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Common Core and STEM Opportunities

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Abstract: There is an increasing need for educators at all levels to equip more students with problem-solving skills that better fit our changing work force. Students are largely unaware of many science-, technology-, engineering-, and math-related (STEM) careers. They often do not understand the importance of those careers or what skills are required to pursue them. Students are exposed to some of those skills if they take Career Technical Education (CTE) classes, but rarely do they see the connections in their core math classes. Math teachers have pointed to their dense curricula as making STEM integration impractical. A study of the Common Core State Standards for Mathematics (CCSS-M), however, reveals open doors for integration. There are specific Algebra I CCSS-M that can be met through STEM-oriented, problem-based learning (PBL). STEM PBL has the potential for increasing students' cognitive engagement while, at the same time, introducing interesting STEM careers. These connections need to be integrated in curricula aligned to the CCSS-M. In order to further develop and implement evolving STEM-PBL connections, there is a need for increased, ongoing dialog between educational leadership and representatives from the STEM working community. The end result can be that most US students will be exposed to a much broader range of STEM careers, STEM skills, and understand how the Algebra they learn is useful in the real world.

Keywords: Stem Education; Common Core; STEM-PBL connections

STEM Education in the United States

The United States economy is becoming increasingly dependent upon mathematics, science, technology, and engineering (STEM), (Vilorio, 2014). Educators are being called upon to find new and effective ways to prepare students to develop skills related to STEM (Partnership, 2015). As Nathan, Tran, Atwood, Prevost, and Phelps (2010) pointed out, if K-12 schools are to increase the number of graduates who enter engineering-related fields they must

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integrate technical and academic preparation. Traditionally, math classes have been fairly compartmentalized, as opposed to being integrated with science, largely because math curricula tend to be topic-dense. Common Core State Standards for mathematics (CCSS-M) were adopted by the majority of states in the US, in part to shift the focus in mathematics instruction from dense mile-wide, inch deep curricula heavily dependent upon memorization toward development of problem-solving skills. That shift would better prepare students to enter our technological workforce (Common Core State Standards Initiative, 2015). Change in content focus could make instructional time available for students to explore some physics- and other science- technology- and engineering-related tasks within the context of learning traditional Algebra I skills.

Building Bridges to STEM Success

A recent research report observes a relationship between exposure to a physics class and whether or not a student declares a STEM major in college (Bottia et al., 2015). Success in physics is highly dependent upon algebra skills (Awodun, 2013). Therefore, it could be beneficial to students for Algebra I teachers to help build a bridge between Algebra I and STEM careers. Introducing Algebra students to cognitively engaging tasks that, like physics problems, can be related to and create interest in STEM careers could enhance and strengthen students' progress throughout the curriculum. There is evidence that Common Core mathematics standards, just as physics courses reportedly do, open opportunities for students to explore age-appropriate, cognitively engaging science, technology, engineering math (STEM) problems while developing and refining traditional procedural skills in Algebra I.

Studies Relating Common Core Mathematics Standards to STEM

Achieve, Inc., in an independent, non-profit advocate for improving academic standards and college readiness for American students. Achieve's recent survey among states noted that few career technical education (CTE) and STEM tasks have found their way into academic classrooms. Career technical education courses combine technical skills with academics. For example, aspiring nurses learn mathematics in the context of medicine and future computer programmers write mathematical algorithms into their code (State of Washington, 2016). Just as few classrooms have integrated CTE, few CTE classrooms have aligned with Common Core State Standards for Mathematics (Meeder & Suddreth, 2012).

The dearth of cohesiveness could explain the lack of published research directly connecting STEM with CCSS-M (Common Core State Standards- Mathematics) *The Oregon Vo-Tech Math Project* (Swearingen, 1975), explained that mathematics booklets were written in the 1970's to provide vocational education students in high schools and community colleges with math problems that fit the course contexts. The math was obviously useful to those students, and surveys at the end of the semester confirmed the anticipated positive reception to those problems. The vocational education students learned the math they needed for the field they were pursuing. According to the authors, the problems were samples of what they would "encounter on the job in various career fields." Colorado State University produced a similar set of problems for grades seven to nine so that students in those grades could see some of the ways the math they were learning was used in employment contexts (Colorado, 1975). James Stone (2008) studied CTE classes in which math teachers worked with CTE teachers (59 total) to integrate more mathematics, contextually, into the CTE curriculum in American high schools. Stone noted that students who took the integrated CTE classes performed equally as well on technical skill assessments as those students in the control groups with no integrated instruction at the end of the year when pre-test scores were considered. Students within the integrated classes scored considerably better on both a traditional math assessment (TerraNova) and a college placement test (Accuplacer). Those differences were statistically significant.

