Dynamic Project-based STEM Curriculum Model for a Small Humanities High School

Chin-Sung Lin, Zhigang Zhu and Tony Ro
clin@erhsnyc.net, zzhu@ccny.cuny.edu, tro@gc.cuny.edu

Abstract – **Reforming STEM education has been an urgent national call for both educational and economic reasons. For Eleanor Roosevelt High School, a small humanities high school in New York City, implementing a large-scale, school-wide STEM education is almost an unattainable goal due to limited STEM resources. However, we have developed a novel, dynamic project-based STEM curriculum model in the past five years. This model will provide students with in-depth exposure to computer science and engineering, broad and rigid training of innovative engineering problem solving, and independent research experience with challenging real-world problems. The curriculum has been vertically integrated over grades to create a cohesive learning experience and to maximize learning outcomes. It can dynamically evolve over time to reflect cutting-edge advancements in the STEM field. One of the most challenging steps in developing the STEM curriculum model is the creation of the 'Research & Development' layer of the model. Fortunately, the NSF-founded Emerging Frontiers in Research and Innovation-Research Experience and Mentoring (EFRI-REM) summer program at The City College of New York provides inspirations and insights to these problems. Though this model has been developed in a small humanities high school, it can easily be scaled up or down for schools of various sizes and adopted by schools of different context and resource levels. We have further proposed a new STEM research paradigm for college-high school collaboration, dramatically accelerating the renew rate of high school STEM curriculum.**

Index Terms – STEM education, High school, Dynamic curriculum, Project-based learning, STEM research.

INTRODUCTION

Due to consistent low performances in international assessments, such as PISA [1], and the severe global competition, reforming STEM education has become an urgent national issue. There are several nation-wide educational initiatives and programs, such as PLTW [2], that have been suggested and deployed in many schools throughout the U.S. However, for Eleanor Roosevelt High School (see Table I for school profile as of 2015), a small humanities high school in New York City, implementing a large-scale, school-wide STEM education is almost an unattainable goal due to limited STEM resources. As shown in Table I, female students account for 59% of the enrollment, but only 1/3 of the AP courses are STEM related. In the past five years, with strong support from the school administration, parent teacher association, and through collaboration with the City College of New York through a National Science Foundation (NSF)-founded Emerging Frontiers in Research and Innovation Research Experience and Mentoring (EFRI-REM) summer program, we have gradually developed a novel, and dynamic project-based STEM curriculum model.

TABLE I
SCHOOL PROFILE OF ELEANOR ROOSEVELT HIGH SCHOOL [3]-[4]
(DEMOGRAPHICS: BLACK, HISPANIC, ASIAN AND WHITE)

Enrollment	557	(M) 41%	(F) 59%	
Demographics	(B) 4%	(H) 11%	(A) 20%	(W) 61%
Graduation Rate	100%			
SAT Average	1889			
AP Courses	12	$^2/_3$ Non-STEM	$^1/_3$ STEM	

The goals of the curriculum model are three-folds: (1) to promote computational and engineering problem solving as basic education for every student; (2) to deepen students' understanding of STEM through project-based learning; (3) to encourage students to explore and pursue STEM careers.

This model will provide students in-depth exposure to a wide spectrum of STEM fields, especially in engineering and computer science. It ranges from computer science and engineering, robotic construction and programming, drone navigation and sensing, 2D engineering drawing and 3D modeling, desktop and mobile application programming, to various specialized STEM fields chosen by students. The model focuses on rigid training of innovative engineering problem solving through intensive project-based learning. All the classwork and homework are aligned and aimed to prepare students to solve a central problem in each unit. The model also provides advanced STEM students independent research experience in solving real-world problems. Although most of the problems are complex and challenging, the mentoring, resource, and project support from City College have broaden students' view and inspire students to conduct challenging STEM research.

The curriculum has been vertically integrated over grades to create a cohesive learning experience. Project content in lower-level courses is designed to form the foundation for advanced projects in higher grades. It increases learning efficiency and maximizes learning outcomes. At the same time, successful, mature research projects from higher grades will be transferred down to the

978-1-4673-9773-5/16/$31.00 ©2016 IEEE

lower-level courses. Through this 'technology transfer' mechanism, the STEM curriculum will dynamically renew itself, and evolve over time to reflect the state-of-art advancements in the STEM field.

In the following sections, we will briefly introduce a series of STEM courses, the distinct features of this model, its preliminary implementation and evaluation, and lessons learned from classroom experiences. We will also propose a new STEM research paradigm for college-high school collaboration. By combining the new research paradigm with our current dynamic curriculum model, we will be able to foster student-centered STEM research, strengthen the collaboration between high school and colleges, streamline the 'technology transfer' process, and bring impact to high school STEM education.

