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Where is the Math in Science Olympiad? Aligning Mathematics Standards to Science Olympiad Events

Abstract

Science Olympiad (SO) is a national non-profit organization which holds science competitions for students in grades 7-12 within 50 states with each event aligned to Next Generation Science Standards (NGSS, 2010). The purpose of this article is not only to align the Common Core State Standards in Mathematics (CCSSM) with Science Olympiad events, but also to determine Webb's Depth of Knowledge Levels (DOK) within the mathematics content. This alignment was achieved by utilizing a content analysis and the Depth of Knowledge alignment processes (Webb, 1999). The findings in this study indicate there are a significant number of SO events that are aligned to the CCSSM with high levels of Depth of Knowledge within the Division B (grades 6-8) and C (grades 9-12) events.

Where is the Math in Science Olympiad?

Aligning Mathematics Standards to Science Olympiad Events

Science Olympiad (SO), a competition for students in grades 6-12, has more than 7,200 teams (15 members per team) and 400 invitational, regional, state, and national tournaments within 50 states (Science Olympiad, 2017). These competitions hold 23 events in biology, chemistry, physics, earth science, and engineering. Science Olympiad is a national non-profit organization devoted to improving the quality of science education, increasing student interest in science, and providing recognition of outstanding achievement in science education by both students and teachers. These goals are accomplished through classroom activities, research, training workshops and encouragement of intramural, district, regional, state and national tournaments (Science Olympiad, 2017). Science Olympiad is broken into four divisions: A1 (grades K-3); A2 (grades 3-6), B (grades 6-9), and C (grades 9-12). Students may compete individually in an event, but the overwhelming majority of students compete in pairs or groups. National rules state that teams need 15 student members to compete.

Keywords: depth of knowledge, mathematics and science education, Science Olympiad

Rationale for the Study

The National Science Teacher Association (NSTA, 2016) recognizes that many kinds of learning experiences, including science competitions, can contribute significantly to the education of students in science, technology, engineering, and mathematics (STEM) subjects. Among the principles that guide this position, NSTA believes that science competitions should supplement and enhance other educational experiences and be closely aligned or integrated with the curriculum. The alignment to the Next Generation Science Standards is clearly documented on the SO website (Science Olympiad, 2017). However, the mathematics that is embedded within activities is not addressed in their literature. Aligning the Common Core State Standards for Mathematics (CCSSM, 2010) and Mathematical Practices with SO events would serve two purposes. First, it will demonstrate the close bond existing between mathematics and science that is often not recognized by students (Brophy, Klein, Portmore & Rogers, 2008; Committee on Science, 2006; Dixon & Brown, 2012). Second, the authors believe such an alignment will encourage STEM teachers to invite student participation, knowing that the Common Core State Standards and Mathematical Practices are integrated throughout, thus broadening the impact of Science Olympiad.

Norman Webb's (1997) Depth-of-Knowledge (DOK) schema has become one of the key tools educators can employ to analyze the cognitive demand (complexity) intended by the standards, curricular activities, and assessment tasks. Webb developed a process and criteria for systematically analyzing the alignment between standards and test items in assessments. In this article, the authors extended the process and criteria to reviewing the mathematics embedded within the SO events. The Webb model categorizes assessment tasks (SO events) by different levels of cognitive expectation, or depth of knowledge, required to successfully complete the task. Hess (2004-2012) further articulated the model with content specific descriptions for use by classroom teachers and organizations conducting alignment studies (See Figure 1). Thus, the purpose of this article is to align mathematical content of the CCSSM with Science Olympiad events and examine the Depth of Knowledge found within the mathematics content and practices.

Literature Review

According to the Science Olympiad website (2018), the organizations goals are to increase male, female and minority interest in science, create a technologically-literate workforce and provide recognition for outstanding achievement by both

Revised Bloom's Taxonomy	Webb's DOK Level 1 Recall & Reproduction	Webb's DOK Level 2 Skills & Concepts	Webb's DOK Level 3 Strategic Thinking/ Reasoning	Webb's DOK Level 4 Extended Thinking
Remember Retrieve knowledge from long-term memory, recognize, recall, locate, identify	○ Recall, observe & recognize facts, principles, properties ○ Recall/ identify conversions among representations or numbers (e.g., customary and metric measures)			
Understand Construct meaning, clarify, paraphrase, represent, translate, illustrate, give examples, classify, categorize, summarize, generalize, infer a logical conclusion (such as from examples given), predict, compare/contrast, match like ideas, explain, construct models	○ Evaluate an expression ○ Locate points on a grid or number on number line ○ Solve a one-step problem ○ Represent math relationships in words, pictures, or symbols ○ Read, write, compare decimals in scientific notation	○ Specify and explain relationships (e.g., non-examples/examples; cause-effect) ○ Make and record observations ○ Explain steps followed ○ Summarize results or concepts ○ Make basic inferences or logical predictions from data/observations ○ Use models /diagrams to represent or explain mathematical concepts ○ Make and explain estimates	○ Use concepts to solve non-routine problems ○ Explain, generalize, or connect ideas using supporting evidence ○ Make and justify conjectures ○ Explain thinking when more than one response is possible ○ Explain phenomena in terms of concepts	○ Relate mathematical or scientific concepts to other content areas, other domains, or other concepts ○ Develop generalizations of the results obtained and the strategies used (from investigation or readings) and apply them to new problem situations
Apply Carry out or use a procedure in a given situation; carry out (apply to a familiar task), or use (apply) to an unfamiliar task	○ Follow simple procedures (recipe-type directions) ○ Calculate, measure, apply a rule (e.g., rounding) ○ Apply algorithm or formula (e.g., area, perimeter) ○ Solve linear equations ○ Make conversions among representations or numbers, or within and between customary and metric measures	○ Select a procedure according to criteria and perform it ○ Solve routine problem applying multiple concepts or decision points ○ Retrieve information from a table, graph, or figure and use it solve a problem requiring multiple steps ○ Translate between tables, graphs, words, and symbolic notations (e.g., graph data from a table) ○ Construct models given criteria	○ Design investigation for a specific purpose or research question ○ Conduct a designed investigation ○ Use concepts to solve non-routine problems ○ Use & show reasoning, planning, and evidence ○ Translate between problem & symbolic notation when not a direct translation	○ Select or devise approach among many alternatives to solve a problem ○ Conduct a project that specifies a problem, identifies solution paths, solves the problem, and reports results
Analyze Break into constituent parts, determine how parts relate, differentiate between relevant-irrelevant, distinguish, focus, select, organize, outline, find coherence, deconstruct	○ Retrieve information from a table or graph to answer a question ○ Identify whether specific information is contained in graphic representations (e.g., table, graph, T-chart, diagram) ○ Identify a pattern/trend	○ Categorize, classify materials, data, figures based on characteristics ○ Organize or order data ○ Compare/ contrast figures or data ○ Select appropriate graph and organize & display data ○ Interpret data from a simple graph ○ Extend a pattern	○ Compare information within or across data sets or texts ○ Analyze and draw conclusions from data, citing evidence ○ Generalize a pattern ○ Interpret data from complex graph ○ Analyze similarities/differences between procedures or solutions	○ Analyze multiple sources of evidence ○ analyze complex/abstract themes ○ Gather, analyze, and evaluate information
Evaluate Make judgments based on criteria, check, detect inconsistencies or fallacies, judge, critique			○ Cite evidence and develop a logical argument for concepts or solutions ○ Describe, compare, and contrast solution methods ○ Verify reasonableness of results	○ Gather, analyze, & evaluate information to draw conclusions ○ Apply understanding in a novel way, provide argument or justification for the application
Create Reorganize elements into new patterns/structures, generate, hypothesize, design, plan, construct, produce	○ Brainstorm ideas, concepts, or perspectives related to a topic	○ Generate conjectures or hypotheses based on observations or prior knowledge and experience	○ Synthesize information within one data set, source, or text ○ Formulate an original problem given a situation ○ Develop a scientific/mathematical model for a complex situation	○ Synthesize information across multiple sources or texts ○ Design a mathematical model to inform and solve a practical or abstract situation

