Student-Driven STEM and Computer Science Curriculum for Rural Students

Table of Contents

A. Significance

Sonoma State University (SSU), an institution of higher education with non-profit status, in partnership with six rural and high-need Local Education Agencies (LEAs) will build on previous work to develop STEM-based computer science pathways and work-based learning experiences for rural and high-need students in northern California. We will also develop, implement and obtain moderate evidence to support our pilot-tested innovative STEM curriculum[1] that has been shown to improve student achievement among high-need, rural students. As the first integrated STEM curriculum developed specifically to address challenges faced by rural schools, *Learning by Making* has the potential to transform rural STEM education nation-wide [1]

A.1. National Significance of the Proposed *Learning by Making* project

Learning by Making (*LbyM*) is an innovation that will increase our nation's economic competitiveness by creating, improving and expanding STEM learning and engagement in rural America. Partnerships with LEAs and non-profit agencies enable *LbyM* to address critical student relevancy, skills, and college and career readiness challenges in STEM and computer science. *LbyM* implements strategies to increase the number and quality of STEM-educated workers and provides innovative solutions to the challenges faced by high-need students in rural regions. Of particular value for high-need students, the curriculum and teacher development components of *LbyM* will be tested for replicability in both rural and non-rural high-need settings.

A.1.1 Increase number and quality of STEM workers.

Development of the STEM workforce is essential to innovation and competitiveness (National Science Board, 2015) and early math and science proficiency is foundational to navigating the STEM career pathway. However, the Program for International Student Assessment (PISA) found that US students ranked 19th in

[1] The *Learning by Making* pilot curriculum *(LbyM-p)* was developed through a 2013 Development grant from the Investing in Innovation program.

science and 30th in math among 35 industrially developed countries (OECD, 2016). In 2017, the National Assessment of Education Progress reported that 34% of 8th graders and 25% of 12th graders achieved a rating of proficient or above in math; similarly in science, 34% of 8th graders and only 22% of 12th graders were proficient or advanced (NAEP, 2015 and 2017). The *LbyM* curriculum targets proficiency levels of students in math and science, simultaneously integrating skill development in engineering, technology, and computer science. While *LbyM* qualifies as a college-prep core science course, it will develop STEM and computer science competencies that can align with Career and Technical Education (CTE) pathways, thus impacting the college and career readiness of students who will pursue post-secondary education. Connections forged between *LbyM* and CTE organizations will strengthen the quality of STEM and computer science education and create a delivery system of competencies and skills for a broader range of students (CTE Is Your STEM Strategy, 2013). Partnerships are a key strategy for quality CTE programs in rural areas (Kirby, 2017). Moreover, *LbyM* could have important value for the national *New Skills for Youth* initiative to support transformation of career preparation systems (https://careertech.org/new-skills-youth).

A.1.2 Innovative Solutions to Rural Education Challenges In the U.S., 53% of all school districts are rural, and a third of all students attend rural schools (Johnson, Showalter, Klein & Lester, 2014). Nationwide, up to 25% of rural students live in poverty, a statistic reflected in our target rural areas: Lake (25%) and Mendocino Counties (21%) of northern California (U.S. Census Bureau, 2017). Lake County also ranks last among California counties on the Human Development Index (HDI), which includes indicators on life expectancy, median earnings, and education (Portrait of California, 2014). Poverty and geographical remoteness are only two of the challenges facing rural education. *LbyM* will implement solutions to “rural brain drain” (Fishman, 2015) through its emphasis on CTE partnerships and increasing technology competencies of teachers. In this proposal, the indicator we use to identify "high-need" students is "socioeconomically disadvantaged" (SED), as adopted by the California State Board of Education. SED students meet either one of two criteria: (1) Neither of the student's parents has received a high school diploma; (2) The student is eligible for the free or reduced-price lunch program. **The percentage of high-need students at *LbyM* target schools ranges from 61% to 88%** (see Section B.1).

Students engaged in *LbyM* will develop skills in computer science, electronics and problem-solving that are critical to improving the nation's competitiveness. More specifically, these skills are critical for success of the new rural CTE and regional economic development strategies illustrated in the 12-state *Pathways to Poverty* initiative (Hoffman et al., 2016). The *LbyM* innovation has major significance for closing the gap in computer science learning for rural and small town school districts across America (Google Inc. and Gallup Inc., 2017). Innovative field experiences for rural students will build on the acquired STEM skills to address solutions to community problems. These work-based learning experiences will take advantage of the natural resources of the surrounding community, helping students to gain a sense of place within this community. In turn, the local communities can benefit from the energy and creative solutions invented by students (Khattri, Riley and Kane, 1997). Teachers participating in *LbyM* will gain competencies that will ensure sustainability of the curriculum delivery and help to prepare students to engage in these work-based learning experiences. To address the geographic challenges of training teachers in rural schools, *LbyM* will utilize distance learning technology and remote interfaces, building a Networked Improvement Community.

A.2. *LbyM* develops promising new strategies that build on existing strategies

The independent evaluation of our previous USED i3 Development grant revealed in a quasi-experimental design study that the piloted curriculum improved student knowledge in science and mathematics content. Additional evidence of effectiveness for a similar approach is provided by the TEEMS project (Zucker et al., 2008), which implemented a sensor-based curriculum for grades 3-6, and showed that these types of scientific experiments will improve student math and science learning. Building on the results of the *LbyM* pilot test in eight rural classrooms, the proposed project aims to further develop the innovation through an iterative process of continuous improvement to improve learning outcomes for a larger population of rural high-need students. Intended developments include:

a) Creation of partnerships with county-based Career Technical Education programs to define STEM pathways and expand access to work-based field experiences in the community that build on the computer coding, problem solving and electronics skills acquired through *LbyM*.

b) Restructured professional development that increases teachers' self-efficacy to minimize the eventual need for technical assistance, and transitions from face-to-face sessions to internet-based delivery methods as the program reaches additional rural regions. Teachers will also be trained to support students who are participating in work-based learning experiences appropriate to rural communities.

c) Development of additional experiments, improved assessments and feedback, and improved infrastructure to provide support for personalized learning and work-based learning experiences relevant to rural communities.

A.2.1. Partnerships with CTE Programs and Work-based Learning Experiences for Students We will create partnerships between our participating school districts, SSU and local community partners including CTE organizations to expand access to student field experiences that improve college and career awareness. Building on our previous i3 work, we will expand our work with individual school districts to create a STEM pathways curriculum that integrates computer science competencies within CTE programs. Students who follow these STEM pathways will qualify for internships that use the acquired STEM and computer science skills to work locally on rural community issues (e.g., use of sensors to measure quantities of interest to local agriculture and nature preserves). Case studies indicate that school-to-work programs addressing local issues are successful and well supported by a wide variety of stakeholders in rural communities (e.g., Khattri, Riley and Kane, 1997). Moreover, our strategy advances CTE's national need to provide learners in rural areas with access to more diverse pathways (CTE on the Frontier, 2017).

