrolled in the new courses. Our Logic Model is graphically depicted in Figure 2.

Fig. 2 *Learning by Making* Logic Model

Situation: Most high-needs students perform below the proficient level in science and mathematics



Assumptions:
- Student difficulties with mathematics stems from a lack of context and connection to the real world
- Students' low-income status limits access to technology
- Rural students face additional barriers to success

External Factor: Rapid changes in technology necessitate updates of implementation platform

Project Overview:

The *Learning by Making* curriculum consists of two year-long integrated laboratory courses: the first course will include Disciplinary Core Ideas (DCIs) in Earth Science and Biology; the second course will consist of DCIs in Chemistry and Physics. Throughout the two-course sequence, we will emphasize the NGSS crosscutting concepts of Cause and Effect, Systems and Systems Models, and Stability and Change. The project will be able to further develop and scale in future proposal cycles,

with the expansion of each semester's work to full-year courses, and with bulk purchases of the needed equipment and customized electronics created through this development phase.

Year 1 (2014) is a project planning year in which SSU staff will meet with science and mathematics teachers from each partner school in order to gauge capabilities and expertise, and will repeatedly visit each school to survey physical facilities, computer equipment and infrastructure. SSU staff will also write a Logo manual, and develop prototype instructional activities, software, and hardware platforms. This will include the design and creation of some custom electronics needed for sensors to communicate with classroom computers. SSU staff and MC mathematics and science teachers will work together to refine lesson plans and instructional activities for the first year-long integrated STEM course. Starting in June 2014, teacher professional development (PD) will occur for one week each summer, and for 5 in-service days during each school year. In the fall of 2015, we will pilot the first-year course as either an elective laboratory science class, or as a replacement course for an existing science class. Continued meetings between SSU and MC staff will allow for brainstorming the investigations to be developed for the second year course, teacher skill-building using the Logo language and hardware, and practice lessons. In 2016, we will apply for approval for the first-year course to fulfill the elective "G" college preparatory requirement, continue to improve and modify the first-year course based on formative input from our evaluators and, in the fall, pilot the second-year course. In 2017, we will apply for approval for the second-year course to fulfill the elective "G" college preparatory requirement, and continue to improve and modify both courses based on input from our evaluators. In the fall of 2017, both first and second year courses will be offered at the larger schools; courses may alternate years at the smaller partner schools. The development project will conclude in 2018 with extensive summative evaluation by WestEd, as described in section E.

Table 4 lists example projects, NGSS DCIs and Performance Expectations. We plan to introduce at least one experimental design that uses sensors and one computer modeling project each semester. In the next section, we provide additional details for the weather station experiment.

Table 4: Example projects, NGSS DCI and Performance Expectations Alignment

Subject	Overarching questions	NGSS Disciplinary Core Idea	Example projects (Performance Expectations)
Earth Science	What regulates weather and climate? How do humans depend on Earth's resources?	Weather and Climate HSS-ESS2.D Global Climate Change HS-ESS3.D	Weather station sensor measurements and analysis; or Danjon experiment to monitor "earthshine" as measurement of Earth's albedo to model climate change (HS-ESS2-4) Model the increase in temperature of air and ground/ocean caused by greenhouse effect. Include effect of changing albedo and changing opacity due to carbon dioxide and water in the atmosphere. Model rates of evaporation and positive and negative feedbacks it causes. (HS-ESS3-6)
Biology	How do organisms obtain and use energy they need to live and grow? How do organisms interact with the living and non-living environment to obtain matter and energy?	Structure and Function HS-LS1.A Interdependent Relationships in Ecosystems HS-LS2.A	Explore regulation of body temperature and/or heart rate during stressed and unstressed scenarios; or root growth for different soil pH or water salinity (HS-LS1-3) Model biodiversity contributions to crop yields (HS-LS2-7)
Chemistry	How do substances combine or change (react) to make new substances? How do the properties and movements of water shape Earth's surface and affect its systems?	Chemical Reactions HS-PS1.B Roles of Water in Earth's Surface Processes HS-ESS2.C	Design a personal heating or cooling device using chemical reactions and containment systems (HS-PS1.6) Measure water quality and relate to macrovertebrate diversity; or measure water evaporation rates for different physical conditions of heat and wind (HS-ESS2-5)
Physics	How is energy transferred and conserved? How are waves used to transfer energy and send and store information?	Defining and Delimiting Engineering Problems HS-ETS1.A Information Technologies & Instrumentation HS-PS4.C	Optimizing solar power or other renewable energy system (HS-PS3-3) Remote control of robot motion or other electronic device using either light or sound waves (HS-PS4-5)

