Underpinning the concept of Integrative STEM Education is Technology and Engineering Education, which remains the disciplinary base—the "T" and "E" in STEM education.

INTEGRATIVE STEM Education at Virginia Tech:

GRADUATE PREPARATION FOR TOMORROW'S LEADERS

BY JOHN G. WELLS

Founded in 1946, the Technology Education program at Virginia Tech (VT) has enjoyed a long history of program excellence in preparing professionals for our field and has a well-earned reputation for leading outside the box. Keeping with those traditions, in the fall of 2005 the VT Technology Education program embarked on a bold new vision for preparing 21st Century educators and to again provide leadership at the bleeding edge of a changing field. The genesis for such a paradigm shift at VT was due in part to national reform efforts addressing the need for preparing individuals equipped to substantively contribute as members of a science, technology, engineering, and mathematics (STEM) literate citizenry (NAE & NRC, 2002; ITEA/ITEEA, 2000, 2002, 2007; CSMEEC, 1999; AAAS, 1989). This need was coupled with national concerns that graduate preparation programs were not "making interdisciplinary work a more integral part of doctoral education" (Nyquist & Woodford, 2000, p. 6). These concerns called for fundamental changes in the paradigm of traditional STEM educator preparation and the development of a new model designed to mentor STEM education leaders of tomorrow. That new model, first proposed at Virginia Tech, was the Integrative STEM Education Graduate Program intent on challenging the traditional paradigms of graduate education.

A NEW STEM EDUCATION PARADIGM

The window of opportunity for substantively changing education opened decades ago, and for more than 30 years the Technology Education (TE) profession in the U.S. has been committed to developing avenues to embed science, engineering, and mathematics content and practices into its curriculum. Likewise throughout this same time period, educational reformers in science and mathematics were revising their respective curricula to incorporate technological content and practices. That these reform efforts were occurring in tandem is no surprise given that in 1983 the National Commission on Excellence in Education declared that "Our nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world" (p 1). Their report placed the blame for our fall from dominance on the soft pedagogical practices of the American educational system: "Our society and its educational institutions seem to have lost sight of the basic purposes of schooling and of the high expectations and disciplined effort needed to attain them" (p 1). Since that starting point early in the Excellence Reform Movement (Berube & Berube, 2007), educational reform in the U.S. has been steadfast on improving student content knowledge and understanding of science, mathematics, and technology (SMT).

The SMT direction for curricular change was promoted at the national level with the 1989 publication *Science for All Americans* (AAAS, 1989) along with *Benchmarks for Science Literacy* that followed in 1993. These documents provided the rationale and conceptual structure that guided major curriculum reform efforts aimed at improving student interest and proficiency in SMT. As important today as it was then, the unmistakable intent behind these AAAS publications was for curricular reformers to envision the teaching of these content areas as an integrative endeavor. This intent was clearly conveyed in the concept of science as being "…the union of science, mathematics, and technology that forms the scientific endeavor…" (AAAS, 1989, p 25) and "…the ideas and practice of science, mathematics, and technology are so closely intertwined that we do not see how education in any one of them can be undertaken well in isolation from the others" (AAAS, 1993, pp. 321-322). In the decades following these publications, each of the science, technology, and mathematics education communities developed curriculum reform documents reflective of this intent. To this day, however, in practice public education continues its support of the traditional silo approaches of teaching STEM disciplines in isolation one from the other. Moreover, no programs were ever designed to develop educators who envisioned the teaching of STEM content and practices as an integrative endeavor.

