S IS FOR SCIENCE AT SECONDARY LEVEL

Discover classroom-friendly practices you can implement immediately to address the demands of the 21st century.

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If we want more high-ability students to enter science fields, then science education needs to be more engaging and authentic. We need our students to think and work as scientists, not technicians.

Discover classroom-friendly practices you can implement immediately to address the demands of the 21st century.

Also learn how the past informs the future, including applying the Constructivist model of science instruction to 21st century learning through a 12-point framework for the secondary classroom.
Backgrounds in English, biology, computer science as well as secondary curriculum and instruction (MA) and gifted education research and policy (PhD)

Taught high school and elementary

40+ publications in STEM and gifted education

Director of gifted education graduate programs, a large Science and Robotics Program, and a new STEM education certificate program among other programs
The National Science Board (NSB; 2010): U.S. economic growth has been based on innovations in science since at least World War II.

The National Academy of Sciences (NAS; 2007) warned that although the U.S. is performing well in scientific innovation internationally, other nations are catching up.


Although the U.S. Bureau of Labor Statistics predicts STEM occupations will grow by 17% this decade, far too few high school graduates are pursuing STEM majors (Langdon, McKittrick, Beede, Khan, & Doms, 2011).

Although 28% of college students begin as STEM majors, about half will either switch majors or drop out of school before graduating (Chen & Soldner, 2013).

Engaging, authentic science education in secondary schools could inspire and better prepare the most capable graduates to pursue science at the university level and beyond.
A PARADIGM SHIFT FOR TEACHERS

Traditional
- Classroom is removed from the world
- Teacher and text are sole sources of information
- Work is individualized and simplistic
- Close-ended, single-answer problems
- Students are dominated by the teacher to restrict their movements, discussions, and habits.

Constructivist
- Science classrooms should model real scientific environments
- Multifaceted sources of information
- Teamwork
- Complex, real-world problems for which students develop and conduct experiments to solve facets
- Teachers serve as facilitators and guides.

(Coxon, 2015)
The best students in a traditional model simply come to a result known by the teacher and long known to science.

Although it is important to learn to follow instructions, to develop lab skills, and to have a base of scientific knowledge, these should be seen as the floor and not the ceiling.

Most schools are training technicians and not preparing scientists.

Scientists seek answers to yet unanswered questions and solutions to yet unsolved problems through rigorous methodology, including designing and conducting their own experiments.

Project- and Problem-based learning are means by which students can prepare to be scientists.

(based on Coxon, 2015)
Brooks and Brooks’ (1993) 12-point framework of Constructivist classrooms, which is summarized here for the secondary science classroom:

- **Encourage autonomy and initiative.** Science careers are some of the most open-ended careers, especially for university faculty, scientific innovators, and entrepreneurs. This requires intrinsic motivation be fostered in students, not authoritarianism and dictated step-by-step instructions.

- **Use manipulative, interactive, and physical materials.** Hands-on work is not only important for children: Adolescents and adults learn better this way as well. It is vital that secondary students are offered experiences to use and explore authentic lab materials and to pursue the sciences in their fields of interest.

- **Use cognitive terminology.** The language of science should be used and never dumbed down for students. Secondary students will be more college and career ready if they have opportunities to learn and use the language of science. This is especially important for students from poverty who are less likely to hear scientific terms outside of school.
Student needs drive lessons, strategies, and content. While science standards and the content of tests, such as AP tests, may drive the content of class, students can be given great autonomy in how they learn as described later with project- and problem-based learning. To the extent possible, students should be encouraged to explore content areas of interest.

Teachers discover students' understandings of concepts before sharing their own. This puts the onus of learning on the student and demands student thinking instead of passive absorption of teacher-directed material.

Encourage students to engage in discussion. Teachers should act as guides, asking questions to steer the conversation. For example, if a student has designed an experiment that is unfair or left out possible threats to the validity of their results, the teacher might ask directed questions to help the students realize the issue instead of merely telling them.
Encourage student inquiry. This corresponds strongly with number 4, and as students are given opportunities to explore the subject with great autonomy, questions will likely arise that are suitable for further exploration both through researching existing information with the Internet, the library, and expert knowledge, as well as through experimentation when the information is unknown.