Example Activity for Earth Science: Earth Weather / Climate:

In this activity students will use sensors to construct a weather monitoring station. The goal is to encourage students to make use of the measuring apparatus in order to answer a question or set of questions determined by themselves and their teacher that relate to the weather changes observed over the course of the measurement period. Student designs may include measurements of air temperature, humidity, precipitation, ground temperature, incident solar radiation, cloud cover, etc. At the beginning of the semester, students will write the Logo words needed to acquire data from the sensors and set up their observational protocols. During the semester, the stations will record measurements; by the end of the semester, students will be able to analyze data to look for correlations between the measured quantities. Other skills to be learned during the semester include the writing and/or use of data analysis tools, graphical display tools and the mathematics needed to model and interpret the results. Example student questions include:

1) Is there a relation between incident solar radiation and air temperature?
2) Is there a relation between incident solar radiation and ground temperature (surface and subsurface)?
3) Is there a relation between ground temperature and air temperature?
4) Is there a relation between cloud cover and temperature (air or ground)?
5) Is there a relation between temperature and humidity?
6) Is there a relation between humidity and precipitation?

For each activity, the appropriate mathematics (aligned with the Common Core Mathematics Standards, CCMS) will be reviewed in the context of the scientific measurements and data analysis. For this example, these include CCMS standards in: Statistics and Probability (Domains: Interpreting Categorical and Quantitative Data (HSS-ID.A.1-9), Making Inferences and Justifying Conclusions (HSS-IC-B.3, 4, 6)), and Functions (Domains: Linear, Quadratic and Exponential Models (HSF-LE.A.1, 2, 5), Trigonometric Functions (HSF-TF.B.5-7)).

Risks and Mitigations:

There are also a number of risks involved in our approach. In Table 5 below we list the most likely risks, as well as planned mitigation measures:

Table 5: Risks and Mitigation Strategies

Risks	Mitigations
Teacher retention at partner schools makes it difficult to keep competent teachers and build a community of practice.	Introductory and refresher material will be repeated during PD sessions for teachers who are new to the project. SSU staff will schedule individual site visits in order to work closely with all teachers to ensure success.
High-needs students are reluctant to take the new courses.	Courses will be widely advertised, especially to high-needs students who might have otherwise chosen vocational courses and science courses which are not qualified for college prep. SSU staff will consult with school counselors to identify high-needs students in these categories who will be encouraged to take the new courses.
Teachers don't have adequate expertise in computers and instrumentation and/or are reluctant to learn.	SSU staff will conduct extensive professional development, starting one year prior to the introduction into the class room. SSU staff will schedule individual site visits in order to work closely with all teachers to ensure success.
Math proficiency of high-needs students is too low to accomplish the goals of the new courses, even with the additional math content provided.	SSU staff will schedule individual site visits in order to customize additional math support materials to ensure success. SSU will provide handouts and/or online tutorials to reinforce needed math concepts.
Working with six different schools with widely differing cultures adds to the complexity of the project.	The first year of the project focuses on project planning. During this time, SSU staff will visit each school and talk with teachers, administrators and students to gain a deeper understanding of the culture, curriculum and student needs.

C. Management Plan

Key Responsibilities and Objectives:

As Project Director, Prof. Cominsky is responsible for ensuring that the project meets its yearly metrics and annual performance targets. Cominsky is also responsible for the interfaces with external evaluators WestEd, and consultants Silverman and Jernigan. Project Manager Susan Wandling will be responsible for overseeing the budget and program compliance with federal and institutional rules and regulations. Wandling will also coordinate the work with MCOE education specialist Katie Sommer and individual MC schools and teachers, assisted by SSU staff member Peruta. SSU staff member McLin is responsible for organizing the annual week-long and five one-day in-service Professional Development sessions. SSU staff member John is responsible for the overall design of the experimental hardware platforms, in consultation with Silverman and Jernigan. SSU staff member McCall and the MCOE Computer Technician will test out the network infrastructure at each school to make sure the experiments will work as designed.