LEADING OUTSIDE THE BOX

Within the context of national education reform, the phasing out in 2003 of all undergraduate teacher preparation programs at VT, and the growing emphasis beginning in 2005 on STEM education in the School of Education, was the opportunity to recast the traditional Technology Education graduate program and envision an entirely new model of graduate preparation—one designed to address the need for a new generation of STEM educators who challenged the existing silo mentality frameworks and embraced the teaching of STEM education as an integrative endeavor. Responding to this opportunity, the VT Technology Education faculty conceived of a graduate program in the fall of 2005 with the primary goal of developing P-20 STEM educators, leaders, scholars, and researchers prepared as catalysts of change for teaching, disseminating, and investigating integrative approaches to STEM education. This goal served as the premise for concept and creation of the new Integrative STEM Education (I-STEM ED) graduate program.

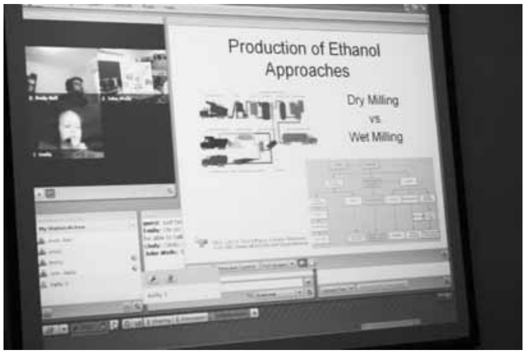
The foundation of Integrative STEM Education is Technology and Engineering Education, which remains the disciplinary base—the "T" and "E" in STEM education. Building on its functional role as an integrator of content and practices across disciplines (ITEA,/ITEEA 2000/2002/2007, pp. 6-9), I-STEM ED provides the pedagogical tenet of integrative practices where technological/engineering design based learning is an instructional requirement. The essence of the new graduate program at Virginia Tech is conveyed in how Integrative STEM Education is defined.

> "Integrative STEM Education is the application of technological/engineering-design-based approaches to *intentionally* teach content and practices of science and mathematics education concurrently with content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels" (Wells & Ernst, 2012).

The term "integraTIVE" implies an ongoing, dynamic, learner-centered process of teaching and learning distinct from "integraTED," which connotes a static, completed teacher-centered process. Concepts critical in structuring this definition, and therefore the graduate program, were carefully selected, vetted over time, and employed to present a unique epistemological position. The leading concept is "technological/engineering-design based" which is presented as the instructional requirement. It is immediately followed by "intentionally," which is italicized to emphasize its importance and refers to instructional design intent on targeting the teaching/learning of selected STEM content and practices—not only those of technology and engineering, but science and mathematics as well. This intent to teach is paramount and implies assessment of learning as a required component of the instructional design. It is central to the concept of integrative STEM education and what distinguishes the VT program from all others. The last sentence of the definition clarifies that integrative STEM education operates along an educational continuum and at natural intersections of learning—it is mutually inclusive rather than exclusive. Specifically, it does not apply solely to the STEM subjects, is applicable in both formal and informal educational settings and is appropriate at any academic level. And finally, when using the program acronym (I-STEM ED) the "I" is capitalized so as to convey the equal significance of "integrative" alongside the S.T.E.M. elements, physically connected to those elements with a hyphen, and "education" always follows the elements to emphasize this overarching goal.

PROGRAM DESIGN

When envisioning the new VT graduate program structure, full consideration was given to the challenges of recruitment, curriculum development, and the broad range of instructional delivery modes. In the context of today's economic impact on



Distance Learning graduate students presenting via Adobe Connect

students' ability to attend graduate school in the traditional on-campus fashion, the program was designed to accommodate both brick-n-mortar and web-based environments, thereby affording equal access by face-to-face (F2F) and distance learning (DL) students alike. Programmatically, the goal was to adopt a model of instructional delivery tailored foremost to attracting on-campus students, while embracing the complex life demands of the off-campus students. To that end, the VT graduate program centers on the F2F student while accommodating DL students, using a synchronous web-based audio/video delivery mechanism for anywhere, anytime engagement through point-to-point access via any broadband device such as a personal computer or handheld. As a result, the program attracts high-quality graduate students from all four STEM education fields, from the full spectrum of related fields, and from all academic levels, inclusive of the public, private, and informal education sectors. Bringing this breadth of disciplines together using a blend of accessible instructional environments immerses graduate students in a unique and robust educational experience. By design, all classes are deliberate in promoting discussions that are truly transdisciplinary in nature, encouraging students to challenge the traditional silo mindset and thoughtfully consider the potency of integrative STEM education perspectives.