Learning through Tasks: from Relevance and Interest to Engagement and Critical Thinking

Problems that are generally interesting to students are critically important vehicles for connecting CCSS-M to other STEM based disciplines. A problem of interest tends to evoke cognitive engagement (Meece, Blumenfeld, & Hoyle, 1988) which is a goal of problem-based learning and for CCSS-M (Savery, 2006). Many studies have highlighted the benefits of student engagement in the classroom (Marzano, 2001; Pope, 2013; Kagan, 1995). Relevance is an important component to effect engagement (Taylor & Parsons, 2013). Through relevant problems of interest, the curriculum and instruction can connect problem-based learning, cognitive engagement, and Common Core because of their unified purposes and goals.

Benefits of Problem Based Learning

Clark and Roche (2009) studied teachers presenting "Type 2" tasks in 87 Australian middle schools in response to the problem of disaffection toward math. The schools were randomly selected in such a way that the sample represented all of Australia's states. Type 2 tasks could also be described as, "problem based learning" (PBL). For example, a Type 2 activity could be mathematically estimating if a car would stop in time to avoid a pedestrian crossing 50 feet ahead. The Type 2 tasks were noted to help middle school students perceive math as useful when guided by teachers who understood how to coach them. The Australian teachers had been trained to use a Japanese teaching model that begins with a brief introduction of a task, student exploration of the task, culminates with a whole-class discussion based upon presentations from a strategically selected group of students. This is the same technique advocated by CCSS-M chief writer Phil Daro (2013) based upon his observations of Japanese classrooms. Japanese students are of interest because they are consistently within the top five countries for fourth- and eighth- grade mathematics scores on the Trends in International Mathematics and Science Study (National Center for Education Statistics, 2016). The Australian teachers reported their students seemed to be developing the ability to think while pondering questions in mathematics. They observed that students of all levels of ability seem to be engaged when working on the Type 2 tasks. Similarly, Sadeth and Zion (2009) studied 50 Israeli biology students and noted that open inquiry, characterized by independent student explorations, trumped guided inquiry in terms of developing higher order thinking skills. Sadeth's and Zions' conclusions were similar to Clark and Roche (2009) in that students who were presented with realistic tasks tended to demonstrate improved ability to think. Open or "free" inquiry is a component of problem-based learning (PBL) (Savery, 2006). Developing problem solving (higher order thinking) skills is a priority for STEM (Partnership, 2015), and incorporating PBL into traditional Algebra curriculum may also influence students' thinking in mathematics.

Wong and Day (2008) completed a comparative study of two high school science classes in Hong Kong where one class was taught with lecture based methods (LBL) and the other with interactive PBL. The PBL group had markedly better rates of comprehension, intrinsic motivation, application, and retention. Pre- and post-test comparisons for factual retention and application of knowledge were generally below 20% improvement for LBL and above 40% for PBL. Short-term comprehension improvement for one PBL was over 80%.for PBL and under 20% for LBL. Similarly, long-term improvement (pre-test to post-test two months later) showed dramatic differences with PBL assessing at over 150% improvement and LBL below 50%. The improvements linked to PBL were consistently significant.

Whereas selecting career-related problems for math students to solve is not a new idea, finding time in the day to include such problems in Algebra I may be a challenge when the curriculum is dense. However, such integration has the potential to help students see how math is useful and improve problem-solving skills while learning the traditional math skills expected of Algebra 1 students.