A.2.2 Professional Development in *LbyM*. The professional development effort will be designed to increase teacher self-efficacy as we transition from a face-to-face model to one that is internet-mediated, allowing us to reach additional widely-separated rural communities. The sustained, multiple-year professional development model that we will use is based on the successful work reported by the ASSET program (Nedley, 2017). The ASSET model includes "teacher to teacher" training that transitions the participants from classroom teacher to teacher-leader to professional development facilitator or resource teacher. The positive ASSET results for elementary school science programs provide evidence that improving teacher competence improves student achievement and attainment. We will extend this approach to rural high-need high schools as well as a few non-rural high-need schools to ensure scalability. Teachers will also receive CTE-oriented training from CTE Foundation Sonoma industry partners in order to ensure that they can support the STEM-based computer science pathways that we will develop in partnership with each LEA.

A.2.3. Develop, implement and scale the *LbyM* curriculum. A third key component is the development of additional infrastructure, experiments and assessments to support personalized learning that allows students agency over what they learn, and "meets them where they are" in terms of ability. Ensuring the relevancy of the student-driven investigations, together with customized feedback should increase student engagement and persistence, resulting in improved student learning outcomes. Research has shown (Halpern et al., 2007) that providing feedback that focuses on strategies used during learning, and providing multiple opportunities for students to receive feedback is especially successful at improving the performance of female students, who are traditionally under-represented in STEM and computer science. We will also follow the IES recommendations (IES, 2003) to increase the richness of the scientific narratives that motivate the investigations to ensure that the experiments are engaging for all students. In addition, we will test several different improvements to our hardware infrastructure to increase scalability, increase the number of available experiments to cover a wider range of personal interests and scientific content areas, and will further emphasize computational solutions to experiment modifications.

A.3. *LbyM* Demonstrates a Rationale, Addressing Absolute Priority 1

During the 2016-17 academic year, WestEd conducted a rigorous, high-quality study of the i3-funded *LbyM* pilot (*LbyM-p)* STEM curriculum: the focus of the study was on the impact of the curriculum in increasing rural high school students' mathematics and science outcomes and enhancing their teachers' instructional practices and technological competency. The results of this study provide the rationale that our planned intervention is likely to improve student outcomes.

A.3.1. *LbyM-p* quasi-experimental design evaluation and research findings. The final analytic sample included 98 students in six *LbyM-p* STEM classes from five high-need rural schools and 52 students in six comparison classes from three out of the five schools. The treatment group engaged in *LbyM-p* STEM curriculum which comprised six units and focused on the three-dimensional learning strategies of the Next Generation Science Standards (NGSS) programming in the Logo computer language, and problem solving and troubleshooting. The comparison group received the "business-as-usual" instruction that they would normally receive if the study were not taking place. The results indicate that the *LbyM-p* curriculum was positively associated with gains in students' science and math knowledge, as measured by assessment items selected from the Certica Assessment Item Bank. Students who engaged in the *LbyM-p* curriculum outscored their comparison group peers on the science assessment by 7 percentage points, a statistically significant result, and outscored their peers on the math assessment by 4 percentage points.

A.3.2. *LbyM-p* Evaluation through Focus Groups, Surveys and Interviews. Findings from teacher surveys and interviews suggest that the *LbyM-p* curriculum helped teachers integrate the NGSS into classroom instruction, and increased their comfort with project-based learning. The *LbyM-p* curriculum supported teachers in applying student-centered instructional practices. Teachers also reported spending more instructional time supporting students to collect, organize, display, and present data. Findings from observations, teacher focus groups, and interviews suggest that the *LbyM-p* curriculum has helped low-achieving students improve math understanding. Students were highly engaged with the *LbyM-p* curriculum and demonstrated increased confidence and problem solving stamina. Teachers reported that some individual students who typically struggle to participate in class exhibited higher levels of participation in *LbyM-p* and even demonstrated leadership. The *LbyM-p* curriculum was accessible to students with different abilities. Teachers reported that some students with special needs, while still requiring extra attention, remained engaged in curriculum and were even quicker to complete certain activities.

A.3.3 Conclusions for *LbyM* from the Rationale. Driven by the impact study findings that students engaged in *LbyM-p* benefit academically, SSU and WestEd have continued to monitor indicators of academic growth and engagement for *LbyM-p* students during the 2017-18 school year. This year's students have expressed increased enthusiasm for this innovative curriculum (See Table 1 for students' quotes). Not only are they excited by the student-driven nature of *LbyM-p*, but they also feel that *LbyM-p* supports them in preparing for college and career and in building 21st century skills (Partnership for 21st Century Learning, 2015). By refining and scaling *LbyM-p*, and adding direct connections to work-based learning experiences through CTE partnerships, we will be able to expand the reach of this innovative STEM curriculum, and make high quality, standards-aligned STEM learning accessible to more students and more relevant to their lives.

Table 1. Selected Student Comments on *LbyM-p*

"We kind of get some more of the skills other people don't get in high school. Like, how many other classes are there where you get to like, do coding and do wiring and stuff like that? So, I feel like we just get a lot more skills that other people don't have. And I think that really stands out."
"I like how if there is a problem, it's not like on the paper. You have to solve it, you have to go deeper to think about what's wrong."
"This coding stuff is gonna make a lot of stuff obsolete, and so college and other stuff will be looking for students with experience with technology."

A.4. *LbyM* represents an exceptional approach to Priorities

The development work proposed here epitomizes **Absolute Priority 3** by offering "field-initiated experiences that promote STEM with an emphasis on computer science." In particular, *LbyM* focuses on student-initiated scientific investigations that require computational thinking, and coding in the Logo programming language to solve interdisciplinary problems. Students write Logo words to read sensors, obtaining data in relevant, standards-aligned investigations in agriculture, biology, chemistry and physics. They also learn to code in Logo, using fundamental computer science concepts such as variables, conditionals, arrays, strings, control structures, algorithms, and packetized data structures.

Developed at MIT in the 1970s, Logo has been extensively used over the past four decades by thousands of teachers worldwide, primarily in grades K-8 (Papert, 1999) to foster computational thinking. As defined by Wing (2006), "Computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science." *LbyM* uses technology to engage students in computational thinking, provides benefits in the process of integrating science and mathematics content (see review by Pang and Good, 2000), and employs Logo programming activities to solve problems in all fields of STEM (Einhorn, 2011).

A.4.1 *LbyM* Approach to Absolute Priority 3 in Rural High-Need High Schools. Since most rural teachers do not have explicit training in computer science or electronics, and many rural schools cannot afford teachers who specialize in these fields, it is important that the programming language used in *LbyM* be as intuitive as possible (Richard October 2017). 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. Students can use simple commands to control switches or to read data from sensors, and then combine the simple commands into other commands to carry out more complex procedures, and to analyze the resulting experimental data.

Integrated STEM curricula such as *LbyM* help isolated rural schools address a common problem – the lack of sufficient credentialed personnel to cover the wide range of science and mathematics classes offered by larger high schools (e.g., Boucke, 2004 and references within). In many states (including California), different credentials are required to teach agriculture, biology, chemistry, mathematics and physics. Integrating the teaching of these subjects within a generalized STEM framework and integrated CTE STEM and computer science pathway provides a solution to the credentialing problem and teacher access challenge of rural schools.