DEGREE OPTIONS AND COURSES

The structure chosen for the Integrative STEM Education graduate program embraces the diversity of students. To this end, every graduate student individually tailors a program of study that carefully considers his or her personal and professional goals while progressing through the set of I-STEM ED core courses in pursuit of one of the graduate options (Table 1). The MAEd is a 30-semester-hour (SH) degree, the EdS requires 30 SH beyond the master's degree, and to earn a doctorate, students must complete 60 SH beyond their master's. For individuals not seeking a degree, we offer a 12 SH Graduate Certificate. Greater detail on each degree option is available from the program website (www.soe.vt.edu/istemed). These core courses are the mainstay of the degree options and delivered both on-campus F2F and synchronously through audio/video web conferencing. The web-based option extends the program globally and allows distance learners to participate in class alongside F2F students synchronously from states as far away as Hawaii or international sites such as Scandinavia and Germany. Whether engaging in group discussion, collaborating on team assignments, delivering presentations, or being actively involved in hands-on design tasks, every F2F and DL student is an equal participant and contributor in all graduate classes.

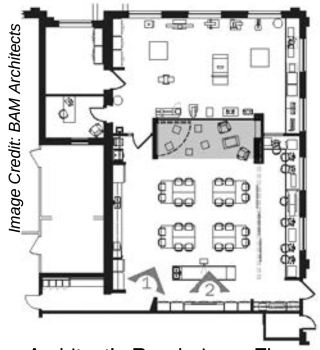
There is no compromise on the rigor of degree requirements ensuring the integrity of the I-STEM ED graduate program. The method through which both F2F and DL students are advised, develop their individual program of study, participate in degree examinations, present prospectus, and defend their dissertation research is the same. Furthermore, all doctoral students must adhere to established university policies regarding residency. In their role as advisor, faculty make full use of Adobe Connect™ web conferencing for advising DL students, including document sharing/editing and recording of sessions for later review by the advisee.

The graduate certificate, master's, and education specialist options target educators, coordinators, administrators, curriculum developers, etc. currently practicing in their home disciplines. These graduates serve as agents of transformative leadership, promoting integrative technological/engineering design-based teaching/learning concepts, perspectives, and pedagogical approaches in their respective fields. For example, in the context of

Table 1: Integrative STEM Education Core Courses and Degree Options

Core Courses:	Graduate Certificate
• EDCI 5804: STEM Education Foundations	• 12 SH (EDCI 5804, 5814, and any 2 more of the following – EDCI 5824, 5834, 5854, or 5964)
• EDCI 5814: STEM Education Pedagogy	**Graduate Degrees**
• EDCI 5824: STEM Education Trends & Issues	• Masters of Education (MAEd)
• EDCI 5834: STEM Education Research	• Education Specialist (EdS)
• EDCI 5844: STEM Education Seminar	• Doctor of Education (EdD) residency required
• EDCI 5854: Biotechnology Literacy by Design	• Doctor of Philosophy (PhD) residency required
• EDCI 5964: Field Studies in [STEM] Education	
• EDCI 5774: Readings in Technology Education	

Architect's Rendering – STEM Collaboratory



Architect's Rendering – Floor Plan STEM Collaboratory

Collaboratory Front View – Projectors and Presenter Station

the national common core (NGA & CCSSO, 2010) and soon-to-be-released next generation science standards (Achieve, 2012), these I-STEM ED graduates are prepared to advocate the use of technological/engineering design-based learning strategies for grade-appropriate integrative STEM education in their respective subjects. Current educational reform is also creating new administrative positions, such as STEM Education Coordinators, for which the Integrative STEM Education Certificate, MAED, and Education Specialist graduates are extremely well prepared.