Benefits of Cognitively Engaging Tasks

Clarke, Breed, and Fraser (2004) reported high school students who were enrolled in math classes with PBL curriculum (called Interactive Mathematics Program or IMP) associated a higher degree of relevance toward mathematics than did their peers who were enrolled in traditional math classes as did Clarke and Rosch (2009). In addition, students enrolled in the PBL (IMP) classes were evaluated with self-assessments They reported feeling more confident in their mathematics, had more positive impressions with respect to mathematics, had better attitudes toward mathematics, and ranked at or above the assessed levels of their peers on the SAT. For each positive response on attitudinal surveys, students scored +1 and each negative response scored -1. The mean for the traditional students was -0.52, whereas the mean for the IMP students was 0.97. These differences were statistically significant.

Shank (2004) explains that when students are taught skills that closely resemble those needed in the work place, they tend to transfer into the work place efficiently. Critical thinking is an important 21st Century skill (Partnership, 2015); and the literature in this review seems to indicate that PBL and cognitively engaging tasks, are effective and important contributors to developing higher order thinking skills, highlighted in CCSS-M and STEM education. .

Cognitive Engagement Specific to STEM Tasks

Along with the advent of the CCSM-M, copyrighted in 2010, the value of "cognitive engagement" has received increased attention. Cognitive engagement occurs when a student's mind is actively involved in the learning process (Chapman, 2003). If there is a relationship between taking physics classes and later declaring a STEM major, there may be a relationship between taking Algebra classes embedded with STEM explorations and later declaring a STEM major. This potential justifies considering the integration of STEM tasks within conventional Algebra I curricula and instruction.

Opportunities for STEM Connections in CCSS-M

Porter, McMaken, Hwang, and Yang (2011) noted that CCSS-M place a heavier emphasis on students being able to explain their thinking and make sense out of math than the typical, existing state math standards (ESS-M) they were designed to replace.

	Percent of standards within CCSS-M	Percent of standards within ESS-M
Demonstrating math concept	35.65%	28.66%
Emphasizing number sense	32.75%	13.84%
Solving non-routine problems	5.16%	2.63%

These differences open opportunities for STEM task integration wherewith students develop number sense, understanding of mathematic concepts (relationships, connections), and transfer to non-routine contexts. STEM integration can expand student exposure to mathematics beyond algorithmic problems that can be solved via execution of rote memory of steps.

The CCSS-M Standards for Mathematical Practice (SMP) are repeated for every grade level. SMP 1 is, "Make sense of problems and persevere in solving them." The following quotes from the SMP underscore the expectation that students become highly competent problem solvers by understanding concepts and by use of reason.

SMP 2: *to abstract a given situation and represent it symbolically*

SMP 3: *reason inductively about data, making plausible arguments that take into account the context from which the data arose*

With previous state standards described by Porter, McMaken, Hwang, and Yang (2011) an Algebra student might be expected to graph a point table, or generate points for a given equation. To meet SMP 2 and 3 the same class might look at crime statistics, plot the data on a graph, and notice the pattern is linear. They could make predictions based on the linear model and discuss whether the correlation coefficient suggests a relationship between the variables.

Interest in PBL is Growing

The interest in incorporating PBL within Algebra I is gaining momentum. Robert Kaplinsky (3k Twitter followers @RobertKaplinsky) and Dan Meyer (49.9K Twitter followers @ddmeyer) have developed dozens of PBL tasks called, "3 Acts." Kaplinsky is a Teacher Specialist in Mathematics in Downey Unified School District and serves as a consultant for districts throughout the U.S. Dan Meyer, Ph.D. Stanford, 2015), is a former school teacher who, likewise, serves as an authority in mathematics instruction in the U.S. Whereas all their strategies appear to pose engaging real-life mathematical questions, few if any, make direct connections with STEM careers as can be noted in an extensive compilation by Dane Ehlert (2015). Developing procedural skills within the process of PBL is a common theme, but references to specific STEM careers are relatively rare. For example, Dan Meyer's *Falling Rocks* and *Falling Glowsticks* PBL tasks require that students be able to write and solve equations. As students solve the problems, they are strengthening their traditional equation-solving skills within engaging activities (Meyer, 2015). While these tasks are likely to be more interesting than traditional word problems, no connection is made to similar thought processes used in realistic careers. As teachers shift toward PBL, there is a need for PBL that explicitly introduces students to STEM careers.