A.4.2. *LbyM* Approach to Invitational Priority 1 (Personalized Learning). Another common aspect of rural classrooms is a mixture of student abilities within a single class as schools are often too small to offer separate AP courses (Goodpaster, Adedokun, and Weaver, 2012). By offering a series of challenges as part of each unit, as well as Going Further exercises, *LbyM* supports a wide range of abilities within a single classroom. “Starter experiments” serve as an introduction to a given observable phenomenon, and personalized learning occurs as the students try to develop their own models for the phenomenon: they pose questions, determine how to modify Logo code and/or the experimental setup to pursue their own investigations, analyze and interpret the resulting data, and present their results to peers and instructors. The *LbyM* design practices also personalize the development and use of models and the construction of explanations and arguments from experimental evidence, as each experiment is suited to individual abilities and interests.

B. Project Design and Management Plan

B.1 Goals, Objectives and Outcomes

We define two phases of the *LbyM* project: Phase 1 (10/1/2018 – 8/1/2020) will include at least 450 students, including students at three of the rural Mendocino County high schools who participated in the *LbyM-p* project, plus three new rural and high-need high schools in Sonoma and Lake Counties. Phase 2 (8/1/2020 – 9/30/2023) will add at least 350 students in additional rural and high-need high schools in northern California. The schools targeted for Phase 1 are summarized in Table 2 (see Letters of Commitment in Appendix C).

Table 2. Phase 1 Partner Schools

School District	2016-17 % SED*	Special Characteristics
Point Arena +	65%	Mendocino Co., Small Rural School Achievement Program
Round Valley +	86%	Mendocino Co., SRSA, 58% American Indian
Ukiah +	79%	Mendocino Co., Rural and Low Income School Program
Healdsburg	61%	Sonoma Co, 25% English Learner (EL)
Roseland Univ Prep	88%	Sonoma Co, Public Charter District, 53% EL
Kelseyville	79%	Lake Co., Small Rural School Achievement Program

Note: + LbyM-p participants
*Source: Equity Report, CA Department of Education

The work proposed here will improve rural and high-need student learning by focusing on three parallel development workflows and corresponding goals and objectives (Table 3):

a) Partnerships with community organizations to develop STEM and computer science pathways and provide expanded access to college and career awareness activities, and work-based learning experiences

b) Restructured professional development that will increase the scalability by using internet based delivery methods

c) Additional development of the *LbyM* curriculum and infrastructure to increase scalability and obtain moderate evidence of effectiveness in improving student learning outcomes by performing randomized control studies with a larger student sample

Table 3: Learning by Making Goals and Objectives

Goal 1: Expand local partnerships to develop STEM and computer science pathways that provide access to work-based learning experiences.
1.1 By the end of Phase 1, 50% of participating school districts will develop STEM and computer science pathways for CTE **Measure/Timeline**: District pathway documents
1.2 By the end of Phase 2, at least 75% of participating school districts will develop STEM and computer science pathways for CTE **Measure/Timeline**: District pathway documents
1.3 In Years 1-5, 80% of students will be able to identify the courses needed to prepare for college readiness in a STEM major. **Measure/Timeline**: Annual survey, administered in May.
1.4 In Years 1-5, 80% of students will participate in at least one career exploration activity, such as classroom presentations by mentors, work-based learning experiences or job shadowing. **Measure/Timeline**: Attendance logs, administered annually
Goal 2: Implement scalable professional development program to improve instructor competencies to deliver innovative STEM and computer science curriculum, using the Plan/Do/Study/Act (PDSA) framework for improving practices.
2.1 Beginning in Year 1, the *LbyM* Leadership Team will convene monthly to conduct needs assessments of targeted schools and teachers and to plan the subsequent professional development sessions. **Measure/Timeline**: Meeting minutes reported monthly.
2.2 During Phase 1 (years 1 and 2), at least 90% of 12 targeted teachers will receive 80 hours of annual professional development from the *LbyM* Development Team. The training sessions will include 40 hours of face-to-face training each year, along with 40 hours of additional training delivered either via face-to-face or via Internet conferencing. **Measure/Timeline:** Attendance logs reported quarterly and annual teacher survey.
2.3 For each academic year during Phase 1, at least 40 hours of PD will be formatively evaluated by WestEd and the results will be provided to the *LbyM* Development Team. **Measure/Timeline:** Evaluation reports
2.4 During Phase 2 (years 3 -5), at least 80% of 24 targeted teachers will receive 80 hours of annual professional development from the *LbyM* Development Team. The training sessions will include 40 hours of face-to-face training along with up to 40 additional hours of training delivered via Internet conferencing. **Measure/Timeline**: Attendance logs reported quarterly and annual teacher survey.
2.5 For each academic year during Phase 2, at least 48 hours of PD (including at least one internet-mediated session) will be formatively evaluated by WestEd and the results will be provided to the *LbyM* Development Team. **Measure/Timeline:** Evaluation reports

Goal 3: Develop and implement additional experiments to ensure scalability and obtain moderate evidence of effectiveness.
Goal 3.1: Use PDSA framework to develop additional experiments
3.1.1 In Year 1, the *LbyM* Development Team will plan, implement and study at least five additional experiments in a variety of scientific subjects. **Measure/Timeline:** Experiment lesson plans, student and teacher guides, and teacher slide sets, reviewed annually
3.1.2 In Year 2, each new experiment will be tested in at least two classrooms. **Measure/Timeline:** Classroom observation studies, reported annually.
3.1.3 In Year 3, the *LbyM* Development Team will study the results of all classroom experiment implementations in Year 2 and revise experimental resources to ensure continuous improvement. **Measure/Timeline:** Experiment lesson plans, student and teacher guides, and teacher slide sets for each experiment, reviewed annually.
3.1.4 In Year 3, the *LbyM* Development Team will plan, implement and study at least five additional experiments in a variety of scientific subjects. **Measure/Timeline:** Experiment lesson plans, student and teacher guides, and teacher slide sets, reviewed annually.
3.1.5 In Year 4, each new experiment will be tested in at least two classrooms. **Measure/Timeline:** Classroom observation studies, reported annually.
3.1.6 In Year 4, the *LbyM* Development Team will study the results of all classroom implementations and revise experimental resources to ensure continuous improvement. **Measure/Timeline:** Experiment lesson plans, student and teacher guides, and teacher slide sets for each experiment, reviewed annually.
Goal 3.2 Increase sample size of treatment group to obtain moderate evidence of effectiveness for improved outcomes in in math and science learning.
3.2.1 In Year 1-2 (Phase 1), *LbyM* curriculum will be delivered to at least 450 students in 6 schools. **Measure/Timeline:** Surveys of schools and class enrollments, reported annually.
3.2.2 In Years 3-5 (Phase 2), *LbyM* curriculum will be delivered to at least 800 students in 12 schools. **Measure/Timeline:** Surveys of schools and class enrollments, reported annually.
3.2.3 By end of years 2-5, 80% of students will improve their math performance as measured by math items selected from Certica item bank. **Measure/Timeline**: Certica math assessment items , administered annually in September and May, reported in December.
3.2.4 By end of years 2-5, 80% of students will improve their science performance as measured by items selected from Certica item bank. **Measure/Timeline**: Certica science assessment items, administered annually in September and May, reported in December.