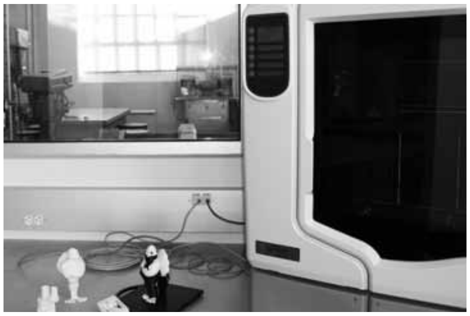
The Ed.D. and Ph.D. programs were carefully designed to address the needs of those individuals seeking higher education teacher preparation and/or research positions in their home disciplines. Through course work and individualized program experiences graduates are well equipped to infuse new integrative STEM education strategies into existing preservice preparation programs and integrative concepts into the growing number of blended STEM education programs. All graduates are equally prepared as educational researchers. Students who choose to pursue an Ed.D. typically focus their investigations on field-based pedagogical topics, whereas Ph.D. students are generally more interested in studying the cognitive issues related to learning theory and student learning, particularly along the natural intersections between the STEM education disciplines.

GRADUATE RESEARCH AND PROFESSIONAL LEADERSHIP

Research and leadership preparation are central to the program goal of developing 21st Century STEM educators and scholars. As part of their graduate experience, students are regularly provided opportunities to engage in funded research, present their work at state, national, and international conferences, and publish in journals of the field. I-STEM ED students are consistently immersed in interdisciplinary collaborations, not only with Science and Engineering Education faculty and graduate students at Virginia Tech, but also George Mason University, Virginia Commonwealth University, the College of William and Mary, North Carolina State University, Colorado State University, and Utah State University to name a few. They are involved in multi-state, multi-discipline STEM Education initiatives promoting integrative STEM education perspectives and practices. As a result, every year since its launch in 2006, I-STEM ED graduate students have been prominent participants in all major research venues offered through the ITEEA profession, with a majority being published prior to completing their degree. Moreover, they are well represented at the national level on ITEEA committees, councils, and leadership initiatives. Consequently, the rigor of I-STEM ED doctoral preparation develops highly desirable quality graduates, which to date has resulted in 100% placement following graduation.

STEM EDUCATION COLLABORATORY: A UNIQUE 21ST CENTURY EDUCATION LABORATORY

One of the newest and most progressive instructional spaces available in the School of Education at Virginia Tech is the STEM Education Collaboratory. Operational fall of 2011, this $1.2 million, 2800-square-foot renovated facility was conceptualized with input from STEM education faculty in the School of Education as an environment for investigating, assessing, and promoting innovative design-based approaches to teaching and learning. The faculty's selection of design as the focal point for this education laboratory resulted in a teaching/learning environment currently found nowhere else in education. The Collaboratory is a fully networked, wireless facility divided into two areas based on purpose. One side serves as a Design and Innovation (D&I) area, and the other functions as a Prototyping and Fabrication (P&F) area. Elements included in the D&I area range from basic equipment you expect to find in a traditional science lab to more advanced biotechnology equipment such as a laminar flow hood. The D&I area is also well equipped for distance learning, with video and web conferencing capabilities using Polycom and Adobe Connect respectively, along with SmartBoards, dual-platform computers, a networked 3D printer, and other such digital education technologies. Designed as well to serve as an educational research facility, the Collaboratory is equipped to capture audio/video recordings throughout both the D&I and P&F areas. To encourage creativity, a nested set of tall extendable whiteboard panels gives students space for collaborative sketching, ideating, and gallery walks. Located at the center of the lab is a quiet space created to give students a place to gather informally in pairs or small groups to envision, brainstorm, and plan. Transitioning from concept to artifact, students move into the P&F side of the Collaboratory where they use more conventional tools to construct, test, and evaluate working prototypes of their technological/engineering solutions. If, during prototype analysis, students find the need for improvements, they simply return to the D&I side to explore new ways of redesigning.



