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A Transformative Apprentice Research STEM Program

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Mr. Cary James has a BS in chemistry and an MS in Plant Pathology. He has received numerous teaching awards including the Siemens Award for Advanced Placement Teacher of the Year for Maine 2009, Pulp and Paper Foundation Maine Teacher Award 2009, New England Institute of Chemistry Maine State Teacher Award 2011, New England Water Environmental Association Public Educator Award 2013, and has received the Francis Crowe Society Honorary Engineering Degree from the University of Maine 2010. Recently he presented a lecture on High School Students as Water Researchers at the Climate Change and the Future of Water Conference in Abu Dhabi. His students have excelled in many national and international level science competitions including the 2010 National Stockholm Junior Water Prize (SJWP) winner and the 2011 Bjorn von Euler Innovation in Water Scholarship winner. Both students represented the United States at the International SJWP in Stockholm Sweden. Mr. James has a passion for improving the quality of water for people in developing countries and has focused student research on water sanitation and conservation. In the classroom he works to differentiate instruction for students using an evidenced based inquiry approach.

A Transformative Apprentice Research STEM Program

(RTP – Strand 4)

University of Maine and Bangor High School

Abstract – This paper presents a Transformative Apprentice Research (TAR) STEM program for high school students. The TAR-STEM program consists of a long term research component and a supportive and rigorous STEM curriculum. The curriculum consists of existing science, mathematics, and other core/elective courses such as would be found in a traditional high school program, specialized courses that include an *introduction to research* method and two *Technology and Engineering* courses, and a University- or industry-based *research mentorship* that starts in the summer of the 10th grade and culminates in a senior capstone project. The *Introduction to Research* method class is designed to provide students with a vital, year long, full-emersion experience into the processes and activities involved with scientific and engineering research and practices. The *Technology and Engineering* courses, in 10th and 11th grades, introduce students to the technology tools and their applications in science and engineering practices through modern, hands-on experiments. These courses integrate a wide variety of university- and industry-based research topics as students participate in their research mentorship. The TAR-STEM program aligns itself with the vision of the National Research Center (NRC) Framework and the recommendations of the Next Generation Science Standards (NGSS), especially students’ engagement in science and engineering practices. The TAR-STEM students have demonstrated a greater appreciation for secondary and post-secondary STEM education.

I. Introduction

In the last few decades, researchers, educators, politicians and the general public have voiced serious concerns relating to the U.S. position in today’s high technology world. In response to these concerns, the 2007 National Academy of Science (NAS) report titled, "*Rising above the Gathering Storm*"¹, made recommendations in the areas of K-12 education, research, post-secondary education, and economic policy. Despite several positive reactions to the report, the low U.S. ranking relative to other countries, as reported in the 2010 NAS report entitled "*Rising Above the Storm Revisited*"², gave rise to a revolutionary vision in the National Research Council "*A Framework for K-12 Science Education*"³. This vision was used by 26 states as a blueprint for revolutionizing their K-12 education through the implementation of Next Generation Science Standards (NGSS)⁴.

To provide an exemplar for the implementation of the NRC Framework and the NGSS engineering practices, a team of the University of Maine faculty from the College of Engineering and teachers from Bangor High School (BHS) developed a STEM (Science, Technology, Engineering, and Mathematics) academy that integrates a Transformative Apprentice Research (TAR) mentorship into a supporting and attractive curriculum. The approach taken to promote high school students’ learning of engineering practices is to provide a coordinated program of

study that combines specialized high school coursework with long-term research apprenticeships in a professional research setting.

