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High School Students' Semantic Networks of Scientific Method in an International Science Olympiad Context

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ABSTRACT

This study examines students' conceptualization of scientific method from three perspectives: (a) participation in an international science fair, (b) gender differences, and (c) participation from different geographic regions worldwide. An online Word Association Test (WAT) with 10 stimulus words that are associated with scientific method was administered to high school students from more than 35 countries. Findings indicated that the semantic network of students who participated in the I-SWEEEP Olympiad had stronger connections among the 10 key concepts compared to that of non-I-SWEEEP students. Findings also revealed that male participants overall had a more complex semantic network of scientific method than their female counterparts. In addition, students from Americas, mostly U.S., had a more complex conception of scientific method than their counterparts from Eastern Europe and Asia. Results have implications about understanding affordances of science fairs in conceptualization of scientific method and about addressing gender and geographic differences.

Keywords: scientific method, science olympiad, semantic networks, Word Association Test (WAT), I-SWEEEP

INTRODUCTION

Although science education and curricula vary among countries, states, school districts, and even among individual schools, developing science literacy and a strong understanding of doing science appear to be highlighted among all (American Association for the Advancement of Science [AAAS], 1989; Rutherford & Ahlgren, 1990). Naturally, raising science literate students has long been a priority for most countries (for both developing and developed countries in particular), including the United States, due to the importance of science and scientific advances for countries' economic well-being (Robeck, 2014; Toulmin & Groome 2007).

AAAS (1989) and National Research Council (NRC; 1996) have long stressed the importance of developing pre-college students' understandings of scientific inquiry and scientific processes for decades. However, research indicates that school science may be quite limited in helping students develop scientific literacy (Lederman, 1992; Trautmann, Avery, Krasny, & Cunningham, 2002). Educational researchers and science organizations suggest alternative ways to teach scientific inquiry by doing science through either in-class science projects or out of classroom work with scientists (NRC, 1996; Rock & Lauten, 1996; Solomon, 1991; Trautmann et al., 2002). "Working on authentic science research projects facilitates the development of scientific literacy by enhancing students' understandings of science content, the processes and logic of scientific inquiry, and the nature of science" (Bell, Blair, Crawford, & Lederman, 2003, p. 488). It is naturally expected that students who experience the messiness of doing science and seeing its real life connections develop better understandings of scientific inquiry.

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Contribution of this paper to the literature

- This study adds to what is known about science fairs and how they impact students' perceptions of scientific method
- Findings reveal some gender differences and differences among participants from different geographic regions of the world in terms of students' perceptions of scientific method.
- Findings have implications for science curricula and teaching addressing gender and regional differences and important concepts perceived weakly by students such as variable and writing.

Research indicates that students lack proper understanding of nature of science and how to do authentic science because they perceive science as a collection of laws and facts without having any background of how existing concepts came into being and how those interacted with the things around us (Jona & Adsit, 2008). According to an NRC report prepared by Siner, Hilton, and Schweingruber (2006), students usually do not understand science as a dynamic notion that happens and changes through new evidence obtained through human efforts. Laboratory environments are usually good places to test and experience some parts of science, but its carefully predetermined procedures leave very limited opportunities for students to understand what the notion of science really is (Jona & Adsit, 2008). Yet, NRC's recommendation about the importance of integrating instruction and investigative processes of labs in students' understanding of science still seems a reasonable way to follow. Activities that help develop scientific inquiry is not limited to brief classroom activities and lengthy projects in research labs, but it also entails more authentic research experiences including an apprenticeship guided by a science professor (Barab & Hay, 2001).

The purpose of this research was to explore how students' level of conceptualization of scientific method differ by three conditions: (a) participation in International Sustainable World Energy, Engineering, and Environment Project (I-SWEEEP), an international science fair, (b) gender, and (c) participation from different geographic regions across the globe. Therefore, this study is important because it contributes to what we know about science fairs and how they impact students' perceptions of scientific method. In addition, this study also informs us about the gender differences and differences due to the geographic locations in terms of students' perceptions of scientific method. The findings may have implications for science teaching including possible adjustments to the school science curricula or standards addressing affordances of science fairs and differences due to gender and students coming from different regions. Differences due to geographic locations is especially critical for countries like U.S. where immigrants coming from all over the world comprise considerable portion of the whole population (more than 13% as of 2012, National Science Foundation [NSF]; 2013).