Collaboratory – 3D Printer

Collaboratory – Extendable Whiteboard Panels

Prototyping and Fabrication Space

Collaboratory – Back View of Design & Innovation Space

The seamless flow between areas allows students to experience the integrative nature of design-based learning and realize firsthand that science, technology, engineering, and mathematics are not isolated subjects, but tools used to understand and design authentic solutions that address real-world challenges. This layout was intent on helping students develop habits of both hand and mind (Schulman, 2005) and promoting their use of higher order cognitive skills (Wells, 2010).

Designed to play multiple roles and serve multiple stakeholders, the Collaboratory functions as a facility for supporting cross-disciplinary outreach, professional development, instruction, and research related to the integration of science, technology, P-12 engineering, and mathematics education. Envisioned as an environment to promote collaborative development of new pedagogical models, it is the ideal setting for what is referred to as the “pedagogical commons” (Wells, 2008, p8). Drawing on a centuries-old concept, the pedagogical commons lies at the shared intersections of content and practice among the STEM education disciplines (Wells, 2010, p 199). This approach results in Collaboratory use by a diversity of VT STEM education faculty. For example, Dr. Michael A. Evans, faculty member in the Department of Learning Sciences and Technologies, is the PI for a three-year, NSF-funded project (DRL 1029756) entitled Studio STEM: Engaging Middle School Students in Networked Science and Engineering Projects. Together with educational psychology faculty from VT, foundations faculty from Temple University, and STEM Research at Auburn University, they use the Collaboratory as a space where youth explore science through engineering design activities (Schnittka et al., 2012). The program integrates digital modeling and game-development tools along with social networking technologies to engage youth in investigating concepts and skills to integrate science, technology, engineering, and mathematics (STEM). The MCPS/VT Robotics Collaborative is a school-based example of an initiative between faculty in Montgomery County Public Schools (MCPS) and those in the Science and Engineering Education programs. This robotics collaborative involves high school students, university students from engineering and related fields, and public school and university faculty. The Collaboratory is ideally suited for exploration of math, science, and engineering principles that are fundamental to the design and fabrication of semi-autonomous robots. Similarly, I-STEM ED and MCPS faculty have worked together on initiatives utilizing the Collaboratory. Over the past two years the facility has supported middle school students in their design, construction, testing, and evaluation of biotechnology solutions for Technology Student Association (TSA) state and national competitions. Their designed solutions and knowledge gained led to first-place winners at both the state and national levels.

Nationally, the Collaboratory has been instrumental in supporting ITEEA in its efforts to develop elementary level integrative STEM education. In the fall of 2011 Engineering byDesign™ (EbD™) collaborated with I-STEM ED faculty to convene a group of STEM educators from around the country for professional development (PD) as Teacher Effectiveness Coaches for EbD's new TEEMS™ curriculum. TEEMS (Technology, Engineering, Environment, Mathematics, and Science) is an elementary level I-STEM ED curriculum provided by ITEEA as part of its flagship EbD™ suite of curricula. Joey Rider-Bertrand, lead author for the TEEMS curriculum and I-STEM ED doctoral student, delivered this PD to master teachers from a number of states working to become proficient in delivering their own PD to classroom teachers on implementing the TEEMS curriculum. The Collaboratory was also host to both the "Assessment Writer Team" and the "Assessment Development Forum" for the TEEMS curriculum.