STEM COURSES

The STEM curriculum consists of three major courses: Computational Thinking (CT), Robotics & Engineering Design (R&ED), and Advanced STEM Research (STEMR) as shown in Table II.

TABLE II
STEM COURSES

Grade	Course	Type	Periods/Week	Length
10	CT	Mandatory	3	½ year
11	R&ED	Elective	4	1 year
12	STEMR	Elective	4	1 year

These three courses correspond to three layers of our STEM curriculum model: concept & skill building, design & problem solving, and research & development (as shown in Figure I.) Each layer represents different level of competency in STEM education.

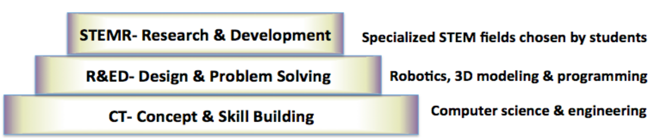

FIGURE I
THREE LAYERS OF STEM CURRICULUM MODEL

I. Computational Thinking

CT is a semester-long course that uses a hands-on approach to introduce students to the breadth of the field of computer science and engineering. Students will explore the full spectrum of theoretical concepts and practical skills of computer science, methodologies of hardware and software design, and real-world applications in visual art and mobile programming. There are two reasons for choosing computer science as the fundamental knowledge and skill-building layer of our model: (1) computer technology has been penetrating into every STEM discipline; (2) students can pick up basic computer concepts and skills without prior knowledge. CT course has been organized into eight units as shown in Table III.

TABLE III
COMPUTATIONAL THINKING COURSE UNIT STRUCTURE

Unit	Title	Key Contents
1	Computer Anatomy	Computer HW/SW structure, components & hierarchy
2	Binary World	Binary arithmetic, digitization & digital technology
3	Logic Gates & Boolean Algebra	Logic gates, truth tables & Boolean functions
4	Digital Circuits Design	Logic circuits, simplification, simulation & synthesis
5	Computational Problem Solving	Problem solving methods & algorithmic problem solving
6	Algorithms & Programming	Algorithm types, flow charts, pseudo code & programming
7	Software Applications	Image structure, formation & Hough transform for digital art
8	Mobile Apps Programming	Mobile programming model, storyboard & UI components

II. Robotics & Engineering Design

The R&ED is a yearlong problem-based course that introduces the basic concepts and skills of robotics and the principles and practices of engineering design. The course covers a broad scope of learning (as shown in Figure II.) For the 2015-16 academic year, the course has been divided into five modules: Remote-Controlled Robots, Autonomous Mobile Robots, Drone Programming, 3D Modeling & Printing, and Mobile Apps Programming. The topics of the course were updated every year to incorporate new development in the STEM fields. Students will learn the concepts and theories in each module, be exposed to a wide spectrum of innovative problem solving and engineering design techniques, and be challenged by a series of real-world application projects.

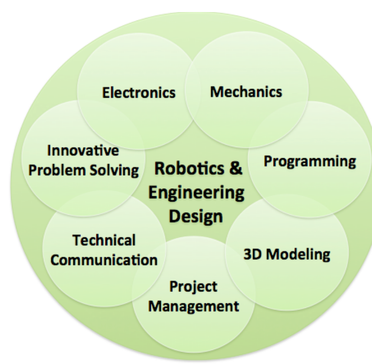

FIGURE II
SCOPE OF LEARNING OF ROBOTICS & ENGINEERING DESIGN

III. Advanced STEM Research

The primary purpose of STEMR course is to provide students opportunities for firsthand research in student-chosen STEM topics. Research is a self-directed, mentored work that enables individuals or groups of students, in collaboration with a teacher, to investigate their own problems of interest. Student researchers will conduct in-depth studies, experiments, designs, implementations, and testing. They will communicate their research results through physical demonstrations, oral presentations, and written technical reports.

In addition to advising and supporting students' research projects, a few research-relevant topics (as shown in Table IV) will be explored and discussed throughout the course of the year. Students will be expected to finish assignments relevant to these topics. These activities will provide students with basic research tools, broaden their views, enhance their understanding of non-technical issues about research, and develop their research capabilities.

TABLE IV
STEM RESEARCH DISCUSSION TOPICS

No.	Topic	Key Contents
1	Introduction to Research	STEM research, research problems & nature of research
2	Literature Review	Types of literatures, formats & evaluation criteria of reviews
3	Project Management	Project definition, phases, personnel roles & Gantt chart
4	Patent Search and Analysis	Patent types, classification, patentability, search & analysis
5	Innovative Problem Solving	Systematic problem solving, solution space & innovation
6	Technical Communication	Presentation skills, technical writing & demonstration
7	Ethics and Responsible Conduct	Scientific misconduct, human subject, & mentoring
8	Funding and Support	Government funding & crowd funding

All the courses are organized into various numbers of units. Students will work in groups to solve problems and design and test complex deliverables - culminating in a challenging project for each unit.