The Mathematics Assessment Project (MAP) (2015) was developed by a team of education professionals from the University of California and the Shell Center team at the University of Nottingham. MAP is an online resource with a wide range of PBL tasks aligned to CCSS-M. MAP PBL tasks are highly detailed with explicit directions for teachers, timing expectations, and sample student responses. The MAP PBLs are rigorous, relevant, and likely engaging, but few direct connections are made between the thought processes required to explore the tasks and similar thought processes used in established, new, or emerging STEM careers. Students, therefore, are unlikely to learn much about STEM careers using MAP PBL.

Access Points for STEM Connections with Algebra I

The CCSS-M content standards include specific access points for career applications that may not have been obvious in previous standards. For example, two CCSS-M standards frame understanding of the properties of exponents within the context of exponential functions providing an opportunity to connect with finance as well as growth and decay within scientific fields. Instead of memorizing properties of exponents through rote procedures in traditional problems like this,

$$3x^4\left(\frac{x^2y^{-4}}{xz}\right)^{-3}$$

CCSS-M students learn about properties of exponents by applying them in modeling functions such as this:

> *...the expression 1.15^t can be rewritten as $(1.15^{1/12})^{12t} \approx 1.012^{12t}$ to reveal the approximate equivalent monthly interest rate if the annual rate is 15%.*

A half-life question from a traditional Holt textbook reads, "Bismuth-214 has a half-life of approximately 20 minutes. Find the amount left from a 30-gram sample after an hour" (Burger, et al., 2007). In order to interest students in learning about half life as it pertains to a STEM career, a related task could be written about a young cancer victim receiving treatment with radioactive isotopes. Whether the patient lives or dies could depend upon a medical professional's understanding of half-life (The American Association of Endocrine Surgeons, n.d.). A video clip could preface the lesson explaining the scope and importance of careers in nuclear medicine.

CCSS-M requires students to go beyond memorizing formulas that represent patterns. Students derive formulas and apply them to different contexts.

> *Derive the formula for the sum of a finite geometric series (when the common ratio is not 1), and use the formula to solve problems. For example, calculate mortgage payment.* (CCSS-M ASSE.b.4).

Instead of spending time memorizing where the geometric formula subscripts go, students explore with tables and graphs, extending from what they have learned in previous grades. In the process, they also see how geometric *sequences* are formed, and recognize them as being functions. From there, students continue to generalize using mathematical symbols to describe patterns, relating other sequences to functions they write based on patterns instead of pre-determined formulas. Understanding the need to describe patterns symbolically is associated with relevance, engagement, and persistence (Goetz & Hall, 2013) which is ultimately associated with better retention than directly memorizing formulas without context (Rosegard & Wilson, 2013).

Thus, learning to understand math in natural contexts as expected with CCSS-M, could result in more efficient use of time traditionally spent having students memorize and retain. This also opens time and pathways to contexts within specific STEM careers such as test engineering, digital signal processing, forensic science, and data mining. These pathways would be expected to provide a more seamless transfer into existing employment opportunities (Shank, 2004). As pointed out by Meeder & Suddreth (2012), CTE answers the question, "When are we going to ever use this in real life?”

The “Creating Equations” domain in CCSS-M expands what students have learned about writing linear equations into writing a variety of linear, quadratic, rational and exponential functions (Progressions for the CCSS-M, High School Algebra, 2012). The same domain also mentions "describing nutritional and cost constraints of different combinations of foods." Educators collaborating with dietitians could produce an engaging inquiry-based activity that would also provide students with realistic experience as dietitians.

Data mining has generated many new STEM careers in recent years (Rajpurohit, 2014) and the CCSS-M has an entire domain of standards for Statistics. Embedding tasks that highlight ways data is mined from private individuals and how that data is organized and used would likely be of interest to many students. Organizing data displays with infographics software may intrigue students who enjoy creating art and may not have previously seen how those talents fit in the field of engineering.