B.2 The Management Plan is Adequate to Achieve the Objectives

B.2.1 Personnel Responsibilities.

SSU, one of 23 campuses in the California State University system, has committed facilities, equipment, supplies, and other assets to support the implementation and success of *LbyM*. The *LbyM* project will be hosted in the School of Science & Technology in the Division of Academic Affairs at SSU. Professor Lynn Cominsky will have full authority to commit and expend grant funds on behalf of the program in compliance with Federal and University policies. An overview of project staff is provided here, with resumes and outline of required qualifications in Appendix B.

Table 4. *LbyM* Project Staff Responsibilities

Leadership Team		
Dr. Lynn Cominsky	PI, Project Director Professor, Physics & Astronomy	Provide project leadership, responsible for fiscal and USED requirements, manage dissemination activities, oversee PDSA processes
Dr. Laura Peticolas	Co-PI, Curriculum Director, Internal Team Manager	Direct curriculum development and teacher institute planning and implementation; ensure adherence to timelines, budgets, milestones
Susan Wandling	Co-PI, External Network Manager	Manage partnerships and communications with districts, County Offices of Education, *LbyM* Advisory Council, CTE organizations, WestEd evaluators, prepare and submit APRs
Development Team Teacher PD (TPD), Curriculum (C), Infrastructure (I)		
Kevin Considine	IT Specialist	(I) Maintain servers, project website, support Logo experts, test infrastructure revisions and remote help system, oversee video production
Dr. Chris Halle	Nature!Tech Lead, Center for Environmental Inquiry	(C) Design experiments, coordinate student internships at Galbreath Wildlands Preserve
Dr. Edward Lyon	Professor, Secondary science education	(TPD) Observe and provide feedback on teacher PDs, advise on lesson design
TBD Curriculum Specialist	STEM and computer science Education Specialist (MA required)	(C, TPD) Develop science experiments, write lesson plans and teacher guides, conduct teacher workshops
Aurore Simonnet	Graphic Artist	(C, TPD) Layout, illustration for educational resources and guides, teacher slide sets
Juanita Tenorio	Administrative specialist	(C, TPD) Coordinate and deliver support activities for PD sessions and production/delivery of classroom materials, organize PD logistics
External Evaluation Team (WestEd)		
Dr. Linlin Li	Lead Evaluators	Leadership of major evaluation activities to ensure evaluation quality
Dr. Ashley Iveland		Conduct usability tests of experiments and remote support system
Dr. Betsy McCarthy		Observe/evaluate *LbyM* implementation
Rachel Tripathy	Project Manager	Coordinate evaluation activities

B.2.2 Timeline and Milestones. The timeline is summarized in Figure 2 on page 25. All milestone dates below assume that new funding is in place by October 1, 2018. The Plan/Do/Study/Act (PDSA) framework for continuous improvement in discipline practices is included in Figure 2 for most activities, with more details on this framework described in Section B.3. During AY 2018/19, three Mendocino high schools will continue to teach the *LbyM-p* curriculum using existing infrastructure and experiments, and will each test up to two new experiments. The entire cohort of Phase 1 schools (see Table 2) will start teaching *LbyM* in AY 2019/20. Phase 2 starts 8/1/2020, and lasts through the end of the grant. Phase 2 will include new schools that will be intentionally selected to meet the following criteria: 1) rural, 2) high-need (see Section A.1.2), 3) ability to provide requested match, and 4) readiness to implement *LbyM* curriculum, participate in the NIC, and support the PDSA process. All Phase 2 schools will begin teaching *LbyM* by AY 2020/2021.

Table 5. Project Milestones

Expanded Partnerships with CTE Organizations	
Videotape guest career speaker, broadcast in *LbyM* classrooms	Each semester
Provide logins to students for access to industry partners and WBL networks	Spring 2019, and then annually
Provide CTE training to teachers	Spring 2019, coordinated with field trips for work-based learning experiences
Continue STEM pathways development with CTE organizations and districts	Ongoing, begin January 2019
Field trips coordinated by Center for Environmental Inquiry and/or CTE Sonoma for work-based learning experiences	Spring 2019, and then annually
Professional Development	
5-day teacher summer institutes at SSU for Phase 1 teachers	June 2019, and then annually.
Five one-day teacher workshops	Five Saturdays throughout each academic year. Year one F2F, transitioning in years 2-5 to complete internet delivery

Curriculum & Infrastructure	
Develop 10 new experiments	5 in Phase 1 (Years 1-2) 5 in Phase 2 (Years 3-4)
Test experiments	Ensure each new experiment tested in at least 2 classrooms, Year 2 and 4
Plan and test new interface that uses (cheaper) commercially available microprocessor, capable of running *Logo*	Spring 2019
Distribute tested interface to Phase 1 schools and study usability	Academic Year 2019/20
Adjust interface as needed, study	AY 2020/21 (largest sample of students)
Deploy remote help system	AY 2019/20
Study remote help system	Spring 2020 (as students begin personalized investigations)
Partnership Management	
MOUs approved with County Offices of Education: Lake, Mendocino and Sonoma	December 2018 and updated annually
Match contributions confirmed in MOUs with Phase 1 partner school districts	April 2019 and updated annually
CTE organizations approve MOUs to partner on access to work-based learning opportunities	April 2019 and updated annually
Convene community members and business professionals for Advisory Group Meetings	Start June 2019, meet twice per year June and Dec.

B.3 Performance feedback and continuous improvement are integral to the design

In all three workflows described above, we will utilize the Plan/Do/Study/Act (PDSA) framework for continuous improvement in discipline practices (Grunow, 2015). Within this framework, the *LbyM* Leadership Team will consider each specific problem that we are trying to solve, and develop an initial strategy to address the problem while ensuring that we collect sufficient data to determine the effectiveness of the strategy as implemented. In the *Plan* phase, we will describe the strategy and make predictions as to what we expect will happen. We will then implement the strategy (*Do*) while documenting what actually happened via formative evaluation by the WestEd Evaluation team *(Study)*. The *LbyM* Leadership and WestEd Evaluation teams will then review the results of applying the strategy to the problem, and determine what, if any, further modifications are needed to address the problem (*Act*). This phase of the management framework is also a time for sharing results of research and evaluation findings via conferences, workshops, or journal articles. If the results of this PDSA cycle are not in accordance with our initial predictions, we will repeat the cycle to ensure continuous improvement.

B.3.1 Expanding Access to STEM pathways and Work-based Learning Experiences.

Traditional school-to-work programs for high school students are structured so that ninth and tenth grade students develop college and career awareness via activities such as interactions with guest speakers and field trips to companies. These activities typically expand to college and career explorations in smaller groups including job shadowing and individual mentoring for junior students, followed by college and career preparation activities such as dedicated internships during the transition to the senior year (San Diego College and Career Readiness Consortium online).