PROJECT-BASED LEARNING

Traditional STEM curriculum model is subject-based. Learning every aspect of the subject is the main goal. Real-world problems or applications are peripheral in this model. However, Project-based learning (PBL), alternatively known as problem-based learning, has a drastically different focus. Authentic, real-world problems are at the center stage. A comparison between these two models are illustrated in Figure III & IV.

PBL is the underpinning of all our STEM courses. Our STEM curriculum shares seven defining features of PBL: project/problem-centered, student-driven, challenging open-ended problems, constructive investigation, collaboration, interdisciplinary, and real-world applications [5]-[6].

Table V shows some STEM project examples in our curriculum. The project topics vary on a yearly basis due to curriculum updates or students' choices. Most of the project topics are complex, challenging, and bearing real-world applications. High school students are very easily frustrated when they encounter difficulties. Students need strong scaffolding through lesson plan design and project technical support in order to finish their projects. All the classwork and homework are aligned and aimed to prepare students to solve the central problem of each unit project. Templates are used widely in every aspect to assist student learning. High-performance students and students from higher cohorts are encouraged to support current students.

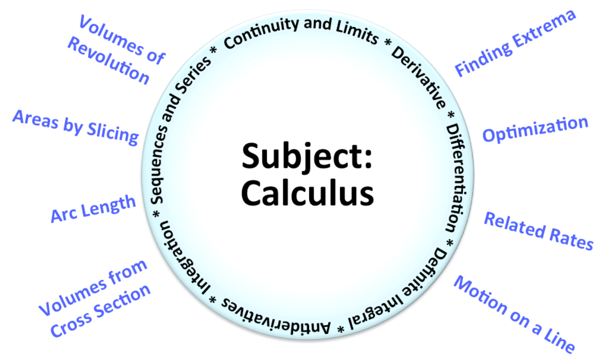

FIGURE III
SUBJECT-BASED MODEL: CALCULUS

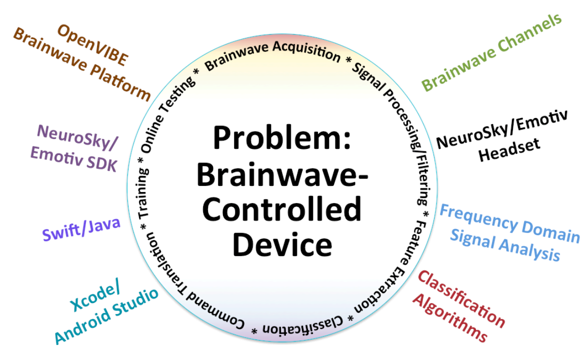

FIGURE IV
PROJECT-BASED MODEL: BRAINWAVE-CONTROLLED DEVICE

TABLE V
STEM PROJECT EXAMPLES

Course	Topics
CT	Computer purchasing (students play different professional roles to purchase computers, software & peripherals)
CT	Skyscraper algorithm (students need to develop optimum and general algorithms to build skyscraper in shortest time)
CT	Logic circuits design (BCD-to-7-segment decoder, 4-bit comparator, multiplier, ALU & BCD adder)
CT	Digital artist (use Hough transform to create visual art)
CT	Data analysis (sort, search & process data of a 2000-people company database)
R&ED	Tennis ball collecting robots
R&ED	Machine design: linkages & mechanisms
R&ED	Walking robots
R&ED	Autonomous parallel parking
R&ED	Autonomous drone landing
R&ED	Polypods: 2D geometric unfolding of 3D polypod structure
R&ED	3D modeling & printing
R&ED	Fractals
R&ED	Mobile apps design
STEMR	Brainwave-controlled device
STEMR	Vision-based autonomous drone navigation in indoor environment
STEMR	Wearable generator design based on human gaits
STEMR	Electrovibration-based tactile display design & programming
STEMR	Compound eyes-based drone tracking & intercepting system

Project topics of STEMR are highly challenging, real-world problems. They are either chosen by students from a given list provided by teacher or proposed by students directly. The teacher created his topic list based on his own independent research and the research experience of EFRI-REM summer program. A proposal evaluation and approval procedure is in place to filter students' proposals and facilitate the project creation process. STEMR projects can be long-term, multi-year projects. Students are exposed to the longevity aspect of STEM research that is seldom a feature in high school student projects. Project groups are asked to document their work properly to ease the technology transfer process and to ensure project continuity.