Tasks related to forensic science and crime scenes would likely intrigue many adolescent students. Analysis of stopping distances would integrate well with students who will soon be driving and could be related to forensics, insurance, test engineering, and other STEM fields. Students are often taught a "three-second rule" in drivers’ education courses. While stopping distances calculated from a three-second rule are linear, more precise measurements are quadratic (Smith, 2006). A task designed to compare such calculations would be appropriate for the CCSS-M Function domain and could be expanded to include over a dozen CCSS-M (Walker, 2015).

Illustrative Mathematics is an online resource for CCSS-M that was founded in 2011, under the leadership of Common Core Chief Writer William McCallum (Illustrative Mathematics, n.d.). Illustrative Mathematics has continued its development to include a task bank covering most of the CCSS-M and more recently has included unit plans. Several tasks in Algebra I are STEM-related including procurement (Selling Fuel Oil at a Loss), agricultural chemistry (Weed Killing), finance (The Bank Account), medicine (Course of Antibiotics), pharmacy (How Much Folate), and solar energy (Solar Radiation Model). All of these tasks could easily be modified to relate to existing employment contexts and be appended to include descriptions of related careers. It seems plausible that increased engagement and interest in STEM could result from simply recasting the tasks in such a way as to enable students to imagine, "You are there."

Besides PBL activities, CCSS-M provide other opportunities to introduce students to STEM careers. For example, CCSS-M Function domain requires students to understand that each input of a function has only one output. Students are understandably confused because two different input values can have the same output. A class period spent introducing students to computer coding (programming) through friendly apps and websites make it clear why an input can only have one output (Walker, 2015). Coding "turn left," for example, must have a consistent result. However, "repeat three times: turn right" will have the same effect.

Absolute value is another challenging concept on paper that can make more sense when connected to real life. Tolerance ranges associated with measurement on blueprints or engineering specifications are applications of absolute value. Metrology is a broad field that includes the blue collar worker on a construction site and engineers designing coordinate measurement machines. Whether measuring pictures of electronic parts with a ruler or the real thing with a caliper, students can experience absolute value in a way that makes sense (Walker, 2015). Students who enjoy measuring objects within the classroom and deciding whether or not they are within tolerance ranges may consider pursuing a career in metrology.

Quality assurance and test engineering are diverse fields with many career opportunities as revealed by search engines like monster.com and careerbuilder.com. Tasks written in contexts such as sports equipment testing, crash-testing automobiles, explosions caused by defective materials, and pyrotechnics safety could provide sparks of interest to motivate students to learn in the short-term, and plan for interesting careers in the long-term.

Students' interests change quickly. Many topics are interesting because they are novel or elicit emotion. For example, the Australian government's goal to cull 2 million feral cats by 2020 (Tharoor, 2015) could provide a fascinating look into problems ecologists tackle with population growth and exponential functions; but the "wow-effect" is likely to diminish shortly after the target date for the end of the project. However, the problem of animal control which would be interesting for animal lovers will likely persist for at least the next few decades, and so a task modeled around animal control (growth with exponential models and extermination with linear models) could be modified to fit current events (Walker, 2015). Connecting STEM careers will need to be an ongoing process to remain relevant.

Conclusions/Recommendations

Teachers and other stakeholders are rightfully concerned that students have time to learn traditional Algebra skills in their Algebra classes. It is important that activities used in class are efficient in terms of time consumption. Problem-based learning inherently comes with risks associated with false starts and wrong conclusions (Sadeh & Zion, 2009). Relating PBLs to 21st Century career skills adds another layer of consideration in the design of lessons. However, if students are going to be college-ready and equipped with 21st Century skills, those skills will need to be developed through cognitively engaging classroom tasks. CCSS-M open the necessary time spaces for students to learn traditional Algebra I skills while developing skills necessary for life post graduation. Well-chosen PBL and other activities for Algebra can address a range of CCSS-M learning standards and 21st Century skill development within a single class period or two. In order to make the STEM connections with PBLs and other activities that are already available, collaboration is critically important between teachers, instructional material developers, and STEM workers. As reported in education literature, that type of collaboration has occurred in the past, resulting with sets of mathematical tasks connecting academics to careers. A significant contribution to education literature could be made by exploring the effects of connecting Algebra with STEM. Ultimately, the continued success of the U.S. economy may rest in increasing the number of STEM workers, and STEM in Algebra may generate enough interest for students to pursue the necessary skills.