Professional Development Schedule:

Starting in 2014, week-long PD sessions will occur each year after the end of the school year in June and will be conducted by SSU staff, including Cominsky, Wandling, McLin, Peruta and John, with additional support by the MCOE Education Specialist and evaluation by WestEd. One-day PD sessions will occur on Saturdays in August prior to the beginning of the academic year, and twice during each semester. The total PD to be provided each year is 8 days in 2014, 10 days in 2015-2017 and 7 days in 2018.

Metrics and Performance Targets:

Beginning in fall 2015, each partner school will offer at least one section of the first year course as a laboratory science elective or as a replacement for the previously offered 9th or 10th grade science class. Beginning in fall 2016, each partner school will offer at least one section of the second year course as a laboratory science elective or as a replacement for the previously offered 11th or 12th grade science class. Based on the sizes of typical classes at each school, we expect the following enrollments for each course: Anderson Valley (20), Ft. Bragg (25), Pt. Arena (20), Round Valley

(15), Ukiah (30), Willits (25) for a total of approximately 135 students each year. Beginning in fall 2017, the larger schools (Ukiah, Ft. Bragg and Willits) may be able to offer both new courses at the same time, for a total of 485 students served during years 2-4 of the project. (This total does not include students who begin the courses in the fall of year 5, but will not complete them by the project end date.)

Project Schedule:

The work plan for the project described in Section B is summarized in Figure 3 on page 17.

Table 6 summarizes the Milestones and Deliverables:

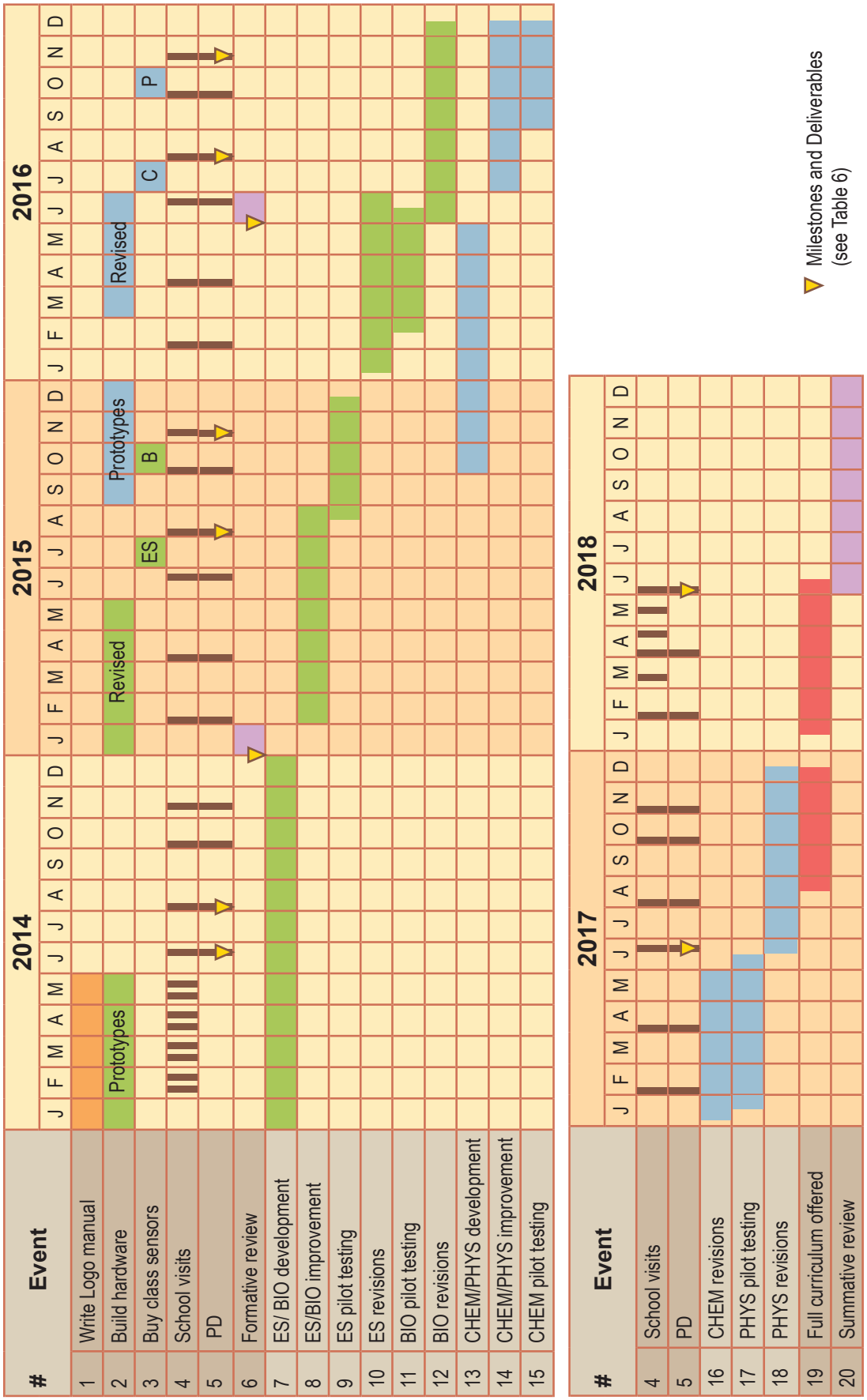
Table 6: Milestones and Deliverables

Date	Milestone	Deliverable
June 2014	Week-long PD	Logo manual draft
August 2014	One-day PD	Earth Science and Biology prototype hardware and draft curricula
January 2015		Logo Manual and curriculum draft to WestEd
August 2015	One-day PD	Earth Science curriculum handouts, classroom hardware sets
November 2015	One-day PD	Biology curriculum handouts, classroom hardware sets
June 2016	Week-long PD	Chemistry and Physics prototype hardware and draft curricula to WestEd
August 2016	One-day PD	Chemistry curriculum handouts, classroom hardware sets
November 2016	One-day PD	Physics curriculum handouts, classroom hardware sets
June 2017	Week-long PD	Revised handouts and hardware for all subjects
June 2018	Week-long PD	Final revised handouts and hardware

Commitment of Partners:

In the Other Attachments, we include letters of commitment from the MCOE Executive Director Paul Joens-Poulton and Education Specialist Katie Sommer, as well as from the superintendents of each of our six partner schools, from project evaluators at WestEd, and from the Lake County Office of Education, which has agreed to provide access to student data for comparison purposes. We also attach letters of commitment from Logo experts Silverman and Jernigan, who are providing in-kind services to help develop the Logo lessons, code and experiment designs. These services comprise more than half the required private sector match.

Figure 3: Project Schedule



Ensuring Feedback for Continuous Improvement:

Through PD sessions and regularly scheduled classroom visits by SSU staff and WestEd personnel, we will be able to adjust the instructional materials and experiments to include the feedback as the materials are developed and tested. This will naturally allow us to gather the input needed to evaluate the success or challenges of the approach and to assess the experimental designs initiated by the students. We will develop rubrics for all teachers to use to evaluate the success of the implementation of each of the eight steps in the NGSS Engineering Design Practice framework. PD sessions during the academic year will review the students' project designs, helping the students and teachers learn together, as their skills build throughout each year. In addition, examples of student work for each step will be shared between participating teachers, and will be examined and discussed to ensure that the best practices and lessons learned will be widely disseminated. We will use Wikis and other electronic communications tools (such as GoToMeeting) to encourage discussions between teachers at different schools, as we build our community of practice.

D: Personnel

Susan Wandling, Director of Early Academic Outreach at SSU, is the Principal Investigator and Project Manager for *Learning by Making*. She has managed federal and foundation grants with a focus on educational equity and college access, and has ensured programs' compliance with federal law and regulations and sponsor guidelines. She has overseen annual program budgets up to $1.2 million. To build successful partnerships, Wandling has developed and maintained cooperative relationships with district and K-16 school personnel and with campus colleagues. Professor Lynn Cominsky, Chair of SSU's Physics & Astronomy Department and Director of SSU's Education and Public Outreach (E/PO) group is the Co-Principal Investigator and Project Director. E/PO group members Drs. Kevin McLin and Carolyn Peruta are the main curriculum developers for the project, and Kevin John is the Instructional Technologist. Under Prof. Cominsky's direction and for more than a decade, the group has excelled in STEM curriculum development, mainly for high school students. Group members Cominsky, McLin, Peruta and John also conduct regular professional development sessions for sec-