Students are expected to be more and more independent when they move up the STEM curriculum ladder. In CT - Computational Thinking, students contribute about 20% of the work to the success of the project, while 80% of the work consists of templates provided by the teacher. The percentage of independent work grows and reaches about 50% in R&ED - Robotics and Engineering Design. Student project groups in R&ED need to solve many open-ended problems with their own designs and implementations. In STEMR - Advanced STEM Research, students will be responsible for most of the work (80%) following the engineering design process as shown in Figure V. Teachers play the role of advisors - providing initial momentum for research and advising project directions and strategies. This training prepares students to be independent researchers and so, readies them also for participation in future, post-graduation, college research opportunities.

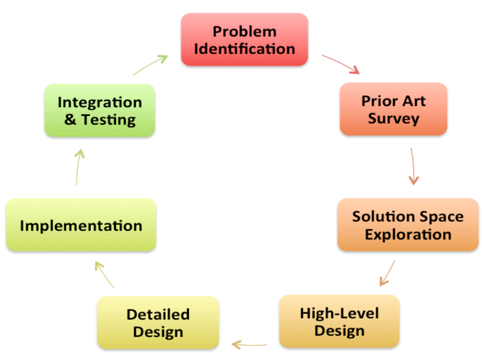

FIGURE V
ENGINEERING DESIGN PROCESS MODEL

Project groups are formed based on student profiles filled out by students at the beginning of the year. It is a combination of students' common interests, background knowledge and skills, collaboration styles, and personal preferences. Each CT project group is made of two students, while each R&ED project group consists of two to four students. STEMR teams include two student researchers. Up to three teams may join together to form a project group. The choice of small STEMR team sizes is to enhance student accountability, while larger group sizes allow students to tackle complex projects and foster collaboration.

Project assessment is completed by both teachers and students. Peer assessments are common in higher-level courses, such as R&ED and STEMR. Figure VI shows a rubric for an R&ED project. The grading of project deliverables regularly includes a 'time to market' factor to encourage project groups to improve project management and optimize workflow.

Grade	Poor 1	Fair 2	Good 3	Outstanding 4
Creativity	Implement a non-effective mechanism	Implement an effective mechanism	Improve the existing mechanism	Create a new mechanism
Functionality	No indication of a functioning mechanism	The design is functional, but has defect(s)	The design fulfill the functional requirements	The design exceeds the functional requirements
Complexity	The design use trivial & simple mechanism	The design has average-level of complexity	The mechanism is complex & difficult to implement	The mechanism is very complex & difficult to implement
Efforts	Robot is built without any major efforts (< 2 hours); presentation is unprepared	Robot is built with some efforts (2~5 hours); presentation and demo are prepared	Robot is built with major efforts (> 5 hours); Presentation and demo are well designed and coordinated	The robot is thru many revisions & with high quality; presentation includes well designed demo routine, logical communication & proper use of multimedia

FIGURE VI
A RUBRIC OF PEER ASSESSMENT FOR AN R&ED PROJECT

VERTICALLY INTEGRATED AND DYNAMIC CURRICULUM

The STEM curriculum has been vertically integrated over grades to create a cohesive learning experience. There are two major processes happening in this integrated curriculum (as illustrated in Figure VII). First, project contents in lower-level courses are designed to form the foundation of advanced projects in higher grades. For example, while the image structure and formation topics help students to create digital art in CT, they also form the foundation for students to create fractals in R&ED and handle video processing for autonomous drone navigation in STEMR. As an additional example, the brief exposure of mobile app design in CT will grow and expand into a full-scale mobile programming project in R&ED. These mobile programming skills will become useful tools in STEMR projects, such as brainwave-controlled games on mobile devices. The vertically integrated curriculum increases learning efficiency and maximizes learning outcomes.

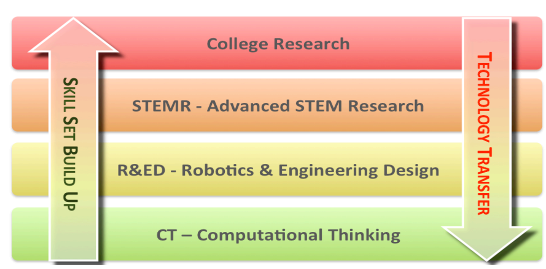

FIGURE VII
TWO PROCESSES IN A VERTICALLY INTEGRATED STEM CURRICULUM

At the same time, successful, mature research projects from higher-grade courses or college research program will be transferred down to lower-level courses. For example, in the past two years, Mr. Lin (with two of his students in 2014 and one student in 2015 from Eleanor Roosevelt High School) has conducted summer research at City College of New York through a NSF-REM Program. The research was focused on 2D tactile display based on electrovibration for the visually impaired. That summer research experiences were then used and filtered back into high school education. They transferred down, resulting in the formation of three STEMR projects (as shown in Table VI), a programming activity in R&ED, and an after school research group based around the original focus on the visually impaired.