Figure 1. Hess, 2017 Cognitive Rigor Matrix used with permission.

students and teachers. In a research study involving elementary, middle, and high school students, Abernathy & Vineyard (2001) found that Science Olympiad helps students develop and use scientific skills such as scientific reasoning to build new content knowledge and increase their interest in science. The SO events in their study encouraged students' natural curiosity in STEM by providing new contexts for them to learn without rigid curriculum constraints.

Preparation for the competition depends on the SO event. Several months before the competition Science Olympiad students are provided with reference sheets which contain the parameters of their events. Students also have a Science Olympiad coach who helps facilitate their preparation. While students know the objectives of their events in advance, they are required to design and collect, analyze, and interpret data during the SO lab and building events (Philpot, 2015). McGee-Brown, Martin, Monsaas and Stombler (2003) discovered Science Olympiad students demonstrated an in-depth understanding of science concepts, principles, processes, and techniques related directly to their science standards. Other research has shown an increase in students' problem solving and critical thinking skills (McGee-Brown et. al, 2003, Hounsell, 2000, Abernathy & Vineyard, 2001).

According to The Next Generation Science Standards (NGSS, 2013):

> "The world has changed dramatically in the 15 years since state science education standards' guiding documents were developed. Since that time, many advances have occurred in the fields of science and science education, as well as in the innovation-driven economy. We need new science standards that stimulate and build interest in STEM."

Science Olympiad also addresses the importance of science content and interest in STEM within their mission and vision. According to Dr. Gerard Putz, president and co-founder of Science Olympiad, the organization was founded to improve the quality of math and science education and to reignite enthusiasm in those fields among students (Putz, 2005). Research on Science Olympiad outcomes found that students who prepare for these events apply not only science, but engineering and mathematics skills (McGee-Brown et. al., 2003; Wirt, 2011; Christie, 2008).

Table 1. Alignment of B Events

B Event Title	Science Standards & Practices (SPs)	Mathematics Topics Addressed	MS CCSSM & Practices (MPs)	Mathematics DOK*
Anatomy	LS1-3	Cellular Measurement	8EEA4: Perform operations with numbers expressed in scientific notation.	1, 2
Bottle Rocket	ETS1-2-4	Engineering Design	7SPC8 Find probabilities of compound events.	1, 2, 3
	SPs: 2-6		7EE3: Solve problems with integers. Convert between forms, assess reasonableness. Design mathematical models to solve a practical or abstract situation.	1, 2, 3
			MPs: 1-8	4
Crime Busters	PS1-3 SPs: 3,4,8	Chemical reaction data analysis with percentages.	6RPA3: Use ratio and rate reasoning to solve real-world problems.	1, 2
			7GB6: Solve real-world problems involving area, volume and surface area.	1, 2
			7RPA2: Represent proportional relationships between quantities.	1, 2
			8FB5: Describe functional relationships in graphs.	1, 2, 3
			6EEC9: Analyze graphical relationships between dependent and independent variables.	1, 2, 3
			MPs: 1-7	
Disease Detectives	ETS1-2-3; ESS3-4;	Population and geological data, calculation of risk and simulation errors.	7EE3:(See Bottle Rockets)	1, 2, 3
	SP: 2		6RPA3: (See Crime Busters)	1, 2
			7SPA2: Use data from samples to draw inferences about unknown populations.	2, 3
			MPs: 2, 4, 5	
Dynamic Planet	MSESS2-3-6;	Analysis and interpretation of fossils, continental shifts, and seismographs.	7RPA2: (See Crime Busters)	1, 2
	SPs: 2, 4, 6		8EEB5: Graph and compare proportional relationships for unit rates (slope).	1, 2, 3
			MPs: 2- 8	
Ecology	MSLS2-1-5; HSLS2-1-8;	Analyze data and develop models of energy flow in organisms. Evaluate ecosystems using rates and tables.	7RPA2: (See Crime Busters)	1, 2
			7EEB4: Use variables for quantities in real-world problems and equations.	1, 2, 3
			8SPA4: Understand patterns of association in bivariate categorical data. Construct/interpret two-way tables.	1, 2, 3
Experimental Design	SPs: 1-8	Analyze, interpret, and discuss statistical trends with data.	7SPA2: (See Disease Detectives)	2, 3
			6SPB4: Display numerical data	1, 2
			6SPB5: Summarize numerical data (A&B)	1, 2, 3
			SPB4: Use measures of center and variability data to draw inferences.	1, 2, 3
			MPs: 1-8	
Fast Facts	SPs: 8	Relaying facts about scientists and minerals.	CCSM: None	1
			MPs: 3, 6	