Seek elaboration from students. Teachers should not accept superficial or low-level answers, but use questions to push and therefore deepen student thinking. Elaboration is a vital skill in the sciences, including in the creative process. Elaboration has decreased a greater amount than any other area of creativity in what has become known as the Creativity Crisis—the overall decline in creativity test scores over the past two decades (Kim & Coxon, 2013). Scientific innovation requires endurance to emerge with a final solution and product. Real-world scientific problems are complex, and solutions to them must be multifaceted and well elaborated upon.
Engage students in experiences that might engender contradictions. Real-world science problems are not clean and easy with textbook solutions, thus problems given in the classroom should be ill-structured. That is, there should be too much information, some of which is not relevant. There should be many avenues to explore and many means by which to search for solutions.

Allow wait time after posing questions. As a teacher educator, I have found this to be very challenging for new teachers in particular. Although the contrasted traditional model of teaching lends itself toward quick recitation of memorized answers, the Constructivist classroom requires deep thinking, and this takes time. Successful scientists spend time considering difficult questions before proceeding; secondary classrooms should model this.
Provide time for students to construct meaning. As described above, understanding takes time. It also means that students should be given opportunities to try and fail without harming their grade. For example, if a student designs an experiment that fails to help answer the research question, opportunities should be provided to the extent possible to make adjustments and try again. Learning to persevere in the face of failure is a real-world skill: Scientists move on and learn from botched experiments, must revise and resubmit manuscripts to meet the demands of critical peers, and get rejected conference proposals. Attempted innovations are not always successful, patent requests may be denied, and entrepreneurial ventures often do not succeed. Successful scientists must learn from failure and move forward. Perseverance in the face of failure takes time and opportunities to develop; time too rarely offered in the traditional classroom.
Nurture students’ natural curiosity. In my experience having taught elementary, middle, high school, undergraduate, and graduate university students, curiosity declines with age for most students. Humans are innately curious, but the traditional classroom seems likely to systematically reduce curiosity by encouraging the memorization of known information instead of encouraging discovery of the unknown. Curiosity is foundational to creativity and scientific innovation. Aristotle, Galileo, and Einstein were each intensely curious adults, as are most groundbreaking, living scientists. Secondary teachers may find it necessary to reinvigorate their students’ curiosity depending on the students’ prior experiences.
“The mind is not a vessel to be filled, but a fire to be kindled.”

-Plutarch
“the threshold of desired uncertainty in the environment that leads to exploratory behavior” (Jirout and Klahr, 2012, pg 1)
Usually measured in children by factors such as number and types of questions, stretches of time spent observing something, and frequency of physical investigations.

The depth of complexity about what one is interested can increase with age.

While some people retain high levels of curiosity as they age, curiosity appears to decline with age.

CURIOSITY
“It is a miracle that curiosity survives formal education.”
- Einstein
Evoking curiosity is very environmental and dependent on developmental readiness:

- Novel experiences
- Encourage questioning (teachers usually ask the questions, simply requiring children to remember and repeat)
- Adult modeling, attitudes, and encouragement
- Visuals (such as natural objects and books)
- The arts (drama, dance, music, sculpture, painting, etc.)
- Science, especially the natural world (plants, animals, the sky)
- Free exploration
Problem-based learning is a subset of project-based learning

I define **project-based learning** broadly as a teaching method in which students create some significant product central to their learning goals.

- Examples: Creating an eBook, a game, a website, a video or book, a research paper or presentation that drives learning
- Unique products, related to time, and student-centered

I define **problem-based learning** more narrowly as project-based learning in which students work to solve a real-world problem related to their learning goals.

In both cases, students are working much more like professionals.

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**A KEY DISTINCTION: PBL VS. PBL**
Lecture, reading, or worksheets

Observing a demonstration or video

Step-by-step experiment

Doing a hands-on activity

ProblemBL

HANDS-ON, MINDS-ON SCIENCE EDUCATION
Wheel of Problem Based Learning

- State the Problem
- Identify what you know
- Identify what you need to know
- Develop a plan to find information and current research

- Develop Need-to-Know Board
- Select specific inquiry questions.
- Use methodology of discipline.
- Collect data.