Conceptual Framework and Review of Relevant Literature

To ground this work on the previous research, the conceptual framework for this study utilized relevant literature focusing on (a) scientific inquiry, b) scientific method, and (c) Word Association Test (WAT). This is study is also informed by the relevant literature to develop the "skeletal structure of justification" (Eisenhart, 1991, p. 209), serving as a guide for data collection, analysis, and interpretations of the results.

Scientific Inquiry

To Linn, Davis, and Bell, (2004), inquiry is defined as an "intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (cited in Nikolova & Stefanova, 2014, p. 19). To others, inquiry is associated with process skills linked with the scientific method (Ayers & Ayers, 2007; Knabb, 2006). Yet, many science educators argue that inquiry is more about thinking process through practices that cannot be formalized into a rigid method such as scientific argumentation and sense making (Hammer, Russ, Mikeska, & Scherr, 2005). Accordingly, inquiry-based science education can be described as a method to learning that involves a process of exploring the things happening around us by asking questions, making discoveries, and testing those discoveries to develop new understanding (Nikolava & Stefanova, 2014).

Involvement in inquiry-based science learning may range from brief classroom activities to lengthy science projects in research labs (Bell et al., 2003). Students learn different aspects of scientific inquiry depending on the level of experience they gain through authentic research experiences—such as an apprenticeship guided by a science professional (Barab & Hay, 2001; Ritchie & Rigano, 1996).

Scientific inquiry is another disputed term, especially in this age of increased calls for inquiry teaching and learning and the flood of inquiry-based curricula (Tang, Coffey, Elby, & Levin, 2010). Tang and colleagues (2010) investigated the relationship between the scientific method and scientific inquiry in their study. The researchers analyzed 90-minute high school environmental science class where the teacher attended students' understanding of scientific method and how it affected their comprehension of scientific inquiry. They argued that students and teacher are distracted from attending to productive scientific inquiry when they viewed scientific method as rigid and decomposable steps. They also stated that students did not have to follow the steps of scientific method to develop authentic scientific questions and hypotheses for their investigations. Tang and rest of the team concluded that focusing on the scientific method as discrete steps can distract students and teachers from having a productive inquiry.

Scientific Method

The meaning of scientific method has long been debated among researchers and practitioners. To date, there is no agreed-upon definition of scientific method (Bybee, 2000; Lederman et al., 2014). However, this should not be perceived as a problem since there cannot be one distinctive approach to all sciences. In other words, one-size-fits-all mindset toward doing science would not be suitable for science branches. Similarly, there are no, and should not be, unified steps or procedures taken to do science. Scientists, as a matter of fact, do utilize a broad spectrum of methods when they do or enact science. Therefore, the ambiguity in the definition of scientific method or scientific inquiry seems to be a natural consequence of doing science.

In very broad terms, scientific method refers to the processes through which scientific knowledge is acquired (Abd-El-Khalick et al., 2004; Lederman et al., 2014; Schwartz, 2004). Organisation for Economic Co-operation and Development (OECD; 2015) put the following three competencies at the heart of science literacy and scientific method: explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically. This involves making observations, question-posing, reviewing what has been already found and known, planning and performing investigations/experiments, gathering, analyzing, and interpreting data (NGSS Lead States, 2013; NRC, 1996; OECD, 2015; Shavelson & Towne, 2002). NRC (1996) specifically adds "communicating the results" on top of aforementioned list since doing science becomes even more meaningful when gone beyond the sake of doing science to inform and share with other scientists and community at large (Lederman et al., 2014). Although the relationship between these essential components of enacting science is not simply in a sequential order, it is evident that there are key concepts that are intertwined with each other and that apply to all branches of sciences such as *problem*, *hypothesis*, and *observation*.