Table 1. continued

B Event Title	Science Standards & Practices (SPs)	Mathematics Topics Addressed	MS CCSSM & Practices (MPs)	Mathematics DOK*
Food Science	SPs: 3-8	Build a calorimeter. Solve equations and proportions involving temperature.	6RPA3D: (See Crime Busters)	1, 2
			7RPA3: Use proportional relationships to solve multistep ratio problems.	1, 2
			MPs: 1-8	
Hovercraft	SPs: 2-6	Use ratio/scale to build a self-propelled air-levitated vehicle.	6RPA3B: (See Crime Busters)	1, 2
			6RPA3D: Use ratio reasoning to convert measurements.	1, 2
			7GA1: (See Food Science)	1, 2
			Design mathematical models to solve a practical or abstract situation	4
			MPs: 1-8	
Invasive Species	HSLS4-2; ESS3-3	Interpret data on natural hazards.	7RPA3: (See Invasive Species)	1, 2
Meteorology	ESS2–5; ESS3–2	Analyze weather maps.	6RPA3B: (See Crime Busters)	1, 2
			5GA2: Represent problems with graphing.	1, 2
Microbe Mission	LS1-1, 6-7; HS-LS1-1, 3-7	Analyze microbe data and find net energy transfer.	8EEA4: (See Anatomy)	1, 2
Mission Possible	HS-PS3 SPs: 2-8	Build Rube Goldberg using data.	Quantities (N-Q), 1-3: Reason quantitatively to solve problems: 1. Choose and interpret units/scales, 2. Define quantities, 3. Measure accurately	1, 2
			Design mathematical models	4
			MPs: 1-8	
Optics	PS4-1-3	Use geometry and physics to direct a laser beam	7GB5: Solve multi-step angle problems.	1, 2
			8G5: Use ideas about distance and angles to solve problems.	1, 2, 3
			6RPA3B: Solve unit rate problems.	1, 2
Reach for the Stars	HS-ESS1-3	Solve equations to study astronomical phenomena.	HSF. IFB4: Interpret and describe relationships of graphs.	1, 2
			HSA.SSEA1: Interpret expressions that represent quantities.	1, 2
			Quantities (N-Q): (See Mission Possible)	1, 2
Road Scholar	SPs: 2	Calculate acreage of areas.	6GA3: Draw polygons in coordinate planes to find real world lengths.	1, 2
			7GB6: (See Crime Busters). MPs: 2, 4, 5	1, 2
Rocks and Minerals	PS1-1; ESS2-1; HS-ESS2-3	Calculate percentages of minerals.	6RPA3C: Find percent of quantities.	1, 2
Scrambler	ETS1-2-4; SPs: 2-6	Measure energy from egg drops.	7EEB3 &7SPC8: (See Bottle Rocket)	1, 2, 3
			Design mathematical models to solve a practical or abstract situation	4
			MPs: 1-8	

Table 1. continued

B Event Title	Science Standards & Practices (SPs)	Mathematics Topics Addressed	MS CCSSM & Practices (MPs)	Mathematics DOK*
Towers	SPs: 2-6	Build a specified tower before competition.	7GB6: (See Crime Busters)	1, 2
			7GA2: Draw geometric shapes with conditions.	1, 2
			Design mathematical models	4
			MPs: 1-8	
Wind Power	SPs: 2-8	Build a blade assembly to capture wind power.	6RPA3B: (See Optics)	1, 2
			7RPA3: (See Food Science)	1, 2
			Design mathematical models	4
			MPs: 1-8	
Wright Stuff	SPs: 2-6	Design a free-flight, rubber-powered monoplane to achieve maximum air time.	6RPA3B: (See Optics)	1, 2
			7GB6: (See Crime Busters)	1, 2
			7GB5: (See Optics)	1, 2
			Design mathematical models	4
			MPs: 1-8	
Write it/Do it	SPs: 2, 5-8	Construct objects from a student's description.	Standards vary.	3
			MPs: 2- 8	

*Due to multiple parts per event, more than one DOK rating may be listed.

Prior studies of Science Olympiad direct their focus toward student perceptions, preparation for SO events, and the impact their participation had on their career choices (McGee-Brown et. al., 2003; Wirt, 2011; Christie, 2008). These studies found that students who participated in SO events demonstrated a higher percentage of positive feelings toward STEM content areas, gained an increase of 21st century skills, and are more likely to follow a STEM related career path (McGee-Brown et. al., 2003; Wirt, 2011; Christie, 2008).

Although this research discusses STEM careers and skills, there exists a gap in the literature specifically aligning the Science Olympiad events to DOK levels, CCSSM, or the Mathematical Practices. While specific science content standards were identified on the Science Olympiad website, no record relating these events to mathematics or DOK levels existed in the review of the literature. As teachers seek to learn how to best prepare their students for these events, it is helpful that connections between SO events and the mathematical knowledge are made explicit.

Methodology

Both a content analysis and alignment of DOK levels were used in this study as a means to determine the relationships between the Science Olympiad Division B and C events, the Next Generation Science Standards and Practices, Webb's Depth of Knowledge Framework, and the Common Core State Standards for Mathematics and Mathematical Practices. Results were used to support mathematics and science teachers, administrators, and school districts that participate in the Science Olympiad competitions.