ondary school teachers, in order to ensure the optimization of the classroom experience. The group's most recent curriculum development projects include "Small Satellites for Secondary Students" (S4) and "Big Ideas in Cosmology." In the S4 project, middle and high-school teachers have learned how to build and program experimental payloads that are flown on weather balloons and/or rockets. Software and hardware designs for this program were produced by John and SSU students. The success of the S4 project has informed our thinking about the integration into high-school classrooms of engineering design problems using sensors and microprocessors. This program is already having positive effects on encouraging STEM learning in Mendocino County: Pt. Arena STEM teacher Roger Little has communicated that as a result of his participation in the S4 program, in fall 2012 the Pt. Arena High School began a STEM academy. In the S4 project, we are also building a community of practice that includes educators located all over the state of California, using Forums, Wikis and other online tools that are designed to continue the development of a mutual knowledge base to which all can contribute. For more information on S4, including materials from the recent week-long professional development experience, see *http://s4.sonoma.edu*.

McLin is the primary curriculum developer for the "Big Ideas" project. Intended for general education first-year college Astronomy students, "Big Ideas" emphasizes computations and graphical analysis of real data. Before working at SSU, Peruta was a major contributor to the "Hand On Optics" curriculum developed at the National Optical Astronomy Observatories. At SSU, she is contributing to the "Big Ideas" project and to a wide variety of educator professional development experiences.

Additional SSU E/PO group staff that will support the project include Aurore Simonnet, who is responsible for the layout of the Logo manual and other handouts needed by the project; David McCall, who maintains the security of the group's computer servers and will help with computers software and web page installation, and Laura Chase, who will provide administrative support.

Consultant Brian Silverman is one of the early developers of the Logo language, and has over 30 years of experience designing Logo-based projects for students of all ages. Consultant Garrett Jernigan has extensively used Logo, and has advised other SSU projects that are currently in initial development

phases and that are using Logo to control hardware sensors in the laboratory. Both Silverman and Jernigan are contributing in-kind services to the project, developing the low-level Logo words that are needed to read from individual sensors that will be chosen for the students' experiments. Each year, Silverman and Jernigan will provide additional advice to SSU staff who are writing and delivering the teacher's professional development experiences. Jernigan will also help to design any special electronics needed for the experiments. Another important task to be contributed to by Silverman and Jernigan is to provide information to SSU staff needed to prepare a Logo User's manual that will be provided to all MC participants (teachers and students).

The MCOE Educational Specialist will facilitate recruitment of target school teachers to participate in professional development; establish, maintain, and ensure clear communication and cooperative working relationships between SSU contact and teachers and districts; assist with planning and observation of professional development activities and coordinate feedback from target school teachers and districts. The MCOE Computer Technician will provide technical support to SSU project staff as needed at target school sites; install and maintain computer equipment purchased by grant for target school classrooms; establish and maintain school-to-school intranet connectivity; and work with SSU staff to design and host web pages for *Learning by Making*.

External evaluation will be provided by WestEd, and led by Dr. Betsy McCarthy. Dr. McCarthy is a Senior Research Associate in WestEd's STEM program and Principal Investigator for several large Federally-funded evaluation projects. In the past, Dr. McCarthy has evaluated other SSU programs, including several for the E/PO group. She will be assisted by Dr. Linlin Li, a senior methodologist at WestEd, who will provide additional expertise in experimental designs, mixed methods, and logic model testing.

E. Project Evaluation:

WestEd will serve as the independent professional evaluator to objectively conduct the program evaluation. WestEd will conduct a rigorous, mixed-method, multi-year evaluation. The evaluation

strategy will focus on four research goals: 1) describe the design and development of *Learning by Making* project model (formative evaluation); 2) evaluate the implementation of *Learning by Making* project model in order to facilitate replication and examine fidelity (formative evaluation); 3) assess the effectiveness of *Learning by Making* project model as used in Mendocino County, CA (summative evaluation); 4) discuss the aspects of success and areas for improvement and provide recommendations that will increase the use and scalability of *Learning by Making* project model. Below are the research questions (RQs), measures/indicators, and data sources to be utilized for each evaluation goal in turn, followed by a description of data collection and analysis activities.