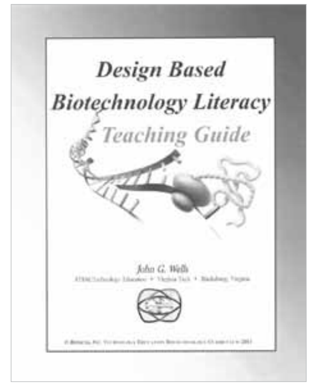
Collaboratory – Studio STEM: Group Activity

Collaboratory – Studio STEM: Laptop Gaming

Collaboratory – TSA Biotech 1st Place State and National: Ryan Wells & Sam Teller

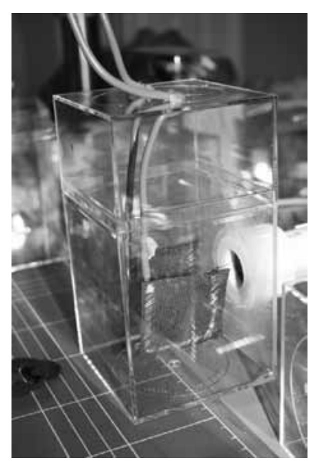
Collaboratory – EbD/TEEMS: Joey Rider-Bertrand Professional Development

INTEGRATIVE STEM EDUCATION EXEMPLAR



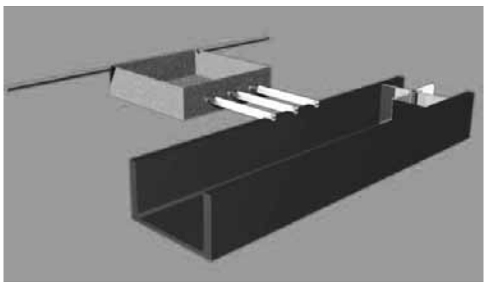
Collaboratory – Wells: *Design Based Biotechnology Literacy Teaching Guide*

For the Integrative STEM Education program in particular, the Collaboratory is the ideal instructional environment to bridge theory and practice by exploring integrative design-based approaches for teaching and learning STEM content and practices. A good illustration of this is what occurs in the Biotechnology Literacy by Design™ course taught by the author and based on his *Design Based Biotechnology Literacy*™ curriculum, first available in the late 1990s (Wells, 2011). As it has been in the STEM fields since the mid-1980s and in technology education since 1992, biotechnology is defined as "…any technique that uses living organisms (or parts of organisms) to make or modify products, improve plants or animals, or to develop microorganisms for specific uses" (OTA, 1988/1991/ FCCSET, 1992/1993; Wells, 1992/1994/1995; Wells, Dunham, & White, 2000; ITEA/ITEEA, 1996/2000/2002/2007; Stotter, 2004; Wells & Kwon, 2008/2009). An underlying course goal is improving graduate student understanding of methods and strategies for teaching an integrative STEM pedagogy by immersing them in the research and construction of biotechnological solutions specifically from the learner's perspective. Beginning with a whole-class design challenge and moving to individual ones, students are presented with Problem Scenarios (ProbScen) where biotechnology is the central element of their solution. For example, ProbScen 4C: Microbial Applications from Chapter 4 Bioprocessing (one of eight biotechnology knowledge areas) provides an authentic local/global context to address the growing need for sources of alternative fuels. The challenge asks students to design a microbial-based fuel cell that can power a low-voltage fan, would have little to no environmental impact, and demonstrates the potential for scale up to larger systems. Design criteria and constraints are presented to students in a way that guides concurrent investigations of both the biology and technology requirements. Starting with



Microbial Fuel Cell Cathode Chamber

Microbial Fuel Cell – Voltage Reading (MFCs in series circuit)



