# Investing in Innovation Development Grant Application

LEA: Albemarle County Public Schools

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A. Significance

During the second industrial revolution (mid-19th century to 1914), science was applied to engineering on a large scale for the first time. An often-untold part of the American experience, the result was many of the great innovations that shaped the world (i.e., telegraph, electric motors, telephone, radio). Today, students are surrounded by technology that was made possible by these early predecessors; however, modern technology is complex and opaque, challenging for even technology professionals to truly understand. Students have an even more difficult time. This issue has been compounded by the disconnected method in which STEM is taught: detailed knowledge proceeds in an abstract sequence from general principles.

The simplicity of the early inventions means these apparatuses have tangible components that can be deconstructed and understood by students through the powerful learning process of reverse engineering. Increasingly inexpensive advanced manufacturing technology like 3D printers and student-friendly computer-aided design programs make this same experience possible for students in a K-12 environment.

In initial planning for this project, collaborators from the Smithsonian and professors of engineering and education at the University of Virginia identified a trajectory of great inventions to teach science and engineering. Collaborators propose to do this through the creation of Smithsonian Invention Kits, based on key inventions that changed the nation such as the telegraph and the telephone. Smithsonian Invention Kits will include resources to re-create these inventions, including a year-long science and engineering curriculum, 3D scans and animations, and online support. The kits will be developed and piloted in the Laboratory School for Advanced Manufacturing. Further revision and testing will be conducted at other Virginia school systems over the course of multiple rounds of testing. The final validated Invention Kits will be
then be distributed nationally through the Smithsonian website.

Support from the *Investing in Innovation* grant, leveraged with existing partnerships with higher education, nonprofits, and the private sector, will extend the work of the Lab School and Smithsonian partnership on a regional level through a middle school curriculum that provides exposure to elements of engineering and advanced manufacturing through integrated middle school science courses. This exposure will be combined with the development of a high school curricular pathway, aligned with college and career ready standards, which allows students to build competencies in advanced manufacturing, design, and engineering. This pathway will fill the gap of middle skill workers identified in the workforce plan, along with providing students planning to enter engineering fields at the community college or university level with practical experiences and the opportunity to earn credit through dual enrollment courses.

Additionally, FableVision Learning has committed $225,000 in matching funds for development of a Computer-assisted Design (CAD) program for schools. Fab@School Designer will be specifically designed to support the educational goals outlined in this initiative. It is a web-based tool that will allow the user to fabricate both 2D models (using a computer-controlled die cutter) and 3D models (using a 3D printer) from the same file; this functionality does not currently exist in other CAD software. This application is more fully described in Objective 1.

Collectively, the partnering school systems of Albemarle, Charlottesville, and Fluvanna serve more than 21,000 students in Central Virginia, in urban, rural-fringe, and rural settings. This project, *The Central Virginia Advanced College and Career Readiness Region: Advanced Manufacturing and Engineering as a Driver of Cross-Curricular Change*, addresses Priority 5 of the Investing in Innovation program: the effective use of technology integrated with rigorous college and career ready standards to: *improve student engagement* through the use of project
based learning activities incorporating advanced manufacturing technologies; improve student achievement through an integrated curriculum and opportunities to develop competencies using emerging technologies; and build teacher efficacy through focused professional development.

Background

Recent reports point to the promise of a new economic driver as we strive to compete in a global marketplace: advanced manufacturing. Several White House initiatives are underway to support the development of advanced manufacturing capabilities, including the Advanced Manufacturing Partnership Steering Committee 2.0 and the Public-Private Manufacturing Innovation Institute. These initiatives address the development of a workforce adequately prepared for employment as this sector grows; the Bureau of Labor Statistics (2013) reported that 8.8 million new “middle skill” jobs will be created before 2022 that do not require postsecondary education, but that do require technical skills like those needed for advanced manufacturing.

The Commonwealth of Virginia, recognizing the potential for economic development through advanced manufacturing, created the Commonwealth Center for Advanced Manufacturing (CCAM) to provide an opportunity for industry and higher education to collaborate in research and development. CCAM commissioned a workforce plan in 2013 by The Boston Research Group to examine existing K-12 and higher education programs in the state. The research group surveyed gaps in workforce skills and experience that could inhibit the economic potential of advanced manufacturing in the state. This research identified deficits in the number of workers prepared for middle skilled jobs in advanced manufacturing. These positions include jobs such as “machinist” that do not require a four-year degree. These results mirror the findings of the Bureau of Labor Statistics and other studies on a national scale (Brookings, 2009). The report identified three components essential for the training of the middle skilled workers: (1) core
skills, such as a foundation in the STEM fields; (2) manufacturing knowledge and foundational engineering concepts; and (3) hands-on experience.