- Conduct Information Quest
- Use varied approaches
- Use multiple data sources
- Redefine the problem

- Conduct specific investigations
- Review and Summarize Findings
- Make inferences
- Draw conclusions
- Identify a solution/resolution

- Communicate Problem Resolution
- Decide on the best way to communicate findings and recommendations
- Prepare final product

- Problem Based Learning
- Identify what you know
- Use methodology of discipline.
- Collect data.

- Robbins, 2008

Center for Gifted Education
College of William and May
1. State the problem
   1. Ill-structured problem statement
   2. Stakeholder roles
2. Need to know board
   1. What you know
   2. What you need to know
   3. How you are going to find out
3. Research review
4. Investigations
   1. Template for experimental design
5. Organize findings
6. Communicate findings
   1. Key opportunity for a project
   2. Audiences are key for engagement

(based on Center for Gifted Education and Robins, 2008)
Your soft drink manufacturing company has been losing money to competitors using real sugar and sugar alternatives instead of corn syrup, which has received a lot of bad press lately.

Corn syrup has been an excellent choice from your perspective because it is cheap, tastes great, dissolves easily, and does not discolor clear soft drinks—some of your most popular sodas.

Your stockholders are upset that you are losing market share as many of your former customers have decided not to consume your current colas, so you must act to keep your job.
Many types of sugar and alternatives
- Corn syrup
- Clear cups
- Access to hot and cool water
- Measuring spoons, graduated cylinder, scale
- Stop watches
- Stirrers
- Thermometers
You are Dr. Susan Ostrovsky. You have been trained as a physician, and also have a master’s degree in public health. You did your residency in infectious diseases and are now on staff at the Eastbridge Public Health Department. This morning, you received the following e-mail message from your boss, who is away at an important training program in Washington, D.C.

Susan: Dr. Johnston called yesterday afternoon to inform us that one of his patients, a 15-year-old boy, has been confirmed as having active tuberculosis. The boy had a positive tuberculin test two weeks ago. A sputum smear was positive for acid-fast bacilli. Dr. Johnston has referred the patient to Dr. Goldstein at University Hospital for treatment. Please follow up on this as soon as possible. The patient is a student at Eastbridge High School. As you know, the school is terribly overcrowded and the potential for a serious outcome is great. I need an action plan from you by tomorrow morning. Please fax it to me at my hotel in Washington D.C. The training lasts another three weeks, so I’ll need daily updates from you until I get back.
Any science unit can be reorganized to be problem-based by:

➤ Creating a problem statement on the topic
➤ Providing students with some background knowledge
➤ Providing sufficient time for them to conduct research, especially scientific experimentation
➤ Having students create final products demonstrating their learning.
➤ It is important for teachers to tailor the products and problems for student readiness; provide scaffolded learning; and provide structure such as small deadlines within larger projects.
PROGRAMMING OPTIONS
Special schools have many advantages for the gifted: academically, socially, and emotionally (Coleman & Cross, 2005).

Special schools that focus on STEM for bright students are rare, but ideal settings.

When available at all, such schools are generally offered only at the high school level.

They allow for high-ability students to pursue areas of strength and interest well before college, for which they traditionally must wait.

If they were to become common, special STEM high schools may help to increase the number of college students pursuing STEM degrees.
A public, competitive-entry residential school on the outskirts of Chicago

Originated by Nobel laureate Leon Lederman in 1986, IMSA enrolls 650 students in grades 10-12.

IMSA curriculum is project- and problem-based with extensive real-world connections and scheduled time for students to pursue their own academic interests.

For example, Finley (2013) described how students developed a robotic arm during scheduled free time after learning that their principal had Lou Gehrig's Disease.

Students participate in research with professional scientists and present at national conferences.

Nearly two-thirds of graduates go on to pursue STEM in college, compared with only 28% of college freshmen nationwide (Chen & Soldner, 2013; IMSA, 2014).

Graduates have discovered new solar systems as well as helped to create companies such as PayPal and YouTube (Finley, 2013).

IMSA demonstrates how the context of acceleration coupled with project- and problem-based learning in a Constructivist environment with excellent teachers can achieve maximized outcomes for high-ability secondary students in science.
• Advanced Placement (AP) courses and the International Baccalaureate (IB) Program both offer advanced science options for secondary students, and their use with advanced students has been recently described by Hertberg-Davis and Callahan (2014).