In this curriculum model, new waves of research in academia can propagate to STEMR. Mature STEMR projects will be transferred to R&ED and the contents of CT course will be updated accordingly to prepare students for the new challenges. In the STEM world, technical innovations are happening daily. High school students have long been isolated from this fascinating reality. Through this 'technology transfer' mechanism, the STEM curriculum will dynamically renew itself, evolve over time to reflect the state-of-art advancements in the STEM field, and potentially ignite cultural change in high school STEM education.

TABLE VI
ACTIVITIES CREATED FROM SUMMER RESEARCH EXPERIENCE

Course	Topic
R&ED	Mobile apps programming using VoiceOver technology
STEMR	Educational mobile app using FeelScreen technology for the visually impaired
STEMR	Subway mobile app for the visually impaired
STEMR	Multi-pixel electrovibration tactile display
Club	After school 'Second Dimension' research group aimed to create technology for the visually impaired

NSF EFRI-REM SUMMER RESEARCH

One of the most challenging steps in developing the STEM curriculum model is the creation of the 'Research & Development' (R&D) layer of the model (i.e. the STEMR course). The reasons why R&D is challenging are that (1) there are not many STEM research resources in a small humanities high school, (2) STEM projects are complex in nature, and (3) students have very limited exposure to STEM. So, the major challenge in establishing an advanced STEM research course is not only technical, but also cultural.

Questions like "What are the cutting-edge research topics?", "How do high school students conduct research?", "How can teachers support students' research in very specialized fields?", and "How can we motivate students to go the extra mile in research?" are very practical questions we have encountered at the beginning. Fortunately, the National Science Foundation (NSF)-founded Emerging Frontiers in Research and Innovation- Research Experience and Mentoring (EFRI-REM) summer program at The City College of New York provides inspirations and insights to these problems. The EFRI-REM program catalyze the development of STEM curriculum model in several aspects:

I. Highly Effective Research Model

There are several important features in the EFRI-REM summer program, which make it a highly effective research model [7]:

- Challenging, interesting and practical research topics.
- In-depth and intensive project contents.
- Aggressive project schedule and goals.
- Regular progress monitoring through individual student presentations at weekly meetings.
- Enthusiastic, quality one-on-one mentoring support on both administrative and technical needs of students.
- Heterogeneous research community consisting of college professors (advisors), Ph.D. students (mentors), community college faculty (mentors), college students, community college students, high school teachers, and high school students.
- Highly motivated, skillful student researchers.

Some of these features have been incorporated into the STEMR course. For example, many interesting cutting-edge EFRI-REM research topics [7]-[8] can be adopted as our research topics, and regular progress meetings have been part of our STEMR class.

Due to resource limitation of high school environment, we are still trying to improve the mentoring support of research projects. We are in the process of building external connections to enlarge our research community. Also, we are communicating with school administration to establish a recruiting and filtering mechanism for the STEMR course.

II. Domain Knowledge

EFRI-REM summer program provides an opportunity for high school teachers and students to conduct hands-on research on real-world problems. Research participants can acquire research methodology, in-depth knowledge and practical lab skills of specific research fields. For example, Mr. Lin has been working on the "2D Tactile Display Based on Electrovibration" project for two years. Mr. Lin reviewed technical literature, searched relevant patents, surveyed commercially available components, evaluated various tactile technology, designed system architecture (see Figure VIII), and implemented electrovibration circuits (see Figure IX), program the mobile application (see Figure X), conduct system testing, and identify future improvement (see Figure XI).

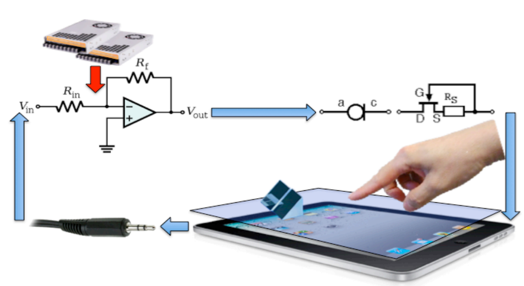

FIGURE VIII
SYSTEM ARCHITECTURE OF AN ELECTROVIBRATION 2D TACTILE DISPLAY

These experiences will give research participants the confidence and domain knowledge of a specific research field. High school teachers will be able to support high school students conducting advanced research in the STEM field.