The Commonwealth of Virginia provided a planning grant in 2013 to establish a Laboratory School to address this need. It is designed to provide a test bed for effective educational practice. In this instance, the University of Virginia jointly established the nation’s first Laboratory School for Advanced Manufacturing in collaboration with the Albemarle and Charlottesville schools.

The Laboratory School for Advanced Manufacturing

The Laboratory School for Advanced Manufacturing is a bricks-and-mortar school modeled on the Advanced Manufacturing Laboratory at the University of Virginia. It was constructed with funding from the National Science Foundation, state, and local funding. It is designed to integrate engineering design into the middle school curriculum through advanced manufacturing technologies. There is a ratio of one 3D printer for every four students in science classes, along with other digital fabrication technologies such as computer-controlled milling machines and laser cutters. The Lab School addresses diverse needs; it is not a magnet school, and every student has the opportunity to participate in advanced manufacturing activities.

The Lab School uses engineering classes as an innovation center to support science teaching. Students taking engineering electives develop demonstration apparatus for use in science classes. There is evidence that students who use commercial science apparatus often do not understand their functions; the electronics of this equipment is a black box that is opaque to students (Olson, 2013). Designing and constructing their own demonstration apparatus for science classes presents engineering students with an authentic challenge. They learn engineering skills in context, while addressing a real need that also improves science teaching and learning.
The introduction to engineering is based on an innovative method pioneered at Princeton by Professors Michael Littman and David Billington, who believe students can learn science and engineering through the coherent and engaging story of great inventions. Billington explains:

A crucial aspect of [great innovations] has never received the emphasis that it deserves: the simplicity of the basic ideas. In examining their work, we found that the engineering innovators of our period described their work in surprisingly simple formulas or concepts. There is good reason that they did so: with innovations so new and unfamiliar, engineers were concerned with expressing them as accessibly as possible. Later engineers, often with the help of scientists, made the new technologies more sophisticated and efficient. . . . This clarity is vital to bring out for two reasons. First, it tells us that simplicity, not complexity, is the characteristic of original [archetypal] engineering thought. Second, through examples of such thinking, students can learn ground-breaking engineering ideas without first having to know calculus. (Billington, 2006, p. xvii-xviii)

The educational potential of early inventions inspired an initiative, *American Innovations in an Age of Discovery*, undertaken by the Laboratory School for Advanced Manufacturing in collaboration with Princeton and the Smithsonian Institution in 2013. This initiative, based on five years of successful experience at the experience at the undergraduate level, extended this approach to middle school teaching. The program teaches science and engineering through the reconstruction of great inventions. The goal for the students is not to create an exact physical replica of the invention, but to reinterpret and reinvent the device using modern manufacturing technology. The program leverages 3D digitization technologies developed by the Smithsonian through their Smithsonian x3D website (http://3d.si.edu/). The site includes a groundbreaking 3D viewing tool that allows unhindered exploration of objects, storytelling functionality, and advanced tools such as measuring, cross-sectioning, and material property manipulation.
In the initial pilot, students designed and manufactured a working reinterpretation of the Morse-Vail telegraph system using 3D printers, objects from the Smithsonian, and Vail’s journals. The success of the pilot project inspired collaborators to develop the Summer Engineering Design Academy. Six teachers were trained on the historical reconstruction teaching methodology and worked with twelve students in the academy over the course of two weeks. This two-week curriculum would be further developed and modified for a classroom environment, ultimately becoming a standards-aligned engineering and physical sciences course of study composed of a series of active-learning explorations of early inventions from the Smithsonian collections. Collaborators propose to do this through the creation of Invention Kits.

*Invention Kits*

A *Smithsonian Invention Kit* will provide the resources and support materials required to allow students to reconstruct historic inventions in the Smithsonian collections. This includes instructions with figures, photographs, animations, 3D-scan, and 3D-printer files that can be downloaded to scaffold reconstruction of the invention. Professional development materials and assessment procedures for teachers will also be provided. Each Invention Kit will address:

1. *technical explanations* describing what the inventor did,
2. the *social context* describing the era within which the inventor worked, and
3. the *cultural impact* describing ways in which the invention changed the world.

Please see Appendix J for a detailed description of Invention Kits.