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Appendix A - Proposed CCSS-M Addressed by Individual Task

Feral Cats

Question	Activity
What percent of the cats will be destroyed under the plan?	N-Q2, 3 for breaking down the total to be culled vs. how many each year. The percent of cats destroyed will depend upon how many are destroyed each year. The earlier the cats are destroyed, the higher the percentage eliminated because there are fewer to reproduce. Students can explore different scenarios to estimate the percent of cats remaining after the culling.
How many feral cats are there? What is the growth rate for the population of feral cats? How many will there be by 2020 if nothing is done?	A.SSE.3c, F.LE.1.c., 2 Represent the feral population with exponential functions.
How many cats will there be by 2020 if the same number of cats are culled each year? Fewer each year? More each year? Compare different scenarios.	F.IF.4 Graph the population numbers over time under various scenarios.
Can we write a combined function for the growth and culling together?	F.BF.1.b Build a function that models the population over time for a particular culling scenario.
Is it possible to effect a statistical zero cat population in ten years?	F.BF.1.b, F.BF.3, F.IF.4 Modify the combined function such that there are zero or nearly zero cats within ten years.
What do you think about the $6.6 million to be spent on this project? Compare with "low cost spay and neuter" options.	

Related STEM careers: wildlife biology, zoology, veterinary science, ecology, animal psychology,

Braking Distances

Plot data from the insurance charts and from the 3-second rule, finding and interpreting the intersection point	A.REI.7 Solve a simple system consisting of a linear equation and a quadratic equation in two variables algebraically and graphically.
Plot data for one of the distance charts. If the dry braking chart is used, it is easy to compare with the 3-second rule later.	F.LE.1 Note that the change appears to be quadratic or exponential. It can't be exponential because there is not a constant multiplier. F.IF.5 Discuss domain/range. F.IF.4 Note the vertex of the quadratic is not at the origin. F.IF.1 Students should appropriately label their graph with units and explain the quantitative relationship N.Q.2. F.IF.6 Calculate average rates of change within different intervals F.IF.9 Note that the second differences in the table are constant because they are associated with quadratic change. F.BF.4 Make a prediction as to how fast a car was going for a selected stopping distance. Compare the graph with the distance formula*: $y = y_0 + v_0 t + \frac{1}{2}at^2$ A-SSE.1.b Interpreting parts of the expression (initial distance+reaction+braking time).
Plot comparative data from another chart	F.BF.3 identify the effect of the change in tables as are made in the graphs.
Fit a quadratic function to a graphed distance chart	**A.CED.2 Create equations and inequalities in one variable and use them to solve problems. Include equations arising from linear and quadratic functions, and simple rational and exponential functions.** Create equation in two variables F.IF.2 Use function notation and discuss input/output It is easiest to do so with vertex form. N.Q.3 Round value appropriately **A.SSE.1 Interpret expressions that represent a quantity in terms of its context.** **a. Interpret parts of an expression, such as terms, factors, and coefficients.** **b. Interpret complicated expressions by viewing one or more of their parts as a single entity**. Explain physical associations to the numbers and variables in the function functions A.REI.10 Discuss decimal and irrational solutions to the equation. A.CED.3 Represent constraints (positive domain).
Make a chart for the 3-second rule taught in drivers' ed	Generate numbers for the 3-second rule that is often quoted for safe braking. For distance comparisons, units (seconds & mph) must be converted (mph)(3)5280/3600). Example: at 20 mph, the 3-second rule allows (20)(3)5280/360 feet of stopping distance or 88 feet.

classes**	N.Q.1 Use units as a way to understand the problem .
Graph the 3-second rule on the quadratic graph of dry braking.	This relationship is linear and students must convert units to graph it y =4.4x. Rounding the slope to 4.5 produces friendlier numbers for the braking distances. A.REI.7 Solve the system
Write the equation for the 3-second rule	
Note the 3-second rule is not good for speeds over 70	Students expand the 3-second rule into a piecewise function for speeds over 70 mph.
Consider all safe stopping distances at various speeds	A.REI.12 Graph the solutions to a linear inequality (this could also include the quadratic).

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