The concept of involving students in apprenticeships is not novel. For undergraduates, it is well known that exposure to research has taught undergraduate researchers independence, tolerance for obstacles faced in the research process, how knowledge is constructed, increased self-confidence, and a readiness for more demanding research⁵. It has also resulted in a large number of undergraduates pursuing M.S and Ph.D. degrees. At the high school level, there are a number of research opportunities, normally from 6-8 summer weeks, for highly accomplished high school students. These opportunities are mostly at university research environments or government research organizations, such as the U.S. Army REAP (Research and Engineering Apprentice Program), SEAP (Science and Engineering Apprentice Program) at the Army nine research centers and affiliated universities⁶, and others. There are two main differences between these existing programs and the one presented in this paper. First, the proposed TAR mentorship is long-term over two years, including 2 academic years at schools and 2 summers at a university or research organization. Second, the TAR mentorship is integrated with a supporting STEM curriculum that also involves teachers as mentors. Findings from other STEM programs demonstrate the effectiveness of both long-term guidance and role models for high school students, especially females and underrepresented minorities^{7,8}. The impact of the long-term TAR mentorship will be significant, and the program itself appealing especially to students often underrepresented in STEM programs, such as females, underrepresented ethnic minorities, the economically disadvantaged, and first-generation college aspirants; these students often do not engage with a STEM professional as an active role model. This synergy of a mentorship with a supporting curriculum will remove the artificial separation between secondary and post-secondary educational systems and promote students' success in higher education.

The remainder of this paper describes the TAR-STEM program and its evaluation.

II. TAR-STEM Program

A. Curriculum

The TAR-STEM curriculum consists of: 1) existing science, mathematics, and other core/elective courses such as would be found in a traditional high school program, 2) three recently developed courses: *Introduction to Research and Technology and Engineering I & II*, and 3) *Apprentice Research (AR)- I, II, III, and IV*. Figure 1 shows the TAR-STEM curriculum identifying the newly developed components in darker blue regions in bold letters. The TAR-STEM curriculum has been developed in the last couple of years by Bangor HS teachers in collaboration with the University of Maine College of Engineering faculty. The *Technology and Engineering I & II* were developed after reviewing existing engineering high school curricula such as those offered by the Boston Museum of Science, Project Lead The Way, and others. TAR-STEM was approved by the City of Bangor School Committee and has been offered since fall 2012 as a track alongside the existing curriculum. The TAR-STEM program is best understood by looking at the curriculum on a yearly basis.

In 10th grade, *Introduction to Research* lays the groundwork for how engineering research and practices is performed and *Technology and Engineering I* introduces students to some of the tools for engineering practices. During the following summer, TAR-STEM students begin apprentice research experience, *Apprentice Research I (AR-I)*, at the University of Maine or another research organization or industry. During 11th grade, students take *Engineering and Technology II*, which introduces and engages students in a series of related engineering materials, and continue their research in *Apprentice Research II (AR-II)*, which had been started in the previous summer. The student mentorship continues through *Apprentice Research III (AR-III)* during the summer after the 11th grade and will finally culminate in a capstone project in *Apprentice Research IV (AR-IV)* in 12th grade. Students will receive one credit for each of the courses including the research mentorship at school (*AR-II*).

	Req courses or Core Electives	Science	Technology & Engineering	Mathematics	Research & Practice
Grade 9	English Language Soc. Studies Health & PE	Introduction to Physics		Algebra II & Precalculus	
Grade 10	English Language Health & PE	Honor/AP Chem or BIO	Tech & Engr I	AP Calc AB	Intro to Research
Summer - Apprentice Research I					
Grade 11	English Soc. Studies Fine Art	Honor/AP Chem or BIO	Tech & Engr II	AP Calc BC or Univ Calc II	Apprentice Research II
Summer - Apprentice Research III					
Grade 12	English	AP Physics or another Science	University Calc	Capstone Project	

Figure 1. TAR-STEM Curriculum

1. Introduction to Research (10th grade)

The *Introduction to Research* class is designed to provide sophomore students in the program with a vital, year long, full-emersion experience into the processes and activities involved with scientific and engineering research. The foundation of knowledge built during this class provides students with the essential tools to complete successful research and project-oriented activities for the remainder of their high school and apprentice research experience. From the initial formation of research ideas and hypotheses to the presentation of results in adjudicated

competitions, students learn by first-hand experience, and are well positioned to begin their own long-term research projects within the apprentice research framework. Included in their intensive study, students learn and practice the most important and relevant forms of statistical analysis, the methods and procedures of conducting a thorough literature search, the design and use of models to test and explore concepts, the elements of engineering design, and the skills necessary to communicate and publish their results in a professional manner. Common research projects explored by students have included studies involving human impacts on earths, water resources exploration, ecosystem dynamics, interactions that explore cause and effect, and energy transformations. Many projects have included a significant engineering component involving design, construction, and application of technology.