David Billington describes the rationale for the introductory introduction to engineering offered to liberal arts majors at Princeton, developed with support from Alfred P. Sloan Foundation through its grant program for *The New Liberal Arts*:

> Engineering in the United States has turned away the new people on which its future depends by an abstract and narrow approach to introductory teaching. … Modern
engineering is more coherent and more appealing when it is introduced as a historical sequence of ideas and events. Engineering education follows the model of the physical sciences in which detailed knowledge proceeds in an abstract sequence from general principals. We believe that modern engineering is better introduced as a narrative of great works. … Too many do not realize that there is a canon, a grand tradition, in modern engineering consisting of great ideas that can be expressed in accessible formulas. (Billington, 2006, p. xviii)

This rationale is the foundation of our efforts, in collaboration with the Smithsonian and Princeton, to extend these methods to middle-school teaching, assisted by new and emerging 3D technologies adapted to support innovation teaching strategies.

**B. Quality of the Project Design**

*Figure 1: Project Logic Model*
Objective 1: Develop Smithsonian Invention Kits and pilot in the Laboratory School for Advanced Manufacturing. Replicate use in other school districts prior to national dissemination.

Based on the success of the pilot effort, we proposed to build upon and extend development of Invention Kits in the following way. Project collaborators will combine significant educational and professional expertise in history, science, technology, engineering, design, and mathematics (see “collaborators” section) to achieve three goals:

- **Objective 1.1** – Pilot Invention Kits in Engineering. Students in pilot middle schools will learn foundational engineering principles and advanced manufacturing technologies through the development and implementation of a semester-long engineering course based on reconstruction of historic inventions.

- **Objective 1.2** Pilot Invention Kits in Science Teaching. Students in pilot middle schools will have their physical science course enhanced with STEM through the use of the inventions constructed in the engineering class.

- **Objective 1.3** Teachers throughout the country will be able to freely access and implement this learning experience through packaged Invention Kits on the Smithsonian X3D website.

Curators at the National Museum of American History will collaborate with engineering and education professors to identify a trajectory of great inventions to teach STEM.

The Smithsonian Inventions Kits would be piloted in at least two rounds, an alpha test and a beta test, in multiple locations over a period of three years. Results from the experimental test groups at Sutherland Middle School and Buford Middle School will be used to inform revisions of the kits. Subsequently, these revised kits will be beta tested at these same two sites, with the addition of control school sites Fluvanna Middle School and Burley Middle School, during the following
school year. As new inventions are added in years 2 and 3, the previous Smithsonian Invention Kits will continue to be beta tested and revised as new students encounter the material. Student Focus Groups will be used to better understand how students perceive the curriculum/course, including what they like or would like to change about the curriculum, as well as to understand what they believe they are learning. Finally, a dissemination website will be developed to host the Smithsonian Invention Kits and make them available to any school. Fabrication software is a crucial element in successful use of fabrication hardware. *A Framework for K-12 Science Education* recommends that CAD tools be introduced to modernize engineering design activities (Section ETS1.B; National Research Council, 2011). Industrial CAD applications are, by and large, design tools rather than *design learning tools*. Educational CAD tools can help students improve their design skills by allowing them to visualize their designs. Fab@School Designer is a CAD program being developed to support middle engineering education. Fab@School Designer, currently in beta testing, is an important component of the proposed Smithsonian Invention Kits. It is a web-based tool that can be used on any browser from any platform. Designs created with Fab@School Designer can be saved to the cloud and accessed from any other computer or hand-held device.

The pedagogical strategy adopted for this initiative is based on a rapid prototyping process that encourages multiple iterations using 2D fabricators (i.e., computer-controlled die cutters). Once a design is finalized, it can be sent to a 3D printer for fabrication in more durable form. Fab@School Designer is currently the only software tool that can generate files for both 2D and 3D fabricators. This capability is a crucial component of the proposed strategy. (Currently available software requires use of different programs for digital die cutters and 3D printers. The necessity of re-doing the design in two separate programs undermines the benefits that otherwise
would accrue, costing limited classroom time, and potentially introducing frustrating errors during the process.) Fab@School Designer is described in Appendix J.

Objective 2: Develop methods for assessing learning outcomes corresponding to science and engineering instructional objectives.

Student Assessments, developed by the teachers and project personnel in conjunction with the evaluator and to include embedded (practicum-oriented) assessments will be used to understand how well students are mastering the science topics they are studying. Embedded assessments will be practicum-based such that students demonstrate mastery of skills and understanding of science and engineering principles, as well as how they interact. Critically, all assessments will reflect the Next Generation Science Standards, including the eight practices of science and engineering that the Framework identifies as essential for all students to learn and the three core ideas of engineering design in which students are expected to engage. Performance tasks and associated grading rubrics will be developed by the science teachers, adhering to standards that require the task to be engaging, complex, accessible to all learners, and open-ended. Results from the performance tasks will be evaluated to identify curricular and instructional improvements to increase student achievement.