We will expand college and career awareness for ninth grade students by creating videos of guest speakers from a wide variety of careers that use the STEM skills taught through *LbyM*. Field trips to technology-oriented industries pose another problem for rural students due to the lack of these industries in the local areas. We will therefore seek out opportunities for *LbyM*-trained students in Mendocino County to use their skills in local agritech and nature preserve settings. Through SSU's Center for Environmental Inquiry, *LbyM* students will have the opportunity to make meaningful measurements at SSU's Galbreath Wildlands Preserve using audio sensors (for bird tracking), weather sensors, soil moisture sensors, energy sensors (for inclusion in facility planning), tree health sensors, and stream flow sensors. For students in Sonoma County, CTE Foundation Sonoma County will design activities to align with the Career Awareness and Career Exploration phases of the WBL Continuum, and built around an industry-led project that reflects real-world work challenges. (See letters of commitment for more details.)

During *LbyM-p*, Prof. Cominsky served on the advisory board for the CTE program at Anderson Valley High School, and helped develop a STEM pathway for this district. She also gave a series of career-oriented lectures to eight classes of Ukiah High School students. Other SSU personnel including Dr. Laura Peticolas also provided career-oriented lectures at Ukiah High School. We will expand on these preliminary efforts by partnering with CTE Sonoma and other County CTE organizations to provide access to their countywide work-based learning systems.

B.3.2 Expanding Professional Development. The face-to-face approach to PD used in *LbyM-p* will not easily scale to include the additional rural communities in adjacent counties that are proposed here. The long distances between rural communities makes driving to workshops impractical as the network scales (Harmon, 2007), however technology can be used successfully to bridge the distances that separate teachers in isolated rural communities (Monk, 2007). We will therefore transition our planned professional development to a low bandwidth online system to grow our rural Networked Improvement Community (NIC), as we add additional districts that are geographically remote. We will also improve our implementation and increase scalability by developing a low-bandwidth method of providing technical support to teachers in classrooms, eliminating much of the staff time previously spent on in-person site visits to solve technical problems, and providing more timely solutions. Additional problems are presented by the frequent turnover of rural faculty, especially those in specialized disciplines such as STEM (Lemke, 1994; Harmon, 2001). Ongoing turnover necessitated restarting the training program for newly added instructors, to ensure that the basic computer coding and electronics skills could be quickly acquired, and that the experimental design practices could be developed. Our initial strategy to address this problem will be to create a series of training videos during Phase 1 that will be available both to newly added instructors as well as to instructors joining the program in Phase 2.

We also aim to create a Networked Improvement Community (NIC), where *LbyM* instructors will "endorse shared, precise, and measureable targets" (Gryk, Gomez and Brunow, 2011), agreeing to implement what has been learned, and setting new, increasingly ambitious targets once the initial targets have been achieved. Part of each training workshop will be dedicated to reviewing the status of the targets previously established and discussing progress and future implementation plans.

B.3.3 Curriculum Scalability. The *LbyM-p* curriculum was implemented as two years of integrated STEM (Biology/Environmental and Chemistry/Physics) within a structure that emphasizes computer coding, computational thinking and electronics skills development. Both courses were approved as college preparatory laboratory science (Area "D") by the University of California high school articulation system. Through ongoing formative evaluation conducted by WestEd, we have determined that offering a one-year curriculum with a greater choice of scientific experiments would lead to greater **teacher competency** and **personalized learning**, thus increasing educational effectiveness. It will also enable greater scalability to rural schools, as teachers will be able to choose experiments that relate to their specific disciplines. We therefore propose to develop and/or complete at least ten new phenomenon-based experiments that students can investigate using simple modifications to our "Basic Board" platform along with the use of additional sensors.

B.3.4 Infrastructure Scalability. Many isolated rural schools do not have high bandwidth Internet connections, so the infrastructure deployed in the classroom must be capable of maintaining connectivity and stability under these often-limited conditions. The *LbyM-p* infrastructure consists of a classroom network of HP Stream personal computers that communicate with a dedicated server at each high school. The server at each school is linked over the internet to a dedicated server at SSU that backs up all student work as well as pushing software and documentation updates. Pairs of students share an HP Stream as well as a "Basic Board" (Figure 1) experimental platform. The Basic Board includes a customized "App" board that runs the Logo programming language using an MSP 430 microprocessor, connected to the HP Stream via an FTDI cable and custom header board. The two small green boards are the only customized equipment needed to support *LbyM*: all the other parts are commonly available and relatively inexpensive. In addition, *LbyM* software is free and open source.

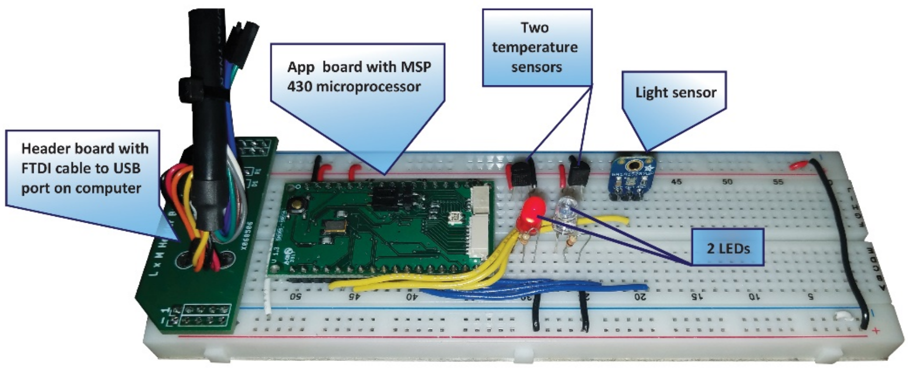

Figure 1 Basic Board with two temperature sensors and one light sensor

Since the initiation of *LbyM-p*, capabilities of commercially available microprocessors have advanced, and many rural schools have begun providing one-to-one computers to students (Zucker et al., 2008), typically Chromebooks. We plan to create strategies to reduce the cost of the hardware by using a commercially available microprocessor board, capable of running Logo. We will also investigate additional hardware modifications that would allow the use of computers already available at the schools to support a one-to-one learning environment. Although evaluation of large-scale one-to-one computer deployment shows mixed results with respect to improving student learning outcomes (Sutton, 2015), there is some evidence that outcomes can be improved with professional development that encourages teachers to become learner-centered facilitators of the new technology (Bebell and O'Dwyer, 2010).

During *LbyM-p*, we developed a method to display the screens of each student laptop on a central website. This allowed SSU support staff to remotely diagnose issues with network connections, and software upgrades. For *LbyM*, we propose to implement a remote help system that will build on the existing technology by adding a voice overlay that will allow teachers and students in the classroom to request expert help in troubleshooting experiments from SSU staff.