Evaluation Goal 1 (Formative Evaluation): Describe the Design and Development of Learning by Making Project Model

RQ1: Is the design and development of the *Learning by Making* STEM curriculum and related professional development progressing as planned? **RQ2**: To what extent is the *Learning by Making* STEM curriculum being designed in alignment with the new NGSS Design Practice standards and Common Core State Standards in mathematics? **RQ3**: Is the *Learning by Making* professional development being developed in alignment with the third iteration of the Standards for Professional Learning (i.e., learning communities, leadership, resources, data, learning designs, implementation, and outcomes)?

To address RQ1 – RQ3, the evaluation process will be interweaved with the design and development process of *Learning by Making* project model, and rely on a highly iterative sequence of design, development, and pilot testing. We will use the following approaches to describe the program design and development: 1) Development and Progress Documentation (e.g. planning and progress meeting agenda and minutes, deliverables of prescribed curriculum and professional development components, documentation of quality assurance testing on sensor-based experiments) throughout the project years; 2) Pilot Testing of the first-year and second-year courses in year 2 and year 3 respectively.

Development and Progress Documentation will be used to inform the progress of the curriculum design, best practices for the implementation of the computational thinking laboratory-based STEM curriculum, and the challenges of developing *Learning by Making* STEM curriculum and professional development to support students' performance on mathematics and science. *Pilot testing* will be used to identify strengths and weaknesses with content, pedagogy, clarity, logistics, and usability and as early indicators of construct validity (i.e., whether the curriculum is eliciting the intended mathematics and science knowledge, skills, computational thinking, and scientific and engineering design practices). Data will be systematically collected from individual teachers, as well as small groups of teachers, as the evaluation team facilitates *Learning by Making* STEM curriculum and professional development design by pilot testing the two-year integrated STEM curriculum that focuses on computational thinking and scientific and engineering design practices. Videotapes, field notes, teacher interviews, and focus groups will be among the sources of data to be collected and analyzed by the evaluation team to inform the curriculum development efforts of the design team. Findings will also be used to modify/refine the content and delivery of the professional development modules with an eye toward enhancing teacher engagement and facilitating classroom application.

Evaluation Goal 2 (Formative Evaluation): Evaluate the Implementation of Learning by Making project Model

RQ4: What are the key components defining the *Learning by Making* project model as implemented in six high schools in Mendocino County, California (e.g. computational thinking laboratory-based STEM curriculum, week-long professional development, follow-up in-service professional development, student academic support)? What components of the *Learning by Making* project model are most useful to teachers in supporting their science teaching practice? Their mathematics teaching practice? **RQ5**: What is the overall level of fidelity of implementation, what aspects of the *Learning by Making* professional development model are critical to effective teaching and learning, and what factors contribute to the ability of teachers to implement the *Learning by Making* STEM curriculum with high fidelity?

To address RQ4 and RQ5, WestEd will develop an evaluation framework based on the *Learning by*

Making project logic model. We will review the following data to describe the program implementation: 1) Implementation document review (e.g., deliverables of prescribed program components, program materials, project meeting agendas and minutes, professional development agenda); 2) Degree of participation/dosage and engagement data (e.g., PD attendance, teacher monthly logs on curriculum usage); 3) Professional development observations and interviews to detect participant experiences with the professional development and their satisfactions with the training; 4) Teacher survey to detect understanding of the *Learning by Making* model and process and practices satisfaction with the model implementation; and 5) Case studies on a random sample of participating teachers that include analysis of classroom video and teacher interviews to evaluate the quality of program implementation. In addition, we will conduct program partner interviews at the end of each semester. These partners include: district leaders, school leaders, and project implementation staff. Bi-yearly review topics will include: general impressions of the program, barriers/challenges in implementation, perceived educator and student progress/engagement, areas for improvement, and best practices utilized.

Quantitative data, such as dosage data and close-ended questions from surveys, will be analyzed descriptively. Grounded theory, or constant comparative analysis, as described by Strauss and Corbin (1998) will be utilized to analyze qualitative data collected from open-ended questions, interviews, and classroom video. In an initial data reduction approach, respondents' comments will be reviewed and assigned categories of meaning (open coding). Then, these categories along with quantitative data results will be reviewed for causal linkages and non-causal relationships related to the central phenomenon (axial coding), which will allow the researcher to develop a "story" that connects the categories (selective coding) and finally posit hypotheses or theoretical propositions. These qualitative and quantitative analyses will inform us around whether the program provided all proposed services to participants and the degree to which the program is being implemented with fidelity.