Reviews of Virginia Standards of Learning (SOL) scores will be conducted to understand how well students perform on Virginia's state standardize SOL tests in the area of science. Students' scores will be compared to past students' scores as well as those of students in similar schools not implementing the new curriculum and between students enrolled and not enrolled in the engineering elective to better understand impacts.
Table 1: Alpha and Beta Testing Timeline

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<th>Year 2</th>
<th>Year 3</th>
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<td><strong>Development</strong></td>
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<tr>
<td>1. Develop kits for galvanometer and Morse telegraph and relay</td>
<td>1. Develop Davenport electric motor and battery kits</td>
<td>1. Develop Bell telephone kit</td>
<td>1. Develop Edison light and generator kit</td>
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<tr>
<td>2. Revise galvanometer and telegraph and relay kits</td>
<td>2. Revise galvanometer and telegraph and relay kits</td>
<td>2. Revise galvanometer, telegraph and relay, electric motor, battery kits</td>
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| **Experimental Group** | | | |
| Laboratory School for Advanced Manufacturing | Sutherland Middle School | Buford Middle School | |
| 1. Alpha test galvanometer and telegraph and relay kits | 1. Beta test galvanometer and telegraph and relay kits | 1. Revise galvanometer and telegraph and relay kits | 1. Revise galvanometer, telegraph and relay, electric motor and battery kits |
| 2. Teacher professional development: kit for galvanometer and telegraph and relay | 2. Alpha test electric motor and battery kits | 2. Beta test galvanometer, telegraph and relay, electric motor, and battery kits with new eighth grade class | 2. Beta test galvanometer, telegraph and relay, electric motor, battery, and telephone kits with new eighth grade class |
| 3. Teacher professional development: kit for electric motor and battery | 3. Teacher professional development: kit for electric motor and battery | 3. Alpha test for telephone kit | 3. Alpha test for light and generator kit |
| 4. Teacher professional development: kit for telephone kit | | 4. Teacher professional development: light and generator kit | |

| **Control Group** | | | |
| Fluvanna Middle School | Burley Middle School | | |
| -- | 1. Alpha test galvanometer and telegraph and relay kits | 1. Beta test galvanometer and telegraph and relay kits with new eighth grade class | 1. Beta test galvanometer, telegraph and relay, electric motor, and battery kits with new eighth grade class |
| | 2. Alpha test electric motor and battery kits | 2. Alpha test telephone kit | 2. Alpha test telephone kit |

| **National Dissemination** | | | |
| -- | -- | 1. Post galvanometer and telegraph kits via website | 1. Post electric motor and battery kits via website |

**Objective 3: Create a regional professional development network**

To enhance this project’s regional approach to developing college and career ready students, several professional development opportunities will be utilized.

(1) A summer professional development institute will be created to support a cadre of educators prepared to integrate advanced manufacturing and other emerging technologies with project based learning across disciplines and across district boundaries. Content for the professional development institute will be developed and delivered through our partnership
with the Curry School of Education to provide teachers an opportunity to reflect on, improve, and refine their practice with the integration of advanced manufacturing technology.

(2) Participants in the three week Summer Engineering Academy each year will develop and refine curricula through the co-construction of knowledge with students also participating in the academy. They will also participate in a seminar on engineering education with Princeton University engineering educator doctoral students. In Year 2 of the project, the professional development will include learning opportunities for teachers on the use of Lab School classroom equipment; in year 3, the professional development will include learning opportunities for teachers on the curriculum integration of engineering concepts and advanced manufacturing technologies.

(3) During the school year, a common planning period will be scheduled for the CTE teacher and science teacher to coordinate activities. In addition, they will participate in a weekly virtual seminar and participate in a full day professional development session during the year. They will also receive an extra planning period to facilitate the work of developing the kits and to meet with relevant experts for professional development. There will be opportunities for teachers to present at local, state, and national conferences.

(4) In terms of the Inventor’s Kits, professional development materials will be provided in an online format to allow teachers to gain the necessary skills and understanding required to implement the modules in their own classrooms. During the alpha and beta tests, videos will be created of the way in which Invention Kits are employed in pilot classrooms. Related case studies that incorporate this video will also be developed to provide context. Some projects will require background knowledge prior to implementation. For example, the telegraph module presumes understanding of batteries and galvanometers.
(5) Technical skills such as computer-assisted design and soldering may also be required for implementation of project. These prerequisite skills will be listed along with links to prior modules that contain the requisite information. Step-by-step instructions with figures, photographs, animations, and 3D-scans incorporated will be supplied to scaffold reconstruction of the invention. The instructions will be developed for levels of reconstruction including Hand Tools, 2D Fabrication and 3D fabrication,