B.4 Dissemination

Interactive, hands-on workshops featuring *LbyM* will be disseminated by the SSU Development team through a variety of conferences, including the reMake Education Summit, California STEAM Symposium, California Science Teachers Association and at least one Computer Science education conference. SSU's dissemination efforts will also include rural-focused conferences including the National Rural Education Association, and publication in journals such as Rural Educator and Computer Science Education. WestEd will submit the final evaluation report from the year 4 impact study to the What Works Clearinghouse for review. Additionally, WestEd will present evaluation results from the *LbyM* formative research studies and impact study at a variety of annual conferences, including the California Educational Research Association, the American Society for Engineering Education, and the Society for Research on Educational Effectiveness. Journals that WestEd will target for publication of research on *LbyM* include the International Journal of Innovation and Research in Educational Sciences and the International Journal of STEM Education.

C. Project Evaluation

C.1 Evidence that would meet WWC evidence standards without reservations.

WestEd will conduct both formative and impact research throughout the grant period to support the development of *LbyM* as a part of the PDSA framework for continuous improvement. The proposed research is designed to determine the effectiveness of *LbyM* in rural high school settings. For the impact study, we propose conducting a randomized controlled trial, often referred to as the "gold standard," enabling findings to meet criteria for inclusion consideration in the national What Works Clearinghouse. In year 4 of the study, a multisite or blocked trial design in which high school students within schools will be randomly assigned to treatment or control conditions will be used to control for threats to internal validity (Cook & Campbell, 1979; Murray, 1998). The study relies on hierarchical modeling techniques to address confirmatory research questions: (1) What is the impact of *LbyM* on high school student science and math performance? (2) What is the impact of *LbyM* on high school student confidence in STEM?

C.1.1 Statistical power analysis. We calculated the statistical power using the Power Up software. This analysis is based on the unit of randomization, the sources of clustering, and other design characteristics using the procedures described by Donner and Klar (2000), Murray (1998), Raudenbush (1997), and Schochet (2005). Specifically, the statistical power estimates assume: (1) an alpha threshold of 0.05, (2) 50% of the cluster-level variance can be explained by a student level covariate (Bloom, Richburg-Hayes, & Black, 2005) and by the blocking variable (school), (3) an effect size variability of 0.10, and (4) a target baseline sample size of 500 students (250 students per condition) from 10 schools (two high school classes and 25 students per class). Under these assumptions, the sample yields 80% power to detect a MDES of 0.204.

C.1.2 The counterfactual. Students in the control condition will not have access to *LbyM*. Thus, it is expected that students in the control classrooms will continue to receive business-as-usual instruction in science. WestEd researchers will develop a similar observational protocol for control classrooms. In particular, we will collect data on science instructional practices, including whole-group instruction, small-group instruction, and individual supports. In this way, we can qualitatively describe any overlapping dimensions of implementation between the treatment and the control classrooms. Control teachers will be observed twice during the course of the intervention—once during the first semester and once during the second semester.

C.1.3 Impact analysis. The analysis of *LbyM* impacts will depend on the random assignment research design as its primary source of inference. Because the study design is a multi-site (blocked) trial, a two-level hierarchical linear model will be used to analyze the treatment effect. We will estimate the following two-level hierarchical linear model (HLM) to address the two confirmatory research questions.

$$Y_{ij} = \gamma_{00} + \gamma_{10}Tx_{ij} + Tx_{ij}\eta_{1j} + \Sigma\gamma_{10}I_{ij} + \eta_{0j} + \varepsilon_{ij} \qquad \textbf{[1]}$$

In equation **[1]**, Y represents an outcome variable of interest (e.g., *Certica test scores*), γ_{00} represents the grand mean outcome, Tx is a dichotomous variable indicating assignment to treatment, I is a vector of student-level covariates measured at baseline, η represents the random effect of school, and ε represents the random effect of student. This model also includes a term, $Tx_{ij}\eta_{1j}$, which represents the treatment and school interaction. In this model, the treatment effect is estimated by γ_{10}.

C.2 Effective strategies suitable for replication or testing in other settings

Our fidelity of implementation study will support replication and testing in other settings by addressing the overarching evaluation question: To what extent is the LbyM project implemented with fidelity across different rural communities? Beginning in year 1, we will begin a longitudinal fidelity of implementation study addressing the key components of *LbyM* project (activities and participation in Logic model – Appendix G). In particular, we will address (1) To what extent does the expanded partnership with community organizations help develop STEM pathways and field experiences for *LbyM* students? (2) Are the *LbyM* teacher PDs, including training videos, online resources, and the Networked Improvement Community suitable for replication or testing in different rural communities? (3) Are the *LbyM* curriculum and infrastructure including newly developed experiments and SSU remote support system suitable for replication or testing in different rural high schools? We will conduct a series of usability tests of the refined and newly developed experiments and of the SSU remote support system with year 1 participating teachers and students. As part of the PDSA framework for continuous improvement, usability testing will explore on the aspects of the experiments and the support system that are most aligned with teaching and learning STEM, will gauge the appropriateness of the experiments and support system in rural high school classroom environment, and will include suggestions for improving the academic potential and usability of the experiments and support systems in different rural settings. We will conduct classroom observations, teacher interviews, and student focus groups with years 2 and 3 teachers and their students to address the feasibility of *LbyM* PD in different rural communities and the scalability of *LbyM* curriculum and infrastructure. Documentation of students' participation in internships and college and career related activities will be analyzed to address whether the expanded partnerships with community organizations are suitable and sustainable for different rural high schools. In addition, bi-yearly interviews with district leaders, school leaders, and project implementation staff will address the general impressions of *LbyM*, student access to internships or work-based learning experiences in STEM, barriers/challenges in implementation, perceived educator and student progress/engagement, areas for improvement, and best practices utilized.

C.3 Valid/reliable performance data on relevant outcomes.

Two short-term outcome measures are included: (1) *High School Student Attitudes toward STEM survey*. The survey will be used to measure student confidence in STEM. This survey is developed by North Carolina State University (Faber, M., Unfried, A., Wiebe, E.N., Corn, J., & Collins, T.L., 2013), and includes 48 5-point Likert scale items. It is designed to measure high school student attitudes toward science, mathematics, engineering and technology, and 21st century skills. It also includes 16 items that measure student interest in STEM careers. Results from exploratory factor analysis indicated that the survey has good construct validity with four clear constructs measuring student attitudes toward, science, math, engineering and technology, and 21st century skills. Internal reliability coefficient was 0.83. (2) *Teacher* *instructional practice and competency survey*. The teacher survey includes three sections. The first section collects teacher demographic data, including gender, ethnicity, academic and technology background, and teaching experience. The second section focuses on teacher instructional practices. It includes three subscales addressing instructional practices in general (14 items, α= .86), instructional practices supporting students to collect, organize, display and/or present data (7 items, α =. 94), and instructional practices on supporting students to use calculators, computers, and other educational technology (10 items, α = .82). The third section addresses teacher competencies and was developed by WestEd and SSU in 2014. It includes two subscales which assess teacher competencies in supporting students' critical thinking skills (12 items, α = .92) and measures teacher technology competencies (22 items, α = .93). **Two major mid-term outcome measures** are used: (1) *Northwest Evaluation Association (NWEA) Measures of Academic Progress (MAP) Growth for Science Test.* (2) *NWEA Common Core MAP Growth for Math.* These tests will be used to measure 9th grade students' science and math outcomes. Test-retest correlations for *MAP* range between .67 and .81; validity of concurrent performance on state tests ranges between .77 and .82. *MAP for Science* covers specific concepts within three major domains of science: life, earth and space, and physical science. *MAP for Math* is aligned with Common Core State Standards. Thus both assessments are aligned with the *LbyM* domains.