2. Technology and Engineering I (10th Grade)

This course has been developed to introduce students to the technological tools and the application of those tools in science and engineering. In this course, student use MATLAB software, which has been accepted globally as a scientific programming language, to learn how to analyze data, develop algorithms, and create models and applications in an interactive environment. Students will also learn the fundamental concepts of computer programming. MATLAB contains many functions to perform tasks ranging from mathematical operations to visualization in real world applications. Emphasis has been also placed on using the MATLAB interactive environment and MySQL for data storage, retrieval, manipulation, analysis, and visualization. Students can be also introduced to freely available alternatives to MATLAB such as Python and R languages.

3. Technology and Engineering II (11th Grade)

This course has been designed to introduce students to science and engineering practices through modern, hands-on experiments. The course also integrates a wide variety of university- and industry-based research topics as students are into the second year of their research projects. The curriculum will introduce students to practices in many areas of engineering and related disciplines. During the course, students apply programming and electronics knowledge to the Raspberry Pi computer and interface with a variety of sensors for real world data collection, such as wireless water quality sensors. Students can also use robotics platforms for understanding basic concepts in kinetics, control, programming, and intelligent systems. Other projects are related to the design and development of floating platforms and turbines for offshore wind energy. While the aim of this course is on integrating general engineering practices with science concepts, *we are aligning students' learning with Maine's specific research expertise and economic development.* For example, the chemical engineering unit in the course is based on the work of the University of Maine researchers to revitalize Maine's conventional pulp and paper industry by creating new products using nano-cellulose fibers. In fact, this engineering unit inspired one female student at BHS to conduct related research with the university researcher and her work received statewide recognition. Similarly, the use of offshore wind turbine platform in the civil engineering and mechanical engineering units is due to the importance of renewable energy as one of the greatest engineering challenges of our time and the unique expertise of the university researchers in developing off-shore wind energy along the Maine coastline to benefit the state economy. While teaching the principles of science and engineering practices, this educational approach appeals to students, and also engages local industries that have supported

and will continue to support this program. In other parts of the country, this course can be tailored to their regional economic and research priorities, if so desired.

B. Apprentice Research

The apprentice research model consists of two summers (after 10th and 11th grades) under the guidance of a university or industry apprentice research mentor combined with an academic year (11th grade) and a senior capstone project under the guidance of a school research mentor (SRM).

1. Apprentice Research I (summer after 10th grade)

During Apprentice Research I (AR-I) students spend a total of 6 weeks during the summer after the 10th grade with an apprentice research mentor at the University of Maine or a local industry. Students are placed with mentors based on their pre-determined interests developed in their *Introduction to Research* course and consultation with the school research mentor. Students meet with their mentors who describe the ongoing research in terms that are understandable to the student. Further, the mentors emphasize the ultimate implication of the research in the advancement of science and engineering. The student interacts with the mentor and finalizes a particular research topic. The student initially begins a literature search relating to the project so that the student is able to ascertain the state of art relative to the research. The student then begins preliminary research under guidance of the mentor. The actual preliminary research may occur at the research facility or the high school. Based on availability of funds from the university mentor or the industry, students participating in AR-I may receive a stipend, which is a key component to engaging lower income students who may otherwise need to seek paid employment in the summer. At the end of AR-I the student would have completed the background associated with the research and would be able to start an in-depth study in the 11th grade.

2. Apprentice Research II and III (11th grade and summer following)

AR-II occurs during the 11th grade and involves about 3-6 hours per week. The participating students continue working on their project initiated in AR-I. The actual research occurs at the high school under the supervision of the school research mentor with assistance from the apprentice research mentor. At the end of AR-II students will have completed the preliminary work associated with the research and will be able to start an in-depth study. AR-III occurs during the summer of the 11th grade where students again spend approximately 6 weeks at their research organizations. The students will focus on the research project to achieve definite results. AR-II and AR-III can have substantial overlap depending on the project, student, and a host of other factors including equipment failure, illness, and availability of resources. Based on their progress, students are encouraged to submit papers to statewide and national science and engineering competitions. As in AR-I, students participating in AR-III may receive a stipend.