National Advisory Panel

A national advisory panel will provide expertise in engineering, engineering education and science education. This group will convene annually at the National Technology Leadership Summit (NTLS). This annual leadership summit brings together the leaders of ten national education associations, including the Association for Science Teacher Education (ASTE), the Association of Mathematics Teacher Educators (AMTE), and the International Technology and Engineering Education Association (ITEEA). This will provide an opportunity to review the project and share it with national leaders. The advisory board members will include educators and engineering educators who can contribute expertise and perspective, including Hod Lipson, director of the Cornell Creative Computing Laboratory, David Burghardt, director of the Hofstra Center for Cultural Literacy, Matthew Hoffman, a specialist with the Smithsonian Department of Educational Outreach, Michael Littman, director of the Joseph Henry Center at Princeton, Paul Reynolds, CEO of Fablevision, and David Slykhuis, president of the Society for Information Technology and Teacher Education (SITE). Their qualifications are detailed in Appendix J.

Objective 4: Create an engineering/advanced manufacturing/design curricular pathway for high school students that is aligned with college and career ready standards.

To continue the advanced manufacturing trajectory that begins at the middle school level, each division will create an advanced manufacturing and engineering centered high school curricular
pathway. The pathways will be developed to align with college and career ready standards: allowing students an opportunity to take dual enrollment courses through the local community college, earn industry credentials, and begin to satisfy requirements for an associates or four year university degree. The pathways will be designed to allow multiple points of entry, allowing students to join the pathway beyond the 9th grade, and to provide student experience in the three components essential for successful middle skilled workers (Boston Research Group, 2013): introductory level core skills, foundational engineering knowledge, and hands-on experience. In addition, the pathways will allow for multiple points of exit, providing both internationally recognized certifications to be used for gainful employment and a base skill set that can be applied towards other career paths should the student so choose.

As is the case with technical employment in advanced manufacturing, there will be two pathways. One path will be for the student interested in pursuing a university-level engineering degree (engineering transfer). The other path will be for the student interested in pursuing an associate of applied science in engineering technology (technology transfer). While students in both pathways will share a common interest in technology and engineering, the engineering transfer pathway will focus more on design and theory, while the technology transfer pathway will focus more on maintenance and other middle skills.

Students in the engineering transfer pathway may enroll in several college-level courses such as Introduction to Engineering and Engineering Graphics where they will learn the design process, fundamental engineering principles for use in other courses, Matlab, and solid-modeling. Students in the technology transfer pathway may enroll in college-level courses focusing on electrical components, mechanical components and electrical drives, pneumatic and hydraulic control circuits, and digital fundamentals and programmable logic controllers. As with their
engineering transfer counterparts, these students will be gaining fundamental knowledge for use in other courses while also earning college credit. However, unlike the students in the engineering transfer pathway, these students will obtain a set of skills that can be used towards gainful employment in the manufacturing sector by the time they graduate high school. In addition to their own respective pathways, each student will be required to take a common course in which engineering and technology students work together, within and outside of their respective expertise, to complete group projects. This allows for 3 main objectives. The first allows students to have a real world understanding of how engineers and technicians work together. The second provides students the opportunity to see what skills are obtained in the other path and what that job entails. And finally, this course is provides students with a transition point between the two pathways should they decide that they would prefer to change their tract. To support these pathways, the community college will provide testing and certification for students at multiple levels of skill. Students completing the high school technology transfer tract will be eligible for a Level I certification equivalent to a certified machine operator. This student will have the knowledge and skill set necessary to run advanced machinery and provide useful knowledge as to its operation. Students who continue on the technology transfer pathway and complete a degree in advanced manufacturing and mechatronics at the community college will be eligible for a Level II certification equivalent to a certified technician. This student will have the knowledge and skill set necessary to troubleshoot and maintain advanced machinery with the goal of operational efficiency and cost and process control. Students who elect to follow the engineering transfer pathway will, at the end of their degree, be eligible for a Level III certification equivalent to a design engineer. This student will have the knowledge and skill set necessary to design, manage, and improve advanced manufacturing equipment.
C. Quality of Management Plan and Personnel

Albemarle County Public Schools will serve as fiscal agent for the project. ACPS has significant experience managing federal grant awards, including the recent Safe Schools/Healthy Students initiative, a five year, joint project with Charlottesville City Schools and community organizations, which successfully met all project objectives in improving school safety.

All project activities will be managed by two co-directors who have worked closely with the Lab School partners and manage innovative projects for their respective divisions. The Project Co-Directors will manage all aspects of implementation, from construction to instruction, across the three school divisions, and coordinate efforts with outside partners. They will also serve as a central contact for the project’s evaluation partner, ensuring that all data collection is complete and other evaluation components are provided, and manage communications with internal and external stakeholders.