CAD drawing of bioremediation system

questions about what they know and moving to what they need to know, their bio/technical research leads to identification and selection of an appropriate microbe, learning the cellular processes behind electron generation, and determining the life requirements their technical system must support. In addition to meeting these metabolic requirements, the technical system must also be designed to capture and harness electrons produced during the bioprocessing of an organic substrate. As students bring together information, they gather and work to envision design solutions; they connect their prior/new science and math knowledge through the predictive analysis necessary for generating alternative designs. At this point students might turn to the computer technologies (CAD) available in the Collaboratory to generate more sophisticated digital models. Based on these models, students then use the more conventional engineering tools (3D printer, CNC lathes, etc.) to construct, test, and evaluate functional prototypes. The ability to address complexities of such design challenges requires more than discrete STEM content knowledge. The learning demand on students promotes higher-order cognitive skills necessary for making conceptual connections (schematic knowledge) and using them to make informed design decisions (strategic knowledge) (Wells, 2010). Evaluation of student learning is achieved through alternative assessment methods where gains in content knowledge and understanding are demonstrated through design portfolios, reflection/lab notebooks, and explanation of prototypes during professional presentations to classmates. Integrative learning motivates and challenges students in ways that go beyond traditional silo approaches. The greater challenge, however, is for STEM educators to develop the abilities needed to employ integrative teaching practices. Development of such educators is the goal of I-STEM ED at Virginia Tech.

PROGRAM GROWTH, STABILITY, AND FUTURE

For more than half a decade the I-STEM ED graduate program has steadily increased in student enrollment and reaffirmed its recognition within the profession as one of the premier graduate programs in the country. The program prepares P-20 STEM educators, leaders, scholars, and researchers for the 21st Century with the capacity to investigate, implement, and disseminate new integrative STEM teaching and learning approaches. Current enrollment exceeds 50 graduate students representing all STEM fields, with growing numbers of on-campus students and distance-learning students participating synchronously from 10 states. The range of faculty and doctoral research includes topics in design-based learning and design cognition, issues of pedagogical content knowledge in STEM education teacher preparation, and investigating grade-appropriate technological/engineering design concepts for elementary learners. Collaborative research and engagement activities of the I-STEM ED program spans five U.S. states (IL, KY, NC, OH, and VA) and four countries (Oman, Turkey, Switzerland, Zimbabwe). Unique lines of research and extension are pursued to provide for learner models and inclusive practice for a variety of populations, including elementary students, preservice teachers, and learners at risk. These activities branch from five active externally funded projects, ten partnership agreements, and two Memorandums of Understanding—one national and one international. Such arrangements assist in maintaining global activities that provide experiences and opportunities for I-STEM ED graduate students. The re-envisioned and retooled programmatic structure provides not only for the promotion of STEM Education leaders, but a foundation for future educational visionaries that will thoughtfully challenge the existing educational makeup and practices through evidence-based methods. All graduates of the program are currently in positions serving the profession at multiple levels across the country, with those just entering to those soon to graduate preparing themselves academically and professionally to carry this trend forward into the foreseeable future.

REFERENCES

Achieve. (2012). *Next Generation Science Standards.* Retrieved from www.nextgenscience.org/next-generation-science-standards

American Association for the Advancement of Science. (1990). *Project 2061.* New York: Oxford University Press.

American Association for the Advancement of Science. (1989). *Science for All Americans.* New York: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Berube, M. & Berube, C. (2007). *The End of School Reform.* Landham, MD: Rowman and Littlefield.

Center for Science, Mathematics, and Engineering Education, Committee on Undergraduate Science Education. (1999). *Transforming undergraduate education in science, mathematics, engineering, and technology.* Washington, DC: National Academy Press.

Federal Coordinating Council for Science, Engineering, and Technology. (1992). *Biotechnology for the 21st Century: Realizing the Promise.* Report by the Committee on Life Sciences and Health, Washington, DC: U.S. Government Printing Office.

Federal Coordinating Council for Science, Engineering, and Technology. (1993). *Biotechnology for the 21st Century: Realizing the Promise.* Report by the Committee on Life Sciences and Health, Washington, DC: U.S. Government Printing Office.

International Technology Education Association (ITEA/ITEEA). (1996). *Technology for all Americans: A Rationale and structure for the study of technology.* Reston, VA: Author.