3. Apprentice Research (IV) – Senior Capstone Project

In AR-IV during the senior year, the student will be required to complete his/her research, write a scientific paper detailing the results of the investigation, and present the results to a committee

consisting of the high school students, teachers and their research mentors. This should include background information on the topics studied, the design and conduct of the investigation including a discussion of procedures and apparatus, experimental results, analysis of the results including experimental errors and uncertainties, conclusions, and questions for further study. With the advice of the apprentice research mentor and school research mentor, results from the research may be submitted for journal publication and/or conference presentation.

C. Alignment with the Framework and Next Generation Science Standards

The TAR-STEM courses explained above engage students in the eight Science and Engineering Practices that the K-12 Framework identifies as essential for all students to learn. These are:

- 1) Asking questions (for science) and defining problems (for engineering)
- 2) Developing and using models
- 3) Planning and carrying out investigations
- 4) Analyzing and interpreting data
- 5) Using mathematics and computational thinking
- 6) Constructing explanations (for science) and designing solutions (for engineering)
- 7) Engaging in argument from evidence
- 8) Obtaining, evaluating, and communicating information

III. Implementation and Results

The TAR-STEM curriculum has been offered as a track along with the regular Bangor High School program since September of 2012. In each year of the program, all incoming students are notified of the TAR-STEM program and connected with the school TAR-STEM program coordinator (a teacher) for any questions. The school holds information sessions illustrating the benefits of the program—including apprenticeships, work experience and community involvement to incentivize underrepresented students such as female and underrepresented minorities and economically disadvantaged students who may not be self-motivated due to a lack of supporting environment to participate in the program. Bangor High School is a public high school and any student can choose to participate in the program. However, in these early years and due to availability of trained teachers and availability of seats in the program courses, the number of students has been limited on a first come first serve basis. With training of more teachers, the program can be made available to all interested students.

Since fall 2012, 57 students (24 freshman, 8 sophomore, 13 juniors, and 12 seniors) have enrolled in the program, representing about 5% of Bangor High School incoming class. Out of the 12 senior students, 10 students (83%) will be continuing their education in a higher education STEM field, including engineering at the University of Maine or other institutions nation-wide. Other interesting results are that 37% of the students in the program are female, 19% are underrepresented minorities, and 8% are economically disadvantaged. About half of the junior and senior students have participated in one or more state, regional, national, and international science and engineering competition individually or in teams, as given in Table 1.

In addition, the TAR STEM students and teachers have also participated in many other activities including:

- Participation in Children’s Water Festival at the University of Maine with demonstrations for kids in grades 1-6.
- Multiple outreach presentations to elementary and middle schools.
- Development of a K-12 storm water education program, integrating science and engineering practices into the curriculum of all grade levels in the Bangor HS.
- Development of local assessments incorporated into the high school curriculum aligned with the Next Generation Science Standards focused on storm water as a pervasive environmental issue.
- Holding informational and training sessions for other high schools in Maine.
- Development of student *Storm Water Teams* that meet weekly to develop best management plans for their communities.
- Presentation to Maine State Legislators.

Table 1 – List of competitions for TAR-STEM students.

Competition	Year	Award	# students
Maine State Science Fair	2014 & 2015	1 st place winner	4
Maine State Science Bowl	2015	1 st place winners	5
Maine Stockholm Junior Water Prize	2014	1 st place winner	1
New England Junior Science & Humanity Symposium	2013, 2014 & 2015	Presenters & poster winners	6
National Science Bowl	2015	Presenter	6
National Junior Science Symposium	2014	Presenter	2
International Science & Engineering Fair	2013 & 2015	Presenter	3
International Sustainable, energy, Environment & Engineering Project Olympiad	2015	Presenter	1

IV. Conclusion

A Transformative Apprenticeship Research STEM (TAR-STEM) program was presented in this paper. The early results have shown that this program offers a promising model for the implementation of the NRC Framework and the NGSS engineering practices. The program can be easily implemented in other high schools nation-wide through a cooperative effort between secondary and post-secondary institutions. Essentials to the success of the program are professional development opportunities for teachers to be able to offer the proposed new courses and commitment of the school administrators to facilitate the implementation of the new curriculum.

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