Chad Ratliff (50%), of Albemarle County Public Schools is currently the Assistant Director of Instructional Programs, and leads ACPS’ Career and Technical Education department and Innovation Team, tasked with implementing the capital improvements, instructional models, and technologies necessary to propel the division forward. He worked on the current lab school initiative since its inception, providing support for teachers and administrators, and managing relationships with partners. Stephanie Carter (50%) is the administrator for career and technical education and virtual education with Charlottesville City Schools. She has worked closely with the Lab School partners at the University of Virginia while strengthening the career and technical curricula to promote the STEM fields and managed large scale grants and initiatives for the system, such as the creation of a virtual education program.
The Project Co-Directors will work closely with a Core Management Team (CMT) of leadership from partnering organizations. The liaison for Fluvanna County Public Schools is Brenda Gilliam, who leads the county’s Department of Curriculum and Instruction and related initiatives. She is also the administrator for the division’s Perkins, Title I, Title II, and Title III grants.

Glen Bull, Ph.D. is a Professor of STEM Education in the Curry School of Education at the University of Virginia. He has served as principal investigator for establishment of the Laboratory School for Advanced Manufacturing, including more than $5 million in state, federal, and local funding culmination in establishment of a Lab School jointly administered by the University and the school system. He has served as principal investigator or co-principal investigator for more than $15 million in funded grants that include federal awards and awards from non-profit foundations and corporate support. He is a founding member and past president of the Society for Information Technology and Teacher Education (SITE), and recipient of the Willis Award for Outstanding Lifetime Achievement in Technology and Teacher Education. He will serve as coordinator of the Laboratory School for Advanced Manufacturing.

Joe Garofalo (Co-P.I.) will work with the team to coordinate conceptualization and design of science activities, identify correspondence of embedded mathematics concepts with mathematics standards and curriculum, and will adapt and refine engineering and science assessments. Joe is an associate professor of math education and co-director of the Curry Center for Technology and Teacher Education. His teaching and research focuses on mathematical problem solving and thinking and use of technology to enhance teaching and learning.

Matthew Hoffman, M.Ed is an Education Specialist at the Smithsonian’s National Museum of American History. He leads professional development online and throughout the country as part
of the A. James Clark Excellence in History Teaching program. He focuses on social studies and STEM integration, particularly as part of the Smithsonian’s recently launched Smithsonian X 3D. He is leading the creation of initiative’s first education resource, *The Mind behind the Mask: 3D Technology and the Portrayal of Abraham Lincoln*. He will coordinate the 3D capture of the selected objects with Smithsonian 3D Digitization Officers and Curators, as well as coordinate and co-develop the historical case studies with Smithsonian curators, Smithsonian contractors, and Professor Littman. He will also guide the integration of the historical aspect of the curriculum in collaboration with science educators and in alignment with the C3 Framework and Common Core.

The CMT will meet monthly at on-site locations (with videoconferencing when necessary) to review and evaluate progress towards program objectives. To ensure continuous improvement during implementation, the CMT and Project Director will use a Plan-Do-Study-Act (PDSA) model. This management method provides steps to ensure careful planning, evaluation for effectiveness, and improvements to processes during the implementation of program activities.

*Project Timeline*

**Year 0**

*Summer 2014*

- Develop open source Invention Kit for galvanometer
- Develop open source Invention Kit for Morse telegraph and relay

*Fall Semester 2014*

- Alpha pilot of galvanometer and telegraph Invention Kits in the Laboratory School engineering classes
- Evaluation: Collect baseline data for engineering classes

*Spring Semester 2015*

- Alpha pilot of galvanometer and telegraph Invention Kits in the Laboratory School physical science classes
- Evaluation: Collect baseline data for physical science classes
Year 1

Summer 2015
- Develop open source Invention Kit for Davenport electric motor
- Develop open source Invention Kit for corresponding battery

Fall Semester 2015
- Alpha pilot of Davenport electric motor and corresponding battery Invention Kits in the Laboratory School engineering classes
- Beta pilot of galvanometer and telegraph Invention Kits in the Laboratory School engineering classes
- Evaluation
  1. Collect baseline data for engineering classes
  2. Compare experimental and control classes for beta pilot in engineering classes

Spring Semester 2016
- Alpha pilot of Davenport electric motor and corresponding battery Invention Kits in the Laboratory School physical science classes
- Beta pilot of galvanometer and telegraph Invention Kits in Lab School physical science classes
- Evaluation
  1. Collect baseline data for physical science classes
  2. Compare experimental and control classes for beta pilot in physical science classes