C.4 Key components, mediators, and outcomes

The evaluation is guided by the *LbyM* logic model (Appendix G). The logic model describes the key components (activities, participation), mediators (short-term outcomes), and mid-term and long-term outcomes. Approaches to assess the implementation of the key components and the outcomes are provided in the previous sections. Measurable threshold for acceptable implementation is discussed in the logic model and Goals and Objectives (Section B, Table 3). Figure 2 below shows the overall project timeline.

Figure 2 *LbyM* Timeline

Phase 1

		2018/2019												2019/2020											
	Academic Year	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
	Partnership Management	COEs					CTE																		
CTE	Activities		G			G		TT	WB						G			G		TT	WB				
CTE	STEM Pathways				MCOE									LCOE			SCOE								
Prof.Dev.	One-day workshops	▼	▼		▼		▼	▼						▼	▼		▼		▼	▼					
Prof.Dev.	5-day summer institutes							P	D	S			A							P	D	S			A
Prof.Dev.	Remote workshops offered													P	D		▼S			▼A					
Curr. & Infra.	Experiment 1	P	D		S				A															Phase 2 begins	
Curr. & Infra.	Experiment 2				P	D		S				A													
Curr. & Infra.	Experiment 3							P	D		S				A										
Curr. & Infra.	Experiment 4										P	D			S				A						
Curr. & Infra.	Experiment 5													P	D		S				A				
Curr. & Infra.	New app board				P	D			S			A													
Curr. & Infra.	Remote help system								P	D							S			A					
Diss.	Conferences		CC							Ed	rM		SS	NR								Ed	rM		
Diss.	Journals													Prep RJ				Sub RJ							

Legend	
Event	
P	Plan
D	Do
S	Study
A	Act
▼	1-day workshop
G	Guest speakers
TT	Teacher Training STEM pathways
WB	Work-Based Learning Experience
MCOE	Mendocino County of Education
LCOE	Lake County of Education
SCOE	Sonoma County of Education
CC	CSTA or CS conference
Ed	EIR Project Directors Meeting
rM	reMake Education Summit
SS	STEAM symposium
NR	NREA
Prep RJ	Prepare Research Journal article
Sub RJ	Submit Research Journal article
Prep EJ	Prepare Eval Journal article
Sub EJ	Submit Eval Journal article

Phase 2

		2020/2021												2021/2022												2022/2023											
	Academic Year	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
	Partnership Management	COEs					CTE																														
CTE	Activities		G			G		TT	WB						G			G		TT	WB						G			G		TT	WB				
CTE	Pathway - phase 2 Counties																																				
Prof.Dev.	One-day workshops	▼	▼		▼		▼	▼						▼	▼		▼		▼	▼						▼	▼		▼		▼	▼					
Prof.Dev.	5-day summer institutes							P	D	S			A							P	D	S			A							P	D	S			A
Prof.Dev.	Remote workshops offered		P	D	▼S		▼	▼A					P	D	▼S		▼		▼	▼	▼A			P	D	▼S	▼S		▼		▼	▼	▼A				
Curr. & Infra.	Experiment 6	P	D		S				A																												
Curr. & Infra.	Experiment 7				P	D		S				A																									
Curr. & Infra.	Experiment 8							P	D		S				A																						
Curr. & Infra.	Experiment 9										P	D			S				A																		
Curr. & Infra.	Experiment 10													P	D		S				A																
Curr. & Infra.	New app board						S			A																											
Curr. & Infra.	Remote help system							S			A									S			A														
Diss.	Conferences		CC							Ed	rM		SS	NR								Ed	rM				CC							Ed	rM		SS
Diss.	Journals					Prep EJ				Sub EJ								Prep RJ				Sub RJ								Prep EJ				Sub EJ			
	Impact Evaluation																Study								Analyze												

REFERENCES

AASA, The School Superintendents Association (Nov 2017). Leveling the Playing Field for Rural Students. Retrieved 5/15/18 from *http://www.aasa.org/uploadedFiles/Policy_and_Advocacy/Resources/AASA_Rural_Equity_Report_FINAL.pdf*

Ali, Saba Rasheed & Hawley McWhirter, Ellen (2006). Rural Appalachian Youth's Vocational/Educational Postsecondary Aspirations: Applying Social Cognitive Career Theory. *Journal of Career Development*, Vol 33, No. 2.

Anderson, Shawn. (2008). Math Infusion in Agricultural Education and Career and Technical Education in Rural Schools. *The Rural Educator*, Vol. 3, No. 1.

Bebell, Damian & O'Dwyer, Laura M. Educational Outcomes and Research from 1:1 Computing Settings (2010). *The Journal of Technology, Learning and Assessment*, Vol. 9, No. 1.

Bouck, Emily C. (2004). How Size and Setting Impact Education in Rural Schools. *The Rural Educator*, Vol 25, Number 3.

Bryk, Anthony S., Gomez, Louis M. & Grunow, Alicia. (2011). Getting Ideas into Action: Building Networked Improvement Communities in Education. *Frontiers in Sociology of Education*, edited by Maureen Hallinan, Springer Publishing.

Comeaux, Patricia & Bryington, Ele McKenna (2003). Computer-mediated communication in online and conventional classrooms: some implications for instructional design and professional development programmes. *Innovations in Education and Teaching International*, 40-4, 348-355 DOI: 10.1080/147032903200128387

Cook, T.D., and & Campbell, D.T. (1979). *Quasi experimentation: Design & analysis issues for field settings*. New York, NY: Rand McNally.

Cooper, Melanie N. (2013). Chemistry and the Next Generation Science Standards. *Journal of Chemical Education*, Vol. 90, No. 6.

CTE on the Frontier (2017). *Providing Learners Access to Diverse Career Pathways*. Retrieved 5/29/2018 at https://cte.careertech.org/sites/default/files/files/resources/CTE_Frontier_Diverse_Pathways_2017.pdf

Donner, A. Klar, N. (2000). *Design and analysis of cluster randomization trials in health research*. London, U.K.: Arnold Publishers Limited.

Einhorn, Susan (2011) MicroWorlds, *Computational Thinking and 21st Century Learning*, LCSI White Paper. http://el.media.mit.edu/logo-foundation/pubs/papers/LCSI%20Computational%20Thinking.pdf

Faber, M., Unfried, A., Wiebe, E.N., Dorn, J., & Collins, T.L. (2013). *Student Attitudes toward STEM:" The Development of Upper Elementary School and Middle/High School Student Surveys.* Paper presented in 120th American Society for Engineering Education Annual Conference & Exposition.