• AP courses are perhaps the most common form of advanced education offered in U.S. high schools: Almost two million high school students took an AP exam in 2011.

• AP classes were developed as freshman college courses in the 1950s.

• AP science classes include physics, chemistry, biology, and environmental science.

• High school students take an end-of-course exam in which the scores are normed with college freshmen. The exams are moderately rigorous. Only 18% of those students earned a 3 or higher, the score most commonly accepted for credit at universities.
The IB Program was developed in the 1980s to be a rigorous university preparation program (Hertberg-Davis & Callahan, 2014).

IB Programs are offered at select schools and have expanded to include elementary and middle school programs. The high school program leads to a special IB diploma.

As of 2011, there were more than 2200 IB high schools internationally.
The benefits of AP and IB for gifted and advanced learners are a subject of debate.

Rogers’ (2007) meta-analysis of 22 studies on AP and IB found only a small effect size ($ES = .29$). By comparison, 32 studies on grade skipping revealed a powerful effect size of 1.0.

If AP courses were indeed accelerated by one year (typically, high school seniors taking college freshman-level courses), these effect sizes should be very similar.

Although both students and teachers report being more satisfied with the courses and instruction in AP courses than with typical high school courses (Hertberg-Davis & Callahan, 2008; Hertberg-Davis, Callahan, & Kyburg, 2006), Scott, Tolson, and Lee (2010) found a significant yet meaningless effect size ($d = .08$) on student grades in the first semester at Texas A&M University for those who had taken an AP class in high school.

AP, IB, and dual-enrollment are all associated with college success (Hertberg-Davis & Callahan, 2014), but correlation does not mean causation. It could be that such courses improve student success, or it could be that students who are already more likely to be successful (e.g., those of high ability, those from better high schools, those from high socio-economic status families) are more likely to participate in those programs in high school.

Offering advanced students an accelerated IB pathway or AP classes earlier in high school may result in more meaningful effects on achievement.

Where available, dual enrollment in strong, 4-year colleges and universities offers tremendous potential for advancing the academic achievement of high-ability students.
Science competitions, summer programs, and other similar opportunities can meet the academic and affective needs of high-ability secondary students when well selected.

They should involve excellent teachers focused on the students’ area of interest and strength.

Ideally, extracurricular programs supplement excellent school programming, but too often such programs are all that are available to meet the needs of high-ability students when schools fail to offer accelerated and enriched science programming (Coxon, 2009).

There are many benefits of extracurricular programs for high-ability students, including science talent development, opportunities for genuine mentorships, open-ended problems, higher order thinking, challenging tasks, no ceiling on excellence, and opportunities to work with ability peers (Omdal & Richards, 2008; Ozturk & Debelak, 2008).
Many universities and school districts offer science-focused afterschool and summer opportunities and a growing number of science competitions are available globally.

Whenever possible, look for those aimed at gifted or high-ability students. For example, Johns Hopkins’ Center for Talented Youth in Baltimore offers on-campus programs in a number of fields, including science as well as online science classes for students through grade 12 (see http://cty.jhu.edu/grade-by-grade/grades9-12/ for details).

The Maryville Summer Science and Robotics Program for High Ability Students in St. Louis offers around 80 classes for students through middle school in all areas of science, technology, engineering, art, and math (for details, visit https://www.maryville.edu/robot).
Competitions may increase creativity and motivation, improve self-concept, and help students to set higher goals (Omdal & Richards, 2008; Ozturk & Debelak, 2008).

Many science-focused competitions are available to secondary students, including Science Olympiad, the Intel International Science and Engineering Fair, and Young Naturalist Awards. FIRST Robotics competitions engage students in grades 1–12 in all elements of STEM.