Year 2

Summer 2016
- Develop open source Invention Kit for Bell telephone

Fall Semester 2016
- Alpha pilot of Bell telephone Invention Kit in the Laboratory School engineering classes
- Beta pilot of Davenport electric motor and corresponding battery Invention Kits in the Laboratory School engineering classes
- National dissemination of galvanometer and telegraph Invention Kits on Smithsonian website
- Evaluation
  1. Collect baseline data for engineering classes
  2. Compare experimental and control classes for beta pilot in engineering classes

Spring Semester 2017
- Alpha pilot of Bell telephone Invention Kit in the Lab School physical science classes
• Beta pilot of Davenport electric motor and corresponding battery Invention Kits in the Laboratory School physical science classes

• Evaluation
  1. Collect baseline data for physical science classes
  2. Compare experimental and control classes for beta pilot in physical science classes

**Year 3**

*Summer 2017*

• Develop open source Invention Kit for Edison light and generator

*Fall Semester 2017*

• Alpha pilot of Edison light and generator Invention Kits in the Lab School engineering classes
• Beta pilot of Bell telephone Invention Kit in the Laboratory School engineering classes
• National dissemination of Davenport electric motor and corresponding battery Invention Kits on Smithsonian website

• Evaluation
  1. Collect baseline data for engineering classes
  2. Compare experimental and control classes for beta pilot in engineering classes

*Spring Semester 2018*

• Alpha pilot of Edison light and generator Invention Kits in the Laboratory School physical science classes
• Beta pilot of Bell telephone Invention Kit in the Laboratory School physical science classes

• Evaluation
  1. Collect baseline data for physical science classes
  2. Compare experimental and control classes for beta pilot in physical science classes

**D. Evaluation**

American Institutes for Research (AIR) will conduct a rigorous external evaluation of the project. This evaluation will assess (a) the fidelity of implementation as well as the facilitating factors and challenges to implementation and (b) the impact of the program on student academic outcomes. The process for selecting participating schools precludes a randomized controlled trial design, yet it is important that the evaluation yield strong results as the partners must know the extent to which the Laboratory School for Advanced Manufacturing model can and should be
replicated. To this end, the evaluation will employ a comparative interrupted time series design to examine the effectiveness of the intervention. This approach and its robustness to threats to internal validity are described in more detail below.

**Evaluation Purpose.** The evaluation is designed to answer the following research questions:

Inputs and Activities: To what extent and in what respects are participating schools receiving technical assistance to (a) Invention Kits in Engineering and Science in a new semester-long engineering course and existing physical science courses; (b) use the expanded fab lab; (c) utilize data from the technology needs assessment results to drive decision making; (d) participate in the regional professional development network; and (e) implement new performance tasks?

Outputs: To what extent and in what respects have participating schools integrated the use of emerging STEM technologies and project-based learning using the Invention Kits? Do participating schools engage in collaborative regional professional development? Do students report authentic learning experiences?

Outcomes: Does implementation of the project model lead to greater academic achievement, increased student engagement, and improved teacher efficacy?

Sample. As described above, four schools across three districts have been selected to participate in the treatment group. Two of these schools are classified as “Tier 1” and have already started to pilot the integrated curriculum. Two of these schools are “Tier 2” and will begin receiving services as part of this grant. Three remaining middle schools are not implementing the program and will serve as comparison schools. Input, output, and outcome data will be collected from both treatment and comparison schools as a part of the evaluation. Collecting both implementation data (information on program inputs and outputs) and outcome data will allow the evaluation to not only determine the extent to which participating schools increase student
achievement, but also have a clear understanding of how participating schools differ from other, similar central Virginia middle schools and thereby realize the critical components associated with any observed program effect.

**Measuring Implementation Fidelity.** AIR will examine program implementation to (a) provide periodic formative feedback to Albemarle County Public Schools (ACPS) and partner organizations, and (b) describe the implementation process to enable future replication and scale-up or testing in other settings. AIR will collect implementation data during twice-yearly site visits in each year of the grant, which will include principal interviews, teacher and student focus groups, a review of program documents, and classroom observations.