International Technology Education Association (ITEA/ITEEA). (2000/2002/2007). *Standards for technological literacy: Content for the study of technology.* Reston, VA: Author.

National Academy of Engineering (NAE) & National Research Council (NRC). (2002). *Technically speaking: Why all people need to know more about technology.* (Pearson, G. & Young, T., Eds). Washington, DC: National Academy Press.

National Commission of Excellence in Education. (1983). *A nation at risk: The imperative for educational reform.* Washington, DC: Author.

National Governors Association Center for Best Practices (NGA Center) & Council of Chief State School Officers (CCSSO). (2010). *Common core state standards initiative*. Retrieved from www.corestandards.org/

Nyquist, J. D. & Woodford, B. J. (2000). *Re-envisioning the Ph.D.: What concerns do we have?* Concerns Brief retrieved from http://depts.washington.edu/envision

Office of Technology Assessment of The Congress of the United States. (1988). *U.S. Investment In Biotechnology – Special report.* Boulder, CO., Westview Press.

Office of Technology Assessment of The Congress of the United States. (1991). *Biotechnology in a global economy.* Washington, DC: U.S. Government Printing Office.

Schnittka, C. G., Brandt, C., Jones, B., & Evans, M. A. (2012). Informal engineering education after school: A studio model for middle school girls and boys. *Advances in Engineering Education, 3*(2). Retrieved from http://advances.asee.org/vol03/issue02/04.cfm

Shulman, L. S. (2005). Signature pedagogies in the profession. *Daedalus, Journal of the American Academy of Arts & Sciences, Summer, 2005*.

Stotter, D. E. (2004). *Assessment of the learning and attitude motivation of technology education students who complete an instructional unit on Agriculture and Biotechnology.* Unpublished doctoral dissertation. Raleigh, NC: North Carolina State University.

Wells, J. G. (1992). *Establishing a taxonometric structure for the study of biotechnology as a secondary school component of technology education.* Unpublished doctoral dissertation, Virginia Polytechnic Institute and State University.

Wells, J. G. (1994). Establishing a taxonometric structure for the study of biotechnology in secondary school education. *Journal of Technology Education, 6*(1).

Wells, J. G. (1995). Defining biotechnology. *The Technology Teacher, 54*(7), 11-14.

Wells, J. G. (2008). *STEM education: The potential of technology education.* Paper presented at the 95th Annual Mississippi Valley Technology Teacher Education Conference, November 7, 2008, St. Louis, Missouri.

Wells, J. G. (2010). Research on teaching and learning in science education: Potentials in technology education. in P. Reed, & J. LaPorte (Eds), *Research in Technology Education*. Council on Technology Teacher Education, 59th Yearbook (Ch. 10, pp. 192-217), Muncie, IN: Ball State University.

Wells, J. G. (2011). *Design based biotechnology literacy: Teaching guide,* (3rd Ed). Biosens, Blacksburg, VA: Technology Education Biotechnology Curriculum Project.

Wells, J., Dunham, P., & White, K. (1999-2000). *Biotechnology curriculum brief* (v. 4). Reston, VA: ITEA/ITEEA.

Wells, J. & Ernst, J. (2012). *Integrative STEM education.* Blacksburg, VA: Virginia Tech: Invent the Future, School of Education. Retrieved from www.soe.vt.edu/istemed/

Wells, J. & Kwon, H. (2008). *Inclusion of biotechnology in U.S. standards for technological literacy: Influence on South Korean technology education curriculum.* Proceedings of the 19th Annual PATT Conference, Salt Lake City, UT [online].

Wells, J. & Kwon, H. (2009). Research trends and issues regarding biotechnology inclusion in technology education: A meta-analysis of relevant literature. *The Korean Journal of Technology Education, 9*(1).

John G. Wells, Ph.D., *is Program Leader, Integrative STEM Education Associate Professor of Technology Education at Virginia Tech in Blacksburg, VA. He can be reached via email at jgwells@vt.edu.*