In particular, the FIRST LEGO League served more than 400,000 students through middle school in 2014. The competition includes an annual real-world science problem related to what participants will engineer and program their robots to perform. For example, in a past competition, students learned about energy use, programmed their robot to place a LEGO solar panel on a LEGO house among other tasks, and could do a related science project, such as perform an energy audit on an actual building and research possibilities for improving energy use in that setting.
CREST-M

- Children using Robotics for Engineering, Science, Technology, and Math
- Creating two units using research-based strategies to teach Common Core math skills (4th measurement, 5th fractions) by engaging children as problem solvers in real-world science subjects using LEGO WeDo robotics.
- Students create unique robots to solve realistic problems.
In the fall of 2015, I visited 8 makerspaces
1) A spare classroom at a middle school,
2) A section of an elementary school library,
3) A dedicated set of classrooms in an inner city charter high school,
4) A showcase space in a pK-6 private school behind floor-to-ceiling windows near the school’s entryway,
5) A basement of a pK-12 private school, in progress
6) Within the Magic House,
7) Within the STL Science Center,
8) CREATE at the Arizona Science Center
Some spaces were very high tech with 3-D printers, Arduino, and wind tunnels.

Others focused on recyclables and craft materials.

Most had a combination of both high and low tech materials.

Some things they all had in common: lots of table space for students to work, great organization, a wealth of age-appropriate tools, and exciting, unique student work.

When possible, it is ideal if students come up with their own problems for which they create novel solutions. However, this can be within specific content areas. Makerspace ties in well with many science and math objectives.

Providing a problem statement, as in problem-based learning, is ideal here.
MAKERSPACE
Let's build a Lego marble run!

Make a ramp with these pieces.
Earn a certificate in STEM Education through hands-on, real-world learning experiences to integrate STEM into classrooms.

MARYVILLE UNIVERSITY AND BOEING OFFER A
CERTIFICATE IN STEM EDUCATION

There is a tremendous national and global need for increased education integrating science, technology, engineering, and math (STEM) to bolster the pipeline of talented individuals ready for 21st century careers. Now K-12 teachers, librarians, media specialists, technology trainers, principals, instructional coaches, and others interested in meeting state and national standards while engaging students in STEM can participate in this innovative program. Learn to integrate STEM into the classroom with research-based best practices led by expert educators in the field.

Complete the entire program June 2-27, 2016
8:30 a.m.–4:30 p.m. at Maryville University’s
9 credit hour intensive June, 2016 session:
- One credit hour STEM Overview
- Three-credit hour Creative Problem Solving
- Four 1-credit hour Electives
- One-credit hour STEM Capstone
Maryville educator discount rate of $440/credit hour

ELECTIVES INCLUDE:
- Integrating Science, Art and Engineering into Mathematics
- Problem-Based Learning
- Makerspace Movement
- Robo Basics with LEGO Robotics
- STEM Up Your Classroom with Theatre Arts
- Filmmaking in the Classroom
- Design Thinking: Incorporating Architectural Projects into the Classroom
- App Development for Teachers

To learn more and register, visit: maryville.edu/stem
or contact Michelle Schoeck
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MANY CONNECTIONS. ONE U.
Summer 2016

maryville.edu/robot

Summer Science And Robotics Program For High Ability Students
Steve Coxon, PhD is associate professor and director of programs in gifted education at Maryville University including the gifted education graduate program for teachers and the new STEM Education Certificate Program. Other projects include the Maryville Science and Robotics Program, the Maryville Young Scholars Program to identify and serve high ability children from groups traditionally underrepresented in gifted programs, and the Children using Robotics for Engineering, Science, Technology, and Math (CREST-M) curriculum development project. He holds his PhD in gifted education from the College of William and Mary and conducts research on developing STEM talents in pK-8th grade gifted children, especially spatial ability, mathematics, and creativity. Steve has more than 40 publications and 30 juried presentations, is the science education columnist for Teaching for High Potential, the book review editor for Roeper Review, and is the author of the book Serving Visual-Spatial Learners. He serves as an educational consultant, project and program evaluator, and professional developer. In 2014, the Missouri Commissioner of Education appointed Steve to a 4-year term on the Advisory Council on the Education of Gifted and Talented Children. He also volunteers as a judge advisor for FIRST® LEGO® League events in the St. Louis region and as a member of the St. Louis FLL Planning Committee. He has helped to start JFLL and FLL teams at several low-income schools in the St. Louis region. Steve was the 2010 recipient of the Joyce VanTassel-Baska Award for Excellence in Gifted Education.
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