Fishman, Dan (2015). School Reform for Rural America. *Education Next*. Retrieved from http://educationnext.org/school-reform-rural-america/

Gibbs, Robert (2005). Education as a Rural Development Strategy. *Economic Research Service/ USDA.*

Goodpaster, Kasey P.S., Adeokun, Omolola A., & Weaver, Gabriela C. (2012). *Teachers' Perceptions of Rural STEM Teaching: Implications for Rural Teacher Retention*. ERIC EJ987 621.

Google Inc. & Gallup Inc. (2017). *Computer science learning: Closing the gap: Rural and small town school districts*. Results from the 2015-2016 Google-Gallup Study of Computer Science in U.S. K-12 Schools (IssueBriefNo.4). Retrieved from http://services.google.com/fh/files/misc/computer-science-learning-closing-the-gap-rural-small-town-brief.pdf

Grunow, Alicia (2015). Improvement Discipline in Practice. *Carnegie Commons Blog.* Carnegie Foundation for the Advancement of Teaching.

Guidelines for ROP Internships (2007) San Diego City Schools School-to-Career

Halpern, D., Aronson, J., Reimer, N., Simpkins, S., Star, J., & Wentzel, K. (2007). Encouraging girls in math and science: IES practice guide (NCER 2007- 2003). Washington, DC: Institute of Educational Sciences, U.S. Department of Education.

Hargreaves, A., Parsley, D., & Cox, E.K. (2015). Designing Rural School Improvement Networks: Aspirations and Actualities, *Peabody Journal of Education*, 90:2, 306-321, DOI: 10.1080/0161956X.2015.1022391

Hoffman, N. & Cahill, C. (2016). The new rural CTE: A promising development. *Techniques Magazine, p. 40-43.*

(IES) Institute for Education Sciences (2007). Encouraging Girls in Math and Science: IES Practice Guide.

Johnson, J., Showalter, D., Klein, R., & Lester, C (2014). *Why Rural Matters 2013-2014: The condition of rural education in the 50 states.* Arlington, VA: Rural School and Community Trust. http://eric.ed.gov/?id=ED556045

Khattri, Nidhi, Riley, Kevin W. & Kane, Michael B. (1997). *Students at Risk in Poor Rural Areas: A Review of the Research*. ERIC ED 461 442.

Kirby, Alisha. https://www.cabinetreport.com/curriculum-instruction/some-states-succeed-in-improving-rural-cte

Kuenzie, Jeffrey J., Mathews, Christine M. & Mangan, Bonnie F. (2006). Science, Technology, Engineering, and Mathematics (STEM) Education Issues and Legislative Options. *CRS Report for Congress.*

Lemke, June Canty (1994). *Teacher Induction in Rural and Small School Districts*. ERIC ED 369 589.

Masumoto, M., & Brown-Welty, S. (2009). Case Study of Leadership Practices and School-Community Interrelationships in High-Performing, High-Poverty, Rural California High Schools. *Journal of Research in Rural Education*, 24(9). Retrieved 5/12/18 from http://jrre.psu.edu/articles/24-1.pdf

Monk, David H. (2007) Recruiting and Retaining High Quality Teachers in Rural Areas. *The Future of Children*. Princeton University.

Murray, D.M. (1998). *Design and analysis of group-randomized trials.* Oxford, England: Oxford University Press.

(NAEP) National Assessment of Educational Progress (2015, 2017). Nation's Report Card. Retrieved on 5/10/18 at https://nces.ed.gov/nationsreportcard.

National Science Board (2015). *Revisiting the STEM workforce*. Washington, DC: The National Science Foundation. Retrieved on 5/5/18 from https://www.nsf.gov/pubs/2015/nsb201510/nsb201510.pdf

NASDCTEc (2010). *Reflect, Transform, Lead: A New Vision for Career Technical Education*. http://www. careertech.org/career-technical-education/cte-vision.html

NASDCTEc (2013). *CTE is Your STEM Strategy*. Retrieved 5/25/18 from https://cte.careertech.org/sites/default/files/CTEYourSTEMStrategy-FINAL.pdf

National Academy Foundation. *Preparing Youth for Life: The Gold Standard for High School Internships.* New York, NY. Retrieved 5/19/18 from www.socialimpactexchange.org/sites/www.socialimpactexchange.org/files/Internship%20Gold%20Standards.pdf

Next Generation Science Standards (NGSS) 2013 http://www.nextgenscience.org/next-generation-science-standards

OCE. (2017). Office of the Chief Economist, U.S. Department of Commerce. STEM Jobs: 2017 Update.

OECD (2016), *PISA 2015 Results (Volume I): Excellence and Equity in Education*, PISA, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264266490-en.

OECD. (2016). *Country note: Key findings from PISA 2015 for the United States*. Retrieved from http://www.oecd.org/pisa/PISA-2015-United-States.pdf

Pang, Jeong-Suk & Good, Ron (2000). A Review of the Integration of Science and Mathematics: Implications for Further Research. *School Science and Mathematics Journal*, 100, 73-82.

Papert, Seymour (1999). Introduction in *Logo Philosophy and Implementation*, published by Logo Computer Systems, Inc., IV-XVI. www.microworlds.com/company/philosophy.pdf

Partnership for 21st Century Skills (P21). www.p21.org

Penuel, William R (2006). Implementation and Effects of One-to-One Computing Initiatives: A Research Synthesis. *Journal of Research on Technology in Education.*

A Portrait of California, 2014-15. Measure of America of the Social Sciences Research Council. Retrieved on 5/1/18 at http://www.measureofamerica.org/california2014-15/.

Nedley, Shula (2016) White Paper. ASSET: A Validated Model to Improve Student Achievement. www.assetinc.org

Raudenbush, S. (1997). Statistical analysis and optimal design for cluster randomized trials. *Psychological Methods*, 2(2), 173-185.

Richard, Alan (Oct 2017). Plugging the Rural Brain Drain. *ASCD Newsletter Education Update*, Vol 59, No. 10.

Schochet, P.Z. (2005). *Statistical power for random assignment evaluations of education programs*. Princeton, NJ: Mathematica Policy Research.

Seal, Kenna R. & Harmon, Hobart L. (1995) *Realities of Rural School Reform*. ERIC ED 384 454.

Student Work-Based Learning Continuum (2016) San Diego County Career Readiness Consortium.

Sutton, Nick (2015). *What the Research Says about 1:1*. Edutopia html.

Wing, Jeanette M. (March, 2006). Computational Thinking. *Communications of the ACM*, Vol 49, No. 3.

Winthrop, Jerauld (2001). The Internship Handbook. Career Academy Support Network, University of California, Berkeley.

Work-based Learning Experience Definitions (2016). San Diego County Career Readiness Consortium.

Zucker, Andrew W., Tinker, Robert, Staudt, Carolyn, Mansfield, Amy & Metcalf, Shari (2007). Learning Science in Grades 3–8 Using Probeware and Computers: Findings from the TEEMSS II Project. *Journal of Science Education & Technology*. 17:42-48