Procedures for Content Alignment

A quantitative content analysis was used to determine which mathematical topics were addressed in the B and C events and how often they occurred (Krippendorff, 2012; Neuendorf, 2002). Data gathered from five resources provided by the Science Olympiad website included: rules of each event, power points, event content wikis, released exams, and videos. After authors defined the purpose of analysis and materials to be analyzed, the identification of rules that constituted a "match" between the standards and events was made. The establishment of the CCSSM and Mathematical Practice categories led the authors to decide that in order for an event to exhibit a particular standard (or fit in a category), the mathematics involved must be at or beyond grade levels for Division B (6-8) or Division C (9-12). For example, many events required calculations but reviewers did not include any mathematics standards lower than fourth grade as evidence. However, if the mathematics was an essential feature of the event, such as developing an experimental design where statistical/graphical analysis was necessary, then the mathematics was matched with the appropriate

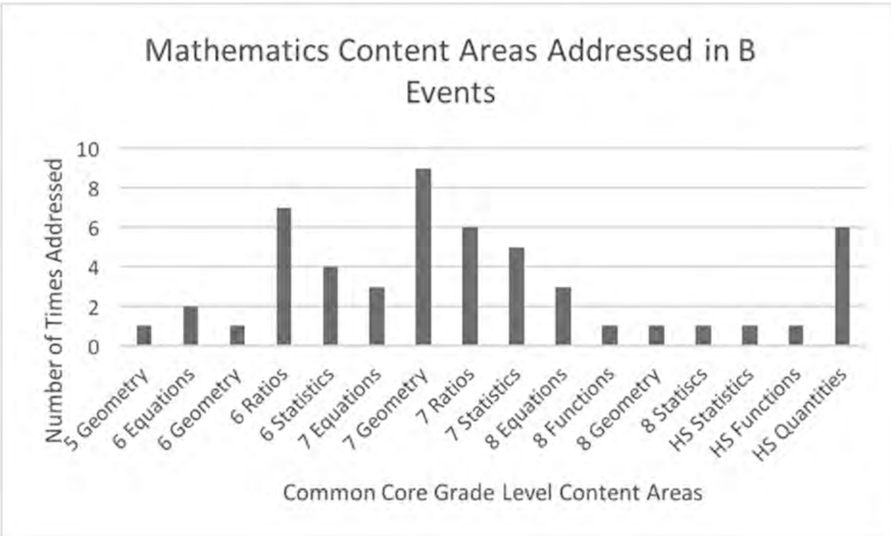

Figure 2. Mathematics Content Standards by Grades Addressed in B Events. This figure illustrates the frequency of math topics included within events.

standard(s) and mathematical practices. The eight mathematical practices (MPs) describe the varieties of processes and proficiencies that mathematics educators seek to develop in their students (CCSSM, 2010). Finally, the frequency of aligned standards was documented with an effort to quantify the number of times each event was dependent on specific mathematical content standards (Division B: grades 6-8 and Division C: grades 9-12).

Alignment Models for DOK

Researchers have developed models to enable more sophisticated alignment analysis of standards (Case, Jorgensen, & Zucker, 2009). The most frequently used are Webb's Model, Surveys of Enacted Curriculum (SEC), and the Achieve Model. Norman Webb's model of alignment has been used frequently in the field of education (Ananda, 2003; Impara, 2001; La Marca et al., 2000). Webb aligns programs along the lines of five dimensions of an assessment: (a) content focus, (b) categorical concurrence, (c) depth of knowledge consistency, (d) range of knowledge correspondence, and (e) balance of representation.

Content focus concerns the development of student knowledge of the subject matter *Categorical concurrence* examines the similarity between the categories of content in the standards and assessments. *Depth of knowledge* consistency compares the content complexity required by the standards and measured by the assessments. *Range of knowledge* correspondence compares the span of knowledge required by the standards in a subject area to that of the assessments. *Balance of representation* compares the emphasis given to certain topics and objectives in the standards to the assessment's corresponding emphasis. To carry out an alignment study using Webb's model, a panel consisting of four to six educators and content specialists trained to identify DOK levels and standards are required. Each criterion is rated numerically, allowing the results to be objectively quantified, calculated, and reported.

Andrew Porter developed the Surveys of Enacted Curriculum (SEC) Model that categorizes the standards and assessments according to content topics and cognitive demand (CCSSO, 2002). Cognitive demand is described using categories that are specific to each specific discipline. In mathematics these include (a) memorization, (b) procedures, (c) understanding, (d) generalizations/proof, and (e) solutions of non-routine problems. This categorization produces a matrix that enables a comparison of the standards and assessments (Porter, 2002).

The third model by Achieve, Inc., has developed an alignment model that can be used to compare a state's standards to those of other states or nations, provide professional development to state educators and perform an audit of a state's education reform. The Achieve model

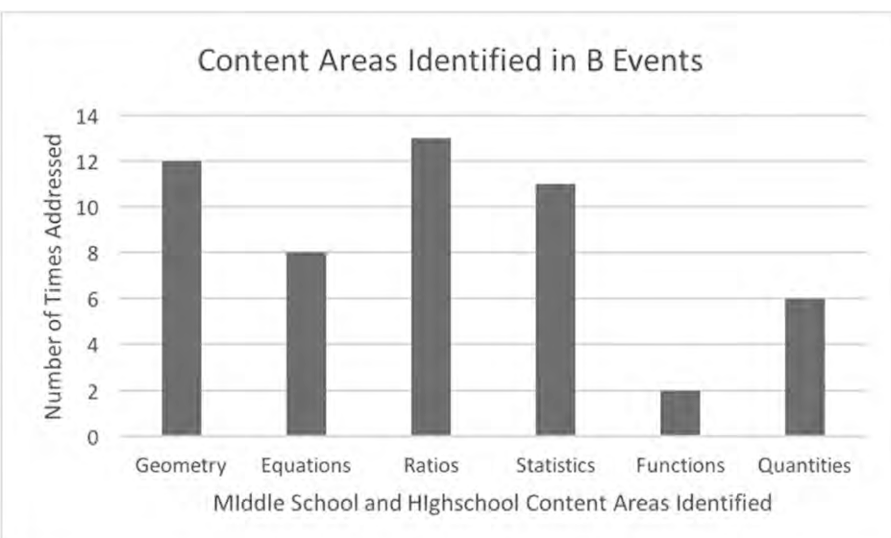

Figure 3. Middle and High School Content Areas Addressed in B Event. This figure illustrates the frequency of specific content areas within event.