The evaluation will employ a continuous improvement-based approach whereby WestEd will analyze the program's progress towards its goals, providing timely feedback, describing implementation of the *Learning by Making* project model, and allowing project leaders to make adjustments to

the *Learning by Making* project model for further improvement. This approach will help structure the *Learning by Making* project by providing data that better enables program development, improves service delivery, and/or enhances program outcomes.

Evaluation Goal 3 (Summative Evaluation): Assess Program Impact

RQ6: What is the impact of the process on teachers' competence in delivering computational thinking laboratory-based STEM curriculum? **RQ7**: What is the impact of the *Learning by Making* project model on student mathematics performance? Student science performance? **RQ8**: Do some subpopulations of students benefit more from the *Learning by Making* project than others (e.g., below grade-level students, English learners)?

A quasi-experimental design will be applied to address RQ6 – RQ8. Teachers and their students from six comparable schools in another county with similar student population (Lake) will be matched to form a comparison group. Quasi-experiments do not use random assignment of participants to intervention and control groups, but instead depend on applying appropriate measurement and statistical controls to nonequivalent groups in order to determine intervention impacts on the outcomes of interest. Well-designed quasi-experimental studies allow strong inferences to be drawn concerning the effectiveness of programs (Cook, Shadish, &Wong, 2008). Statistical significance tests will be applied to analyze whether treatment and comparison groups have significant differences on their demographic and baseline measures. Variables will be used in the significance tests include teaching credential, teachers' highest degree, and their baseline knowledge and understanding of computational thinking and scientific and engineering design practices. WestEd will also analyze the equivalence of the student population in terms of the percentage English Language Learners, ethnicity, free/reduced-price lunch, and baseline student achievement in science and mathematics. Teacher's knowledge, understanding and implementation of computational thinking and scientific and engineering design practices and teaching strategies will be measured by scoring video of classroom instruction and analyzing responses to teacher surveys. Student academic performance will be measured by the Smarter Balanced Assessments aligned to the CCSS in mathematics, and CST in science.

WestEd will apply multi-level models to analyze the program impact on student outcomes. The primary hypothesis-testing analyses will involve fitting conditional mixed-effects ANCOVA models (HLM or multilevel models), with an additional term to account for the nesting of students within teachers (Raudenbush & Bryk, 2002; Murray, 1998). Potential fixed effects include treatment group status, student-level baseline (pretest) measures of mathematics proficiency and/or ELA/literacy, and other observed covariates such as free/reduced-price lunch status, ELL status, and gender as well as teacher-level covariates, such as teaching credential, highest degree, and knowledge and understanding of computational thinking and scientific and engineering design practices. The purpose of including statistical controls is to minimize the error associated with group assignment and to increase the precision of the estimates. With a target baseline sample size of 20 teachers (25 students per teacher) in the treatment group and 20 teachers (25 students per teacher) in the comparison group, we estimate that the study will achieve the minimum detectable effect size of 0.28[i].

Evaluation Goal 4: Discuss Program Success, Areas for Improvement and Scalability:

RQ9: In what ways is the program successful? Not successful? Why? **RQ10**: How replicable and scalable is the *Learning by Making* project model? What factors affect replicability and scalability? To address RQ9 and RQ10, WestEd will integrate data collected for the implementation evaluation of *Learning by Making* project model to identify aspects of success and areas for improvement. These analyses will allow for WestEd to generate recommendations. In addition, WestEd will conduct key informant interviews, focusing on the success of the program, best practices, ways of implementing *Learning by Making* project model, components and procedures to ensure the implementation of *Learning by Making* project model, efficacy of bundles of services, resource leveraging/partnering, general impression of the collaboration, value-added for the partners, and challenges in collaboration, areas for improvement, and evidence of scalability. Qualitative analyses will be conducted and grounded theory methodology will be applied, as described earlier.

[i]*The minimum detectable effect size estimates assume: 1) Type-1 (α) error rates of 0.05 (two-tailed); 2) statistical power levels of 0.80; 3) classroom intra-class correlation (ICC) for student performance average 0.15; 4) teacher-level and student-level baseline explanatory variables explain 60% of the between-teacher and within-teacher variance in student outcomes, respectively (Bloom, Richburg-Hayes, & Black, 2006; Schochet, 2005).*