Some researchers naturally opposed that the traditional presentation of the scientific method in the form of a linear checklist leading to the formation of a theory and argued that this is not an accurate understanding of real scientific process (e.g., Reiff, Harwood, & Phillipson, 2002; Windschitl, Thompson, & Braaten, 2008). The perceiving of such rigid structures focused on checking off each step may even denounce science as lacking flexibility, creativity, and in turn productivity (Alexakos, 2010; Windschitl et al., 2008). This is parallel with Taylor's (1962) statement indicating, "the scientific method has tended to emphasize verification stages rather than science as a creative process" (cited in Reiff et al., 2002, p.2). Overall, some researchers agree that a step-by-step approach to the scientific method provides a static set of steps that are more procedural and unable to catch the important parts of the inquiry process of the nature of science including reflection.

On the other hand, another group of researchers suggested that the importance of teaching the scientific method cannot be underestimated; especially for younger students as long as it helps students comprehend necessary structure (Watson, 2004). Scientific method has never disappeared totally but became part of other science understanding approaches. For instance, it has been placed as a critical component of scientific literacy (AAAS, 1989; National Science Teachers Association, 1982; Rutherford & Ahlgren, 1990). Also, the scientific method is still given as an integral part of myriad science textbooks (Watson, 2004). Unsurprisingly, it has been required to be structural frame of "most science fair projects, as a component of student lab reports, and as the basic structure of research reports, theses, and dissertations" (Watson, 2004, p. 37).

One issue in discussing the scientific method is the steps taken to effectively and authentically perform a scientific inquiry (McPherson, 2001). The scientific method is a stepwise, circular approach to solving problems. Therefore, the list may change to the level and content of the problem or situation. For example, the list may contain only six steps including *problem, research, hypothesis, experiment, observation*, and *conclusion* for an elementary level science fair project. However, it may include many more steps for a real life situation including but not limited to *communication, analysis, prediction, identification of variables* in addition to the six steps mentioned above when a secondary school student encounters a real life problem or completes a research project (Tang et al. 2010; Watson, 2004). Indeed, Dewey, who was the inventor of five step idea of scientific method, later emphasized that "*The Sequence of the Five Phases* [Steps] *is Not Fixed.*" (mentioned in Rudolph, 2005). Then, it should not be surprising to see different naming and steps for different projects depending on the level and content of the project/problem students are studying.

In this paper, we base our work on the core concepts we identified and alluded above that are common across different schools of thought for scientific method: *inquiring*, *researching*, *hypothesizing*, creating a course of action (devising *project*), *collecting data*, *observing*, carefully selecting *variables*, *experimenting*, *writing reports*, and disseminating results by participating in conferences or *science fairs*. From these core concepts, we devised 10 stimulus words to be included in the word association test that are discussed in the *Instrument* section below. Science literature and research indicates that these core concepts are integral for enacting science and they are interconnected with each other (AAAS, 1989; Lederman et al., 2014; NGSS Lead States, 2013; NRC, 1996; OECD, 2015). A high level understanding and conceptualization of scientific method would then reflect strong connections among all these core concepts (Gulacar, Sinan, Bowman, & Yildirim, 2015; Nakiboglu, 2008).

Word Association Test (WAT)

Visualizing students' semantic networks (or knowledge structures) related to scientific method is important for exploring how they understand science (Nakiboglu, 2008). There are several ways to make visible the knowledge structure of students (see Gulacar et al., 2015). A word association test (WAT) is one of the most common methods for investigating knowledge structures (Bahar, Johnstone, & Sutcliffe, 1999; Nakiboglu, 2008). A WAT is very good at assessing conceptual development (Gulacar et al., 2015). Word associations involve providing an individual with a succession of carefully chosen words about a specific subject to which the individual has to respond with the first word that occurred to him or her within a short reaction time (Jung, Adler & Hull, 2014). WAT was first invented by Sir Francis Galton with the turn of the 20th century to show how it could be used to explore the hidden recesses of the mind (Stevens, 1994). It was later revised by Wundt who attempted to experimentally establish the laws of the association of ideas (Jung et al., 2014). The basic premise of the word association test is:

> *Stimulus words are presented to the subject (either verbally or in written form) who is asked to respond with the first word or words that come to mind. The resulting word association is thought to mirror the way the words are stored and linked in the mental lexicon (Peppard, 2007, p. 4).*