Table 2. Alignment of C Events

C Event Title	HS Science Standards & Practices (SPs)	Mathematics Topics Addressed	HSF CCSSM & Practices (MPs)	Mathematics DOK*
Ecology	LS1–2-3	Growth Curves of Populations, Exponentials, Logistics, Number Pyramids, Invasion Curves, and Predator-Prey Graphs.	IFB4: Interpret features (quantities) of graphed and give a verbal description of the relationship. LEB5: Interpret parameters in a linear or exponential function. IDB6a: Fit a function to data to solve problems in context.	2, 3
Invasive Species	LS4– 2	Time series and Invasion Curves.	IDA1: Interpret categorical and quantitative data. Summarize, represent, and interpret data on a single count or measurement variable.	2, 3
Microbe Mission	LS1–1, 3-7	Exponential Growth Curve.	IDA1: (See Invasive Species). 6SP4: Summarize and describe distributions and display data in graphs. IFC7e: Analyze functions using different representations. Graph exponential, trigonometric, and logarithmic functions. Show key features by hand and using technology.	1, 2, 3
Anatomy and Physiology	LS1–2-3	Homeostasis-Action Potential Graph	N-QA2: Reason quantitatively and use units to solve problems. Define appropriate quantities for the purpose of descriptive modeling.	1, 2
Disease Detectives	ESS3–4; ETS1–3 SP: 2	Odds Ratio, Epidemic Curve, Identify types of error and statistical analysis. MPs: 2,4,5	IDA2: Interpret Categorical and Quantitative Data. Summarize, represent, and interpret data to compare center) and spread.	1, 2, 3
Hovercraft	SPs: 2-6	Kinematic Equations, Projectile Motion, Momentum, Density, Pascal's law,	REI.A1: Reasoning with Equations and Inequalities by explaining steps and constructing viable arguments. N-Q2: (See Anatomy and Physiology). MPs: 2-5, 7-8	1, 2
Wind Power	SPs: 2-8	Power of Wind Formula Multimeter Readings	N-Q2: (See Anatomy and Physiology).	2
Materials Science	PS1–3; PS2–6 SPs: 2-8	Young's Modulus Stress/Strain Curve, Creep Rate, Viscosity, Surface Area/Volume, Ratios.	7GB6: Solve problems involving area, volume and surface area. N-Q.1-3: 1. Use units to understand problems 2. Define appropriate quantities for modeling. 3. Choose a level of accuracy when reporting quantities.	3, 4

Table 2. continued

C Event Title	HS Science Standards & Practices (SPs)	Mathematics Topics Addressed	HSF CCSSM & Practices (MPs)	Mathematics DOK*
Optics	PS4–1, 3-5	Angles of reflection and refraction and Snell's Law.	8GA3: Describe the effect of dilations, translations, rotations, and reflections using coordinates. TFB5: Choose trigonometric functions to model phenomena. 8EEA4: Perform operations in scientific notation.	1, 2, 3
Forensics	SPs 2-8	Angle of Impact of Blood Spatter.	TFB7: Use inverse functions to solve trigonometric equations. Evaluate and interpret solutions using technology.	2
Chemistry Lab	PS1–2, 4-5, 7	Stoichiometry.	N-Q.A1-3: (See Materials Science). SSE.A1b: Interpret expressions by viewing one or more of their parts as a single entity. CED.A1: Create equations and inequalities in one variable and use to solve problems. CED.A2: Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. REIB3: Solve linear equations and inequalities in one variable.	1, 2, 3
Hydrogeology	ESS3–4, 6 SPs: 2, 5-6, 8	Algebraic Equations, Matrices, Mathematical Modeling, Estimation, and Numerical Modeling.	N-Q.1-3: (See Materials Science).	3, 4
Game On	SPs: 2, 5	Programming with Technology.	MPs: 2-5, 8	3
Write It Do It	SPs: 2, 5-8	Measurement, and Precision in Description.	N-Q.1-3: (See Materials Science).	1, 2
Experimental Design	SPs: 1-8	Creating a graph from a table. Graph Statistics (Central Tendency, and Hypothesis Testing.	IC-B.3. Recognize purposes and differences among surveys, experiments, and observational studies; explain how randomization relates to each. IC-B4: Use survey data to estimate population means or proportions; and develop a margin of error through simulation models. IC-B5: Use data and simulations from a randomized experiment to compare two treatments. IC-B6: Evaluate reports based on data.	1, 2, 3
Electric Vehicle	SPs: 2-8	Motor cogging formula	CEDA2: (See Chemistry lab).	2
Robot Arm	SPs: 2-8	Construction of a robotic arm to grab, lift, and deposit specific items in prescribed locations.	MPs: 1, 2, 4-6	2, 3
Towers	SP's: 2-6	Problem solving, Precision in Measurement, and Geometric Structures.	MPs: 1-8	1, 2, 3

Table 2. continued

C Event Title	HS Science Standards & Practices (SPs)	Mathematics Topics Addressed	HSF CCSSM & Practices (MPs)	Mathematics DOK*
Helicopters	SPs: 2-6	Precision in Measurement, Problem solving, Modeling, look for and expressing regularity in repeated reasoning.	MPs: 1-8	1, 2, 3,
Rocks and Minerals	MS-PS1–1; MS-ESS2–1; ESS2–3	Crystal structures of minerals.	GMDB4: Identify shapes of two-and three-dimensional cross-sections generated by rotations.	1
Remote Sensing	PS4–1, 2, 5; ESS2–2, 4-5	Image Interpretation, Radiation, and find surface area using graphs.	7GB6: (See Materials Science).	2, 3, 4
Dynamic Planet	MS-ESS2–2-; ESS2–2-3	Drift velocity and Magnitude of Earthquakes.	N-Q1-3: (See Materials Science).	1, 2
Astronomy	ESS1–2-3	H-R Diagram, Distance modulus, Scientific Notation, and Hubble's Law.	N-Q1-3: (See Materials Science).	1, 2

*Due to multiple parts per event, more than one DOK rating may be listed.

uses five criteria for alignment: content centrality, performance centrality, challenge, balance, and range (CCSSO, 2002; Resnick et al., 2003). *Content centrality* compares the content of each test item to the corresponding standard. *Performance centrality* compares the difficulty (cognitive demand) of each item to the difficulty required by the corresponding standard. *Challenge* examines whether a set of items considered together expresses the degree of proficiency required by the standards. *Balance* and *Range* provide a quantitative and qualitative evaluation of the emphasis placed on topics in the assessment compared to the emphasis placed on the same topics in the standard (Case, Jorgensen, & Zucker, 2009).

The authors selected Webb's model primarily for the DOK criteria which had been used in previous publications aligning assessments with the Common Core. The reliability within Webb's model has been well established by its use in alignment studies for more than 10 states (Council of Chief State School Officers [CCSSO], 2002). Producers of standardized tests rely on Webb's model to augment norm-referenced assessments for compliance. Webb's model is adaptable to other purposes for which an alignment study may be required (Impara, 2001).

Reviewer Panel Participants and Training

Because this content alignment requires a panel of experts in particular mathematics and science content fields, six pre-service and two in-service mathematics and science teachers were asked to serve as reviewers. For this study, the Webb Alignment Tool was used, where alignment analysis is a two-part process. Two training and work sessions (approx. 3 hours each) with the mathematics and science panelists were held. On day one all participants were provided with copies of the CCSSM grades 5-12, Next Generation Science Standards grades 5-12, Webb's Depth of Knowledge framework, Hess's Model (2013), and the 2016 Science Olympiad Event Guides and resources. Reviewers used these materials for their training on assigning DOK levels to the mathematics embedded in the SO events. On day 2, reviewers aligned an SO event to the mathematics standards and identified the DOK levels using Hess's model (see Figure 1).

Interrater Reliability

To ensure that raters coded the items in a consistent manner, the authors conducted two rounds of review. The process involved coding randomly selected mathematics items from each event, with a total of 73 mathematics items selected for calibration. In the first round reviewers rated items independently and reconvened to discuss ratings and resolve any discrepancies. In the second round, the authors rated the remaining items independently to check the interrater reliability. Results showed acceptable interrater reliability for the content analysis at an 81% percent agreement using CCSM and SO events. For DOK results, the weighted kappa coefficient, which is a measure of rater agreement that takes into account agreement of ordinal data due to chance, was at 0.78 for mathematics.

Findings

Table 1 illustrates the relationship between science and mathematics topics behind the B events within middle school Science Olympiad divisions. The first two columns describe the individual events and science standards addressed (Science Olympiad, 2017). The next two columns identify the middle school (MS) mathematics topics, corresponding standards, and practices that were aligned by reviewing documents shared on the SO website (i.e. power points, handouts,

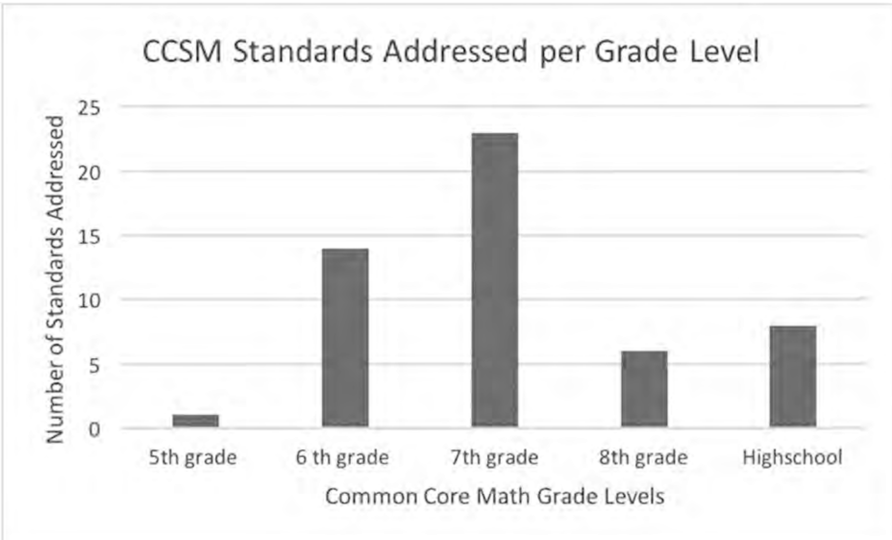

Figure 4. B Event CCSSM per Grade Level. This figure illustrates number of standards per grade level.

practice tests). The last column identifies the mathematics DOK levels using Webb's identification for mathematics and science (Hess, 2013).

Analysis of Group B Events

As observed from Table 1, one event may contain multiple standards and/or practices for math or science. Comparing the Mathematical DOK levels among all 23 events, 7 were categorized at a Mathematical DOK level of 4, while 8 were at a level 3, 7 were at a level 2 DOK and only 1 was at a level 1 DOK. All of these events fell under one of the following science strands: Life, Personal & Social Science, Physical Science & Chemistry, Inquiry & Nature of Science, Technology & Engineering, and Earth and Space Science. The highest DOK levels for Math (Level 4) were in the areas of: Technology & Engineering (4 out of 7), Physical Science & Chemistry (2 out of 7), and Inquiry & Nature of Science (1 out of 7). It may be that these three content areas require high scientific DOK demands for students that also transfer to high levels of mathematics problem solving situations. Additional data of B events are illustrated in Figures 2 and 3.

As illustrated in Figure 2, most standards addressed were within 7th grade (44%), with the highest categories in Geometry (17%), Ratios (11%), and Statistics (9%). Sixth grade was second highest (Figure 2) at 27%, with the highest topics in Ratios (13%) and Statistics (7%). With all grade levels combined (Figure 2), most standards addressed were: Ratios (25%), Geometry (23%), and Statistics (21%). Similar findings within all middle and high school events identified the areas of Geometry, Ratios, and Statistics as representing the majority of topics within the B events (Figure 3).

Analysis of Group C Events

Table 2 illustrates the relationship between science and mathematics topics within the Division C high school SO events. The first two columns describe the individual events and science standards addressed (Science Olympiad, 2017). The next two columns identify the high school (HS) mathematics topics, corresponding standards, and practices that were aligned by reviewing documents shared on the SO website (i.e. power points, handouts, practice tests). The last column identifies the mathematics DOK levels using Webb's identification for mathematics and science (Hess, 2013).

As observed from Table 2, one event may contain multiple standards and/or practices for math or science. Comparing the Mathematical DOK levels among all 23 events, 3 were categorized at a Mathematical DOK level of 4, while 11 were at a level 3, 8 were at a level 2 DOK and only 1 was at a level 1 DOK. All of these events fell under one of the following science strands: Life, Personal & Social Science, Physical Science & Chemistry, Inquiry & Nature of Science, Technology & Engineering, and Earth

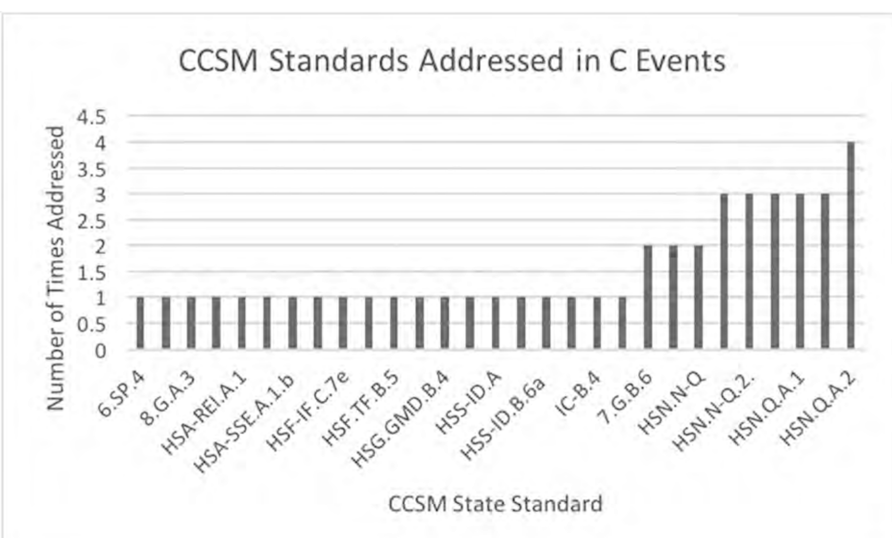

Figure 5. Mathematics Content Standards Addressed in C Events. This figure illustrates mathematics topics found in grades 6-12.

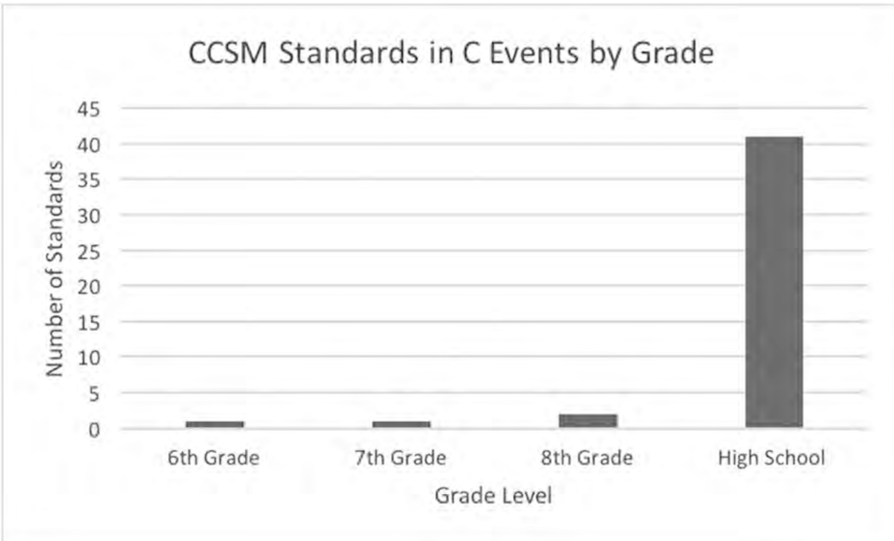

Figure 6. Middle and High School Content Areas Addressed in C Event. This figure illustrates the number of high school standards addressed.

and Space Science. The highest DOK levels for Math (Level 4) were in the areas of: Technology & Engineering (2 out of 4), Physical Science & Chemistry (2 out of 4), and Inquiry & Nature of Science (1 out of 4). There were the same three areas for the Level 4 Division B Events. Additional data of C events are illustrated in Figures 4-6.

Most of the standards addressed in the C Events were within the areas of Number and Quantity (47%), Statistics (17%), and Algebra (13%). This did not correspond with the B events where Geometry was the highest overall category (17%), Ratios and Proportions was second highest (11%) and Statistics was third (9%). The majority of the standards addressed in the C events were from the Common Core High School standards (91%), while only about 9% were from 6-8th grade (see Figures 6 and 7).

Conclusion and Discussion

At the heart of College and Career Readiness is the need to increase the level of rigor in our classrooms for all students. However, even though the CCSSM has identified rigor as a central tenant, the standards alone will not bring it to our classrooms. The implementation of these standards requires activities or tasks that support high demand in content and processes.

The findings in this study indicate that there is a significant level of mathematics content found in both divisions of Science Olympiad. What may be more significant is that the mathematics within these events demonstrate high Depth of Knowledge levels. Specifically, events which require students to engage in analysis, synthesis, and generalizability of results over time are particularly demanding since students are to produce new knowledge. The Division B and C events of Science Olympiad create a passion for learning science by supporting middle and high school science and mathematics content with an emphasis on teamwork and a commitment to academic excellence.

By analyzing the connections between events and the standards in mathematics, it is evident that the mission of Science Olympiad is to improve science *and* mathematics education (Putz, 2005). These findings are also consistent with the literature published about Science Olympiad, specifically in the areas of enhancing student learning in the field of STEM. Research conducted by Calvin Taylor of the University of Utah has concluded, "Extra-curricular training experiences and accomplishments do show noticeable predictive power of later adult performance, achievement, and accomplishments" (Science Olympiad, 2018).

Although this study found significant relationships existing between the Science Olympiad events and Common Core State Standards in Mathematics (CCSSM) and Webb's Depth of Knowledge levels, more research is needed to analyze this relationship in more depth. For example, observational studies of students solving problems during events could determine more specific learning outcomes and whether students use the mathematics content standards. Students' and teachers' perceptions of the mathematics required

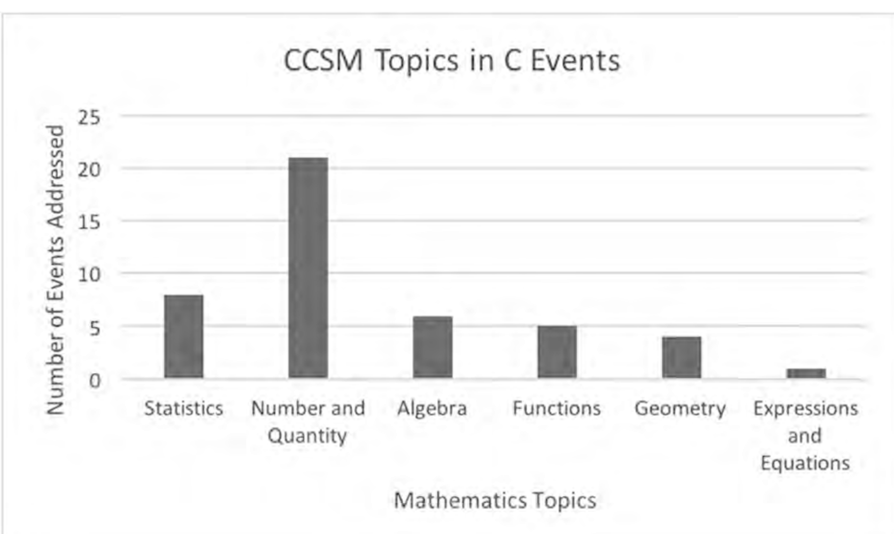

Figure 7. C Event CCSSM per Topic. This figure illustrates number of standards per topic.

in these events could also provide a different a perspective beyond analysis of documents.

References

Abernathy, T. V., & Vineyard, R. N. (2001). Academic competitions in science what are the rewards for students? The Clearing House, 74(5), 269-276.

Ananda, S. (2003). *Rethinking issues of alignment under No Child Left Behind.* San Francisco: WestEd.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education, 97* (3), 369-387.

Case, Betsy J., Jorgensen, Margaret A & Sasha Zucker. (2008). *Alignment in Educational Assessment*, Pearson Education, Inc.

Christie, K. (2008). Middle and high schoolers get hands-on STEM experiences. Phi Della Kappan, 90(1), 5-6. Retrieved from EBSCO~OSI

Committee on Science (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washingston, DC: National Academic Press.

Council of Chief State School Officers (CCSSO). (2002, September). Models for alignment analysis and assistance to states. Washington, DC: Author. Retrieved from http://www.ccsso.org/content/pdfs/AlignmentModels.pdf.

Hess, K. (2013). A guide for using webb's depth of knowledge with common core state standards. Common Core Institute. Retrieved June 14, 2017, from https://education.ohio.gov/getattachment/Topics/Teaching/Educator-Evaluation-System/How-to-Design-and-Select-Quality-Assessments/Webbs-DOK-Flip-Chart.pdf.aspx.

Dixon, R. Brown, R. (2012). Transfer of learning: Connecting concepts during problem solving. *Journal of Technology Education*, 24 (1), 2-17.

Impara, J. C. (2001). *Alignment: One element of an assessment's instructional unity.* Paper presented at the 2001 annual meeting of the National Council on Measurement in Education, Seattle, WA. Retrieved from http://www.unl.edu/BIACO/NCME/Alignment%20revised.pdf

Krippendorff, (2012). *Content analysis: An introduction to its methodology.* Thousand Oaks, CA: Sage Publications.

La Marca, P. M., Redfield, D., Winter, P. C., Bailey, A., & Despriet, L. (2000). State standards and state assessment systems: A guide to alignment. Washington, DC: Council of Chief State School Officers.

McGee-Brown, M., Martin, C., Monsaas, J., & Stombler, M. (2003). What scientists do: Science Olympiad enhancing science inquiry through student collaboration, problem solving, and creativity. Paper presented at the annual National Science Teachers Association meeting, Philadelphia, PA.

National Science Teachers Association (2018). *Position statements*, Retrieved from http://www.nsta.org/about/positions/.

Neuendorf (2002). *The content analysis guidebook*. Thousand Oaks, CA: Sage Publications.

Next Generation Science Standards (NGSS) (2013). Appendix L: Connections to the common core state standards for mathematics. Retrieved June 14, 2017, from https://www.nextgenscience.org/sites/default/files/Appendix-L_CCSS%20Math%20Connections%2006_03_13.pdf

Porter, A. C. (2002, October). Measuring the content of instruction: Uses in research and practice. Educational Researcher, 31(7), 3–14.

Philpot, C.J. (2007). Science olympiad students' nature of science understandings. Dissertation, Georgia State University. Retrieved from http://scholarworks.gsu.edu/msit_diss/20.

Resnick, L. B., Rothman R., Slattery, J. B, & Vranek, J. L. (2003). Benchmarking and alignment of standards and testing. Educational Assessment, 9(1 & 2),1–27.

Science Olympiad (2017). B/C Events. Retrieved June 14, 2017, from https://www.soinc.org/bc-events

Science Olympiad Inc. (2017). Mission Statement. Retrieved February 25, 2018, from http://www.soinc.org.

Webb, N. L. (1999). *Alignment of science and mathematics standards and assessment in four states* (NISE Research Monograph No.18). Madison: University of Wisconsin–Madison, National Institute for Science Education. Washington, DC: Council of Chief State School Officers.

Wirt, J. L. (2011). An analysis of Science Olympiad participants' perceptions regarding their experience with the science and engineering academic competition. Seton Hall University Dissertations and Theses (ETDs). 26. Retrieved from http://scholarship.shu.edu/dissertations/26.

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