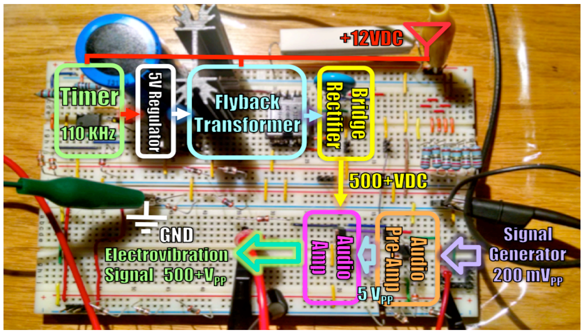

FIGURE IX
IMPLEMENTATION OF ELECTROVIBRATION CIRCUITS

FIGURE X
MOBILE APPLICATION FOR 2D TACTILE DISPLAY

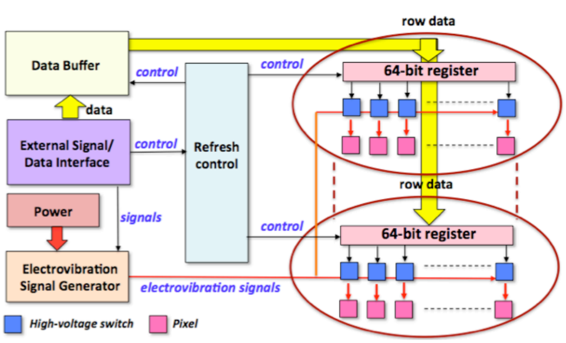

FIGURE XI
FUTURE IMPROVEMENT: MULTI-PIXEL TACTILE DISPLAY

III. Integrated, Dynamic Curriculum and Beyond

EFRI-REM summer program bridges the gap between college and high school by involving high school teachers and students in advanced STEM research projects and channeling research ideas, resource, experiences, and mentoring support to high schools. The college research has become part of this vertically integrated STEM curriculum model, and brings direct impacts to the high school STEM education.

In addition, the EFRI-REM program has accelerated the process of STEM curriculum updating. Figure XII shows the temporal view of how the summer research triggers curriculum change. It used to take an indefinite time to update a curriculum. Now, it only takes about 2~3 years to transfer a new research from colleges to high schools. EFRI-REM program provides a structured mechanism to foster and trigger that change and create a dynamic curriculum.

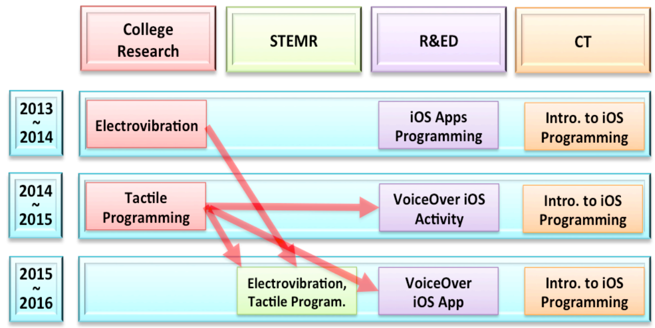

FIGURE XII
TEMPORAL VIEW OF THE DYNAMIC CURRICULUM

Furthermore, summer research provides high school teachers and students an open window to the academic world through attending research conferences, forming new connections, participating in academic activities, and exposing to new STEM opportunities.

Though this vertically integrated, dynamic curriculum can reduce the time of technology transfer from college to high school to about 2~3 years, however, is there anyway to further accelerate the pace of technology transfer? In addition, EFRI-REM program at City College will end this year since it is a supplement to the core four-year EFRI research grant there. How will the STEM curriculum model become self-sustainable? Based on the implementation experience of the current technology transfer process, there are a few issues in this model:

- **Limited research topics**: Though high school teachers can gain valuable, in-depth knowledge and skills of a specific research field, there will be only one topic per year.
- **Teacher-centered**: Since the specific research topics will be passed down from the teacher, students may not be interested, and be motivated to participate.
- **Limited expertise**: Since teachers are trained only in specific research field, it will be very difficult to provide technical support to other student research projects outside the specific field.
- **Time resource**: When teachers are busy catching up multiple students' research projects, there will be no time left to create new lesson plans and integrating higher-level projects into lower-level courses.

These issues will prolong the technology transfer throughout the whole curriculum pipeline, reduce its effectiveness, and even affect the sustainability of the current model. It shows the need to have a new research paradigm.