Interview and observation protocols will focus on documenting how staff members implement key components of the program and which factors support or impede their ability to do so. Focus group protocols will be designed to collect qualitative information from teachers and students about the fidelity of implementation and the extent to which implementation is contributing to the achievement of outputs, including authentic student learning experiences and project-based learning. AIR proposes to utilize the Classroom Assessment Scoring System (CLASS) observation method to provide formative feedback to individual teachers and make summative inferences at the school level. CLASS is a research-based observation protocol that was developed by the University of Virginia’s Center for Advanced Study of Teaching and Learning. The CLASS protocol focuses on effective teacher and student interactions. CLASS covers interactions across three domains: emotional support, classroom organization, and instructional support. As such, it will provide a valuable measure of the extent to which students in program classrooms are engaging in authentic learning activities that lead to higher levels of student engagement. In order to provide formative feedback to individual teachers, CLASS
observations will occur twice yearly and each participating teacher will be observed for two hours. Together with ACPS and its partners, AIR will develop a feedback mechanism for individual teachers to receive their CLASS observation results twice annually. The teacher and student focus group data will be analyzed to determine the extent to which key elements of the program are implemented at each school and the level of buy-in among teachers and students. For student focus groups, the protocol will include measures of engagement and student perception of the authenticity of the learning experience. The teacher focus group protocol will gather information on the supports that teachers receive for implementing the new curricula as well as facilitators and barriers to incorporating engineering into the middle school science curricula. Transcripts from these focus groups will be coded according to a structure designed to provide comparative information among participating schools and identify factors contributing to any differences. Site-visit data and documents will be coded according to specific themes, and a team of analysts will use a consensual qualitative research method (Hill et al., 1997) to identify recurring themes and patterns across all three sources of data.

**Measuring Impact on Student Outcomes.** Ultimately, the goal of the Central Virginia Advanced College and Career Readiness model is to increase student achievement in core middle school STEM courses and create a pathway for students to pursue advanced STEM courses in high school and advanced manufacturing careers. Academic and nonacademic data will be provided by ACPS and partner districts for individual students in both the program and comparison schools. Academic measures will include enrollment and attendance in STEM courses in middle and high school, and Virginia Standards of Learning (SOL) scores in science at Grade 8. Although Virginia SOL scores will serve as the primary source of data for student academic outcomes, the program is seeking to provide students with advanced instruction and
experience in concepts not yet measured by that test. With that in mind, teachers and project personnel will consult with AIR when developing practicum-oriented assessments to measure student mastery of the science topics they are studying. The results of these assessments, together with pre- and post-tests of engineering concepts, will be used to describe student growth. Because a primary goal of the project is to develop student desire to pursue advanced STEM education and careers, it is important to measure the extent to which implementation of the program is influencing student interest and engagement. AIR also will design and administer a student survey at baseline and at the end of each year to both program and comparison students to measure student engagement and interest in STEM career development.

AIR will use data for all outcome measures from at least three years prior to implementation of the program and each year following implementation in both program and comparison schools for the interrupted time series analysis. The time series data will allow AIR to evaluate student outcomes using a comparative interrupted time series design (CITS). CITS is one of the strongest quasi-experimental designs when a comparison or control series can be constructed (Shaddish, Cook, & Campbell, 2002). In such a design, the program effects are identified by comparing changes in the outcomes of one group over time with changes in the outcomes of another (comparison) group during the same time period. This design thus relies on two sources of variation to inform the analyses: comparisons across individuals and comparisons over time. This combination supports more robust impact estimates than a design that only relies on change over time (the standard interrupted time series framework) or on comparisons across individuals (such as a propensity score analysis).

The analysis will compare outcome trends in schools in the years preceding program implementation with outcome trends in the years following program implementation to
determine (a) the extent to which there is a sharp discontinuity in participating schools at the point of implementation, and (b) the extent to which there is a change in the slope after the initiative was introduced. Given the nested structure of the data, three-level hierarchical linear models (students nested in time nested in schools) will be used to measure the effect of the program on student outcomes. The trends in comparison schools will be included in the model to control for factors other than the program that influence student performance in ACPS and partner districts. A difference-in-difference modeling approach will be used to analyze the data from the teacher survey because only one year of pretreatment data will be available.

**Reporting and Communication.** The mixed-methods evaluation proposed here will provide detailed information on the implementation and effect of the key elements of the project. Two memoranda per year will be provided to ACPS and its partners—one midyear and one at the end of the year. The midyear memo will provide formative feedback at the school level from CLASS observations, interviews, surveys, and focus groups, and highlight key findings to guide the program’s continued development. In addition, the spring memo will include analysis of student achievement data. In the last year of the project, there will be a final summative report. After the release of each report, the evaluation and implementation teams will meet to discuss the findings and identify future areas of interest for subsequent data collection periods. For example, interview and focus group protocols may be adjusted to focus on a particular area of interest not previously identified. The final report will synthesize all findings, comparing practices, student academic performance, and student nonacademic measures over time. The proposed plans for reporting and meetings with the evaluator will ensure that ACPS and its partner organizations obtain sufficient information to allow refinement and further development of the approach.
References