More specifically, WAT can be used to measure the participant's mental model, verbal memories, thought processes, emotional states, and personality (Sinopalnikova & Smrz, 2004). It is one of the most often-used methods to study students' knowledge structure and has been validated, found reliable, and used widely by researchers (Bahar & Hansell, 2000; Gulacar et al., 2015; Hovardas & Korfiatis, 2006; Nakiboglu, 2008). WAT provides extensive lists of concepts that are relevant to the concepts in pupils' minds (Gussarsky & Gorodetsky, 1988). These are related meanings of the key concepts we try to study (Deese, 1965). This related meaning represents mainly the static facets of knowledge structure (Gussarsky & Gorodetsky, 1988). The order of responses we obtain from WATs reflect majority of the structure within the semantic memory[1] and between given concepts (Shavelson, 1972). It is the knowledge within semantic memory that enables humans to evaluate ideas, infer, extrapolate or use for other purposes (Jonannsen, 1993). The degree of overlap of response orders is a measure of the semantic proximity of the stimulus words in a WAT (Nakiboglu, 2008). If the same associations can be obtained, this might help researchers to comprehend future information (Sutton, 1980). This technique seemed useful for researchers because it lets them develop operational definition of connectedness and is flexible to quantification.

This study examined students' level of conceptualization of scientific method from three perspectives: (a) participation in International Sustainable World Energy, Engineering, and Environment Project (I-SWEEEP), an international science fair, (b) gender, and (c) participation from different geographic regions across the globe. I-SWEEEP is a science fair competition open to high school students from all over the world. We chose I-SWEEEP students because research says scientific method is still very important part and requirement of completing a science fair project (e.g. Watson, 2004). We also assumed that any I-SWEEEP participants had already completed several science fair projects in different organizations before they were qualified to attend I-SWEEEP Olympiad. Therefore, they had to have a great exposure to scientific method during completions of those projects. We developed and administered a WAT to map the cognitive structure of scientific methods in both student groups to see if there is any difference that might stem from their I-SWEEEP participation, gender, and geographic area of participation.

We sought answers to the following three research questions:

1. To what extent do I-SWEEEP participants' conceptions of scientific methods differ from those who did not participate in I-SWEEEP?

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[1] Semantic memory is one of the two systems of long-term memory. According to Tulving (1972) the human memory (that is, the long term memory) can be divided into an episodic system and a semantic system. Semantic memory is the store of a person's knowledge as expressed in linguistic performance: "*Semantic memory is the memory necessary for the use of language. It is a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of these symbols, concepts, and relations*" (Tulving, 1972, p. 386, in Prior, 2004, p. 19).

2. To what extent do I-SWEEEP students' conceptions of scientific methods differ by their gender?
3. To what extent do I-SWEEEP students' conceptions of scientific methods differ by their geographic region of participation?

METHOD

Setting: I-SWEEEP

I-SWEEEP is an international sustainable world energy, engineering, and environment project Olympiad with the mission "to spark interest and awareness in our planet's sustainability challenges, help young people grasp the extent of these issues, find workable solutions to these challenges, and accelerate the progress toward a sustainable world by engaging the youth at an early age" (I-SWEEEP 2015, p. 1). One of the objectives of I-SWEEEP competition is to position secondary-school students as the pre-eminent scientists and engineers of the future to contemplate contemporary global problems (Gulacar et al., 2015).

To be eligible to compete for I-SWEEEP, U.S. students should hold an award at a regional, state, or national science fair competition where use of scientific method in their project completion is one of the requirements (Weseley et al., 2016). International students qualify to compete with approval of their projects by the I-SWEEEP Scientific Review Committee. Students submit their research papers, power points, and all other supplementary materials that are used in completion of their projects to the online system. All applicants are expected to be familiar with basic steps of scientific methods and submit their application proposal aligned with the core concepts of scientific inquiry given at the student handbook on I-SWEEEP website (I-SWEEEP, 2014). They compete in one of four categories: (1) Energy, (2) Engineering, (3) Environment (Health and Disease Prevention), and (4) Environment (Pollution & Management).[2]

Students who come for the competition usually have participated in several field trips including tours of Houston city, NASA, and local higher institutions, and in social events occurring at the convention center and in local hotels. Winners of the grand award, gold, silver, and bronze medals receive money awards of $1,500, $600, $300, and $150 respectively. We should note that participation in I-SWEEEP is not only about attending the multi-day Olympiad (finals) but also involve creating a science project, which in many case is a months-long process and all the work leading up to the finals.

Participants

Participants for this study were high school students from 35 countries. We had two groups of participants: (1) We sent the survey to all the I-SWEEEP participants (395) after we got permission from the I-SWEEEP director; and (2) We also recruited control group people by requesting participating students' mentors to share the survey with the other students in the schools of participating students. However, control group students were not subjected to any evaluation process. The only criterion for control group students was to be from the same school as I-SWEEEP students. I-SWEEEP participating school administrators were asked to administer the online WAT survey to at least one class at their high school. Therefore, authors had no control over who would take the test for the control group. The total number of participants in the study was 363 (164 I-SWEEEP participants (42%) and 199 control group students). Both control group students and I-SWEEEP participants came from same schools but control group students did not participate in I-SWEEEP. **Table 1** shows the characteristics of students as a percentage of their respective groups (I-SWEEEP or control). More than half of the participants (246) were from the United States. Rest of the participants was from countries such as Canada, China, Mexico, Romania, Turkey, and 30 more other countries.

When investigating the second and third research questions, only I-SWEEEP participants were analyzed to, in a way, minimize the confounding factors. Since I-SWEEEP participation, hypothetically would have an impact on students' perceptions of scientific method, narrowing gender and geographic region comparisons to only I-SWEEEP students would control for the impact of I-SWEEEP participation.

[2] More information about the I-SWEEEP and participation requirements can be found at https://isweeep.org/.

Table 1. Number (and Percentages) of Students According to their Characteristics

Characteristic	I-SWEEEP (%) *n*=164			Control (%) *n*=199		
Gender						
Female	87 (53.0)			118 (59.3)		
Male	77 (47.0)			81 (40.7)		
Ethnicity	Female (%)	Male (%)	Total (%)	Female (%)	Male (%)	Total (%)
White	43 (26.2)	32 (19.5)	76 (45.7)	75 (37.7)	47 (23.6)	122 (61.3)
Asian	32 (19.5)	32 (19.5)	64 (39.0)	19 (9.5)	18 (9.1)	37 (18.6)
African American	3 (1.8)	5 (3.1)	8 (4.9)	7 (3.5)	4 (2.0)	11 (5.5)
Hispanic	7 (4.3)	3 (1.8)	10 (6.1)	9 (4.5)	6 (3.0)	15 (7.5)
Other	2 (1.4)	4 (2.8)	6 (4.3)	8 (4.0)	6 (3.0)	14 (7.0)
Grade level						
9th Grade	12 (7.3)	5 (3.1)	17 (10.4)	16 (8.0)	14 (7.1)	30 (15.1)
10th Grade	21 (12.8)	18 (11.0)	39 (23.8)	26 (13.1)	24 (12.0)	50 (25.1)
11th Grade	36 (22.0)	32 (19.5)	68 (41.5)	39 (19.6)	21 (11.6)	60 (30.2)
12th Grade	18 (11.0)	22 (13.4)	40 (24.4)	37 (18.6)	22 (11.0)	59 (29.6)
Geographic Region						
Americas	66 (40.2)	42 (25.6)	108 (65.9)	86 (43.3)	56 (28.1)	142 (71.4)
Asia	12 (7.3)	24 (14.7)	36 (22.0)	6 (3.0)	9 (4.5)	15 (7.5)
Eastern Europe	9 (5.5)	11 (6.7)	20 (12.2)	24 (12.6)	16 (8.4)	40 (20.1)

Instrument

Ten words or phrases were selected as stimulus words to construct the online Word Association Test (WAT). The stimulus words were presented in the following order: *inquiry*, *data collection*, *science fair*, *writing reports*, *experiment*, *project*, *variable*, *research*, *observation*, and *hypothesis*. These words are core concepts of the scientific method identified in the literature and were modified version of Gulacar and colleagues' (2015) work which is validated and found reliable. These ten stimulus words were obtained by careful synthesis of research on scientific method (e.g., Abd-El-Khalick et al., 2004; Lederman et al., 2014; NGSS Lead States, 2013; NRC, 1996; OECD, 2015; Schwartz, 2004; Shavelson & Towne, 2002) followed by collective decision-making process by the experts in science education. A semantic network resulting from WAT with very strong connections between all possible pairs of stimulus words would represent very complex and deep understanding of scientific method (Gulacar et al., 2015; Nakiboglu, 2008). After getting required permissions from schools, supervisors, parents, and students, the organizing committee of the I-SWEEEP sent a link through a commercial online cloud-based survey platform with the details of the study to participants and teachers of the control group students and instructed them to complete the tests in two weeks. The whole test took approximately 20 minutes. The time limit and the structure of the test was adapted from the paper-and-pencil version of the test and modified to deliver the test digitally and collect data in an efficient way (Nakiboglu, 2008).

Data Analysis

WAT seeks to determine the strength of connections between the stimulus words and the response words. For every word listed on separate pages, students were asked to enter five response words into five boxes on the page in no more than two minutes and move on to the next stimulus word. The main goal of the WAT is to determine the relatedness coefficients (RC) among the stimulus words. RC is a value between 0 and 1 with higher values representing stronger connections between stimulus words within a semantic network of a group of people (Garskof & Houston, 1963). In order to calculate these coefficients, first, all the students' responses after separating into experimental and control groups were coded and grouped. The development of codes was a daunting, multi-step task. WAT results depend on the RC among the stimulus words. Since the way RC works is through common responses among the stimulus words and WAT has an open-response format, all the responses of students needed to be streamlined. For example, although the response "crucial" to stimulus word *observation*, and the response "vital" to stimulus word *data collection*, are synonymous, RC would conclude that the two stimulus words are not connected unless the responses have the exactly the same wording. Moreover, it is also possible to have some typos in students' writing. Lastly, some students wrote rather long phrases instead of one word or wrote meaningless phrases, which needed some data cleaning. Therefore, each author first skimmed through all student responses (more than 18,000 words: 5 responses for 10 stimulus words for more than 350 students) for two goals in mind: (a) to clean the data from noisy words phrases and (b) to generate some general codes. For example, the following students' responses to stimulus words were all coded as "analysis": analyze, analyzing, analyzing data, and analyzing results. After duplicates removed, the list student responses had about 3,500 words. After the initial screening, the authors met several times (1-2 hours for each meeting) to develop and finalize the codes to obtain a common understanding and agreement among the authors. This consensus contributed to the overall reliability of the instrument. A random sample of 200 words were coded by each author as practice and as checking the interrater reliability. The interrater reliability was high as 95% of the coding were matched among the three authors. After reaching the interrater reliability, each author coded one third of the response set. Each author marked the codes that they were not very confident which were discussed as a group and finalized. This also helped ensure the interrater reliability. The final coded response set was used to develop RCs among the stimulus words. This way all the typos, synonymous words, and other issues were eliminated for an accurate calculation of RCs. The final coded response list had 336 words that served as the basis for the connection between ten stimulus words and for their respective RC value calculations.

To ease the grouping of hundreds of codes and speed the calculations and ranking, one of the authors wrote an Excel code. Resulting groups were ranked and numbered and made ready for RC calculations. RC is basically the overlap between the responses given to a pair of stimulus words. Frequency of a response to a stimulus word matters in this sense: the more frequent a response is mentioned for a stimulus word, the more weight it will have to represent the particular stimulus word. RC calculation method suggested by Garskof and Houston (1963; also see Bahar et al., 1999; Gulacar et al., 2015; Nakiboglu, 2008) was used in this study. A very simplified version of RC calculation is illustrated in Appendix A as an example. Later, for experimental group, control group, males and females in the experimental group, and for each geographic region of participation in the experimental group, RC values were ranked and used in constructing semantic networks (i.e., knowledge structures) with a cut-off point of 0.50. When checking the structures, it should be noted that they are partial semantic networks accounting for the ones greater than 0.50 among 45 RC values (which is equal to the number of all possible pairs in a group of 10 stimulus words). Weaker connections among the stimulus words were ignored. For research questions 2 and 3, only I-SWEEEP students were taken as the sample for analysis.

To remind ourselves within the context of RC values, a semantic network resulting from WAT with very strong connections (high RC values) between all possible pairs of stimulus words would represent very complex and deep understanding of scientific method.

RESULTS

The Effects of Participation in I-SWEEEP Olympiad Competition

For all I-SWEEEP and control group students, 