PRELIMINARY IMPLEMENTATION AND EVALUATION

The project-based STEM curriculum started from 2010-2011 academic year as a semester-long, elective Robotics course for juniors and seniors. Before that, there were a few Art-Technology electives focusing on Digital Photography and Animation. The Robotics course expanded into a yearlong R&ED course in 2011-2012. In order to bring broader impact to students in their early-year of high school education, we have created CT level course for all the sophomore students in 2013-2014. As all the students received basic CT training, project-based STEM education became more acceptable in school and more popular among students. Feedbacks from parents through parent-teacher conference were also very positive. In 2014-2015, we initiated the STEMR course (Lin) to increase the depth of STEM education. STEMR course links to college research through the NSF EFRI-REM summer program. Started form this academic year (2015-2016), two other teachers in the school have started two new project-based STEM courses: Audio Science (AUD) and Game Design (GAME). Though the enrollment of individual STEM courses may fluctuate due to differences among cohorts and scheduling issues, the overall students' involvement in project-based STEM education increases steadily (see Table VII). Currently, there is about 40% of the student population participating in some sort of project-based STEM education this year, compared to the 1/3 STEM related AP courses.

TABLE VII
STUDENT ENROLLMENT OF PROJECT-BASED STEM COURSES

Course	10-11	11-12	12-13	13-14	14-15	15-16
CT	N/A	N/A	N/A	127	133	134
R&ED	24	23	34	66	37	13
STEMR	N/A	N/A	N/A	N/A	11	18
AUD	N/A	N/A	N/A	N/A	N/A	34
GAME	N/A	N/A	N/A	N/A	N/A	33
Total	24	23	34	193	181	232

Based on a survey at the beginning of the year in STEMR class, the top choices of possible college majors are shown in Figure XIII.

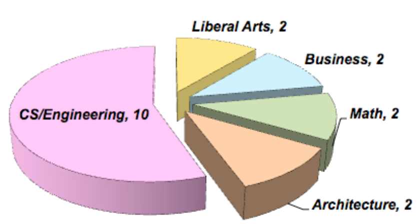

FIGURE XIII
TOP CHOICES OF POSSIBLE COLLEGE MAJORS IN STEMR CLASS

NEW STEM RESEARCH PARADIGM

A new STEM research paradigm has been proposed to resolve the problems in the current model. Teachers' role as the lead researcher actually becomes the bottleneck of the technology transfer process. In the new paradigm, the role of the teacher has been dramatically transformed from a 'researcher' to a 'facilitator'. The new role of the teacher is illustrated in Figure XIV.

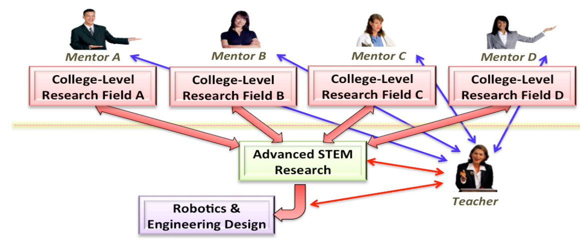

FIGURE XIV
TEACHER'S ROLE IN THE NEW STEM RESEARCH PARADIGM

The features of this new paradigm are listed below.

- Multiple mentors from various research fields will directly mentor the corresponding research teams in high school.
- Students conduct the research of their interests, and receive advice and support from experts in the fields.
- Teachers receive intensive training from each mentor to get the essence (theoretical background, key domain knowledge, computer languages, or equipment) of each project.
- Teachers coordinate, support, supervise, and assess students' daily research activities.
- Teachers update the curriculum and lesson plans to incorporate the new technology into the lower-level courses.

The roles of people involved in this new paradigm are summarized in the following list and illustrated in Figure XV.

- **Program director**: College professor coordinates the overall activity on the college side.
- **Mentors**: Ph.D. students are the mentors who advise high school research teams, and provide or coordinate training to high school teachers.
- **Consultants**: Graduate/college students with technical specialties who will provide technical support as requested on specific topics within their specialties.
- **High school coordinator**: High school teacher coordinates the overall activities on the high school side, supports and supervises students' daily research.
- **Research teams**: High school students who conduct intensive STEM research of interests.

The timeline and major activities of this model are summarized in the following list and illustrated in Figure XV.

- **STEM project proposal fair**: Before the end of the previous academic year, there will be a physical or online project proposal fair for high school research teams and college mentors to find research topics of common interests. Topics can originate from both. It is a matching and creation phase of new research projects.
- **Teacher research workshop**: During the summer, high school teachers will attend workshops and receive intensive training on essential knowledge and skills relevant to the new research projects.
- **Online research forum**: During the academic year, the forum allows high school research teams to receive real-time technical support from college mentors and consultants to resolve problems and issues.
- **On-site technical support**: For complex technical problems or complete training of specific technologies, consultants will provide on-site technical support as requested throughout the academic year.
- **STEM project showcase**: Near the end of the academic year, research teams will have a formal meeting to showcase and publish their research results.
- **STEM curriculum sharing**: At the end of the academic year, teachers will share their new curriculum and lesson plans online.

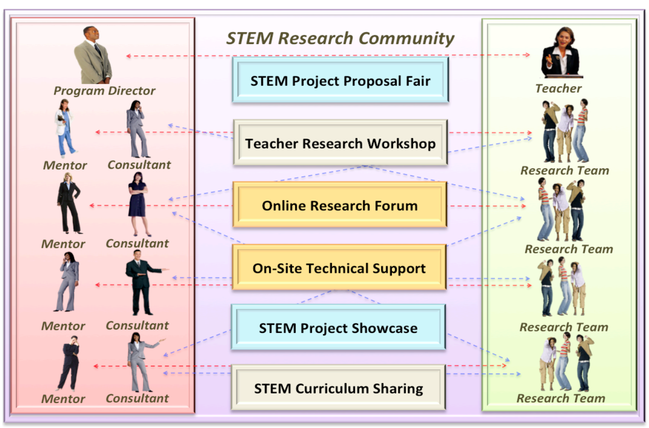

FIGURE XV
STEM RESEARCH COMMUNITY UNDER THE NEW STEM PARADIGM

Based on this new research paradigm, the technology transfer time from college to high school can be further reduced to one year. If college treats high school research teams as part of their research groups, college and high school research teams can even conduct same research synchronously. Through this research paradigm, a new, heterogeneous research community will form, and conduct diverse student-centered research activities. This paradigm can be easily scaled up to include multiple colleges and high schools, or even beyond geographic boundaries. An online research portal will be able to integrate nation-wide resource and foster collaboration of research teams across the country.

CONCLUSION

A vertically integrated, dynamic STEM curriculum model has been implemented. It makes basic computational and engineering problem solving education accessible to all students. It deepens students' understanding of STEM through intensive, hands-on, project-based learning. It provides advanced student opportunities to conduct STEM research to solve complex real-world problems. Though this model has been developed in a small humanities high school, it is scalable for high schools of various sizes, and adopted by schools of different context and resource levels. A new STEM research paradigm for college-high school collaboration has been proposed. This new paradigm will dramatically accelerate the high school STEM curriculum renewal process, support student-centered research, narrow the gaps between colleges and high schools, create a heterogeneous, collaborative research community, and maximize research effectiveness and outcomes. It has the potential to be scaled up and foster collaboration among multiple colleges and high schools beyond geographic boundaries, and bring long-term impacts to both STEM education and industry.

ACKNOWLEDGEMENT

This work is supported by NSF EFRI-REM under Award # EFRI-1137172, to The City College of The City University of New York.

REFERENCES

[1] "PISA Results 2012: United States – OECD." 2012. www.oecd.org/unitedstates/PISA-2012-results-US.pdf. Accessed: December 11, 2015.
[2] PLTW, "Project Lead the Way." www.pltw.org. Accessed: December 11, 2015.
[3] NYC Department of Education: School Quality Snapshot 2014-2015. schools.nyc.gov/OA/SchoolReports/2014-15/School_Quality_Snapshot_2015_HS_M416.pdf. Accessed: January 24, 2015.
[4] NYC Department of Education: Annual Arts in School Reports 2014-2015. schools.nyc.gov/documents/ArtsReport/2014-15/ArtsReport_M416.pdf. Accessed: January 24, 2015.
[5] John W. Thomas. "A review of research on project-based learning." www.newtechnetwork.org.590elmp01.blackmesh.com/sites/default/files/dr/pblresearch2.pdf. Accessed: December 11, 2015.
[6] John R. Savery. June 2007. "Overview of problem-based learning: Definitions and distinctions." *Essential Readings in Problem-Based Learning,* pp. 8.
[7] Zhigang Zhu, Wai L. Khoo, Camille Santistevan, Yuying Gosser, Edgardo Molina, Hao Tang, Tony Ro and Yingli Tian, EFRI-REM at CCNY: Research Experience and Mentoring for Underrepresented Groups in Cross-disciplinary Research on Assistive Technology. The 2016 IEEE Integrated STEM Education Conference (ISEC), March 5, 2016, Princeton, New Jersey.
[8] REM 2015 @ CCNY: Partnership of Government, Academia, Communities and Families to Train the Next Generation STEM Workforce, ccvcl.org/%7Ekhoo/REM2015/Program.html. Accessed: January 24, 2015.

AUTHOR INFORMATION

Chin-Sung Lin, Teacher, Eleanor Roosevelt High School.
Zhigang Zhu, Professor of Computer Science, The City College of New York, CUNY.
Tony Ro, Professor of Psychology, The Graduate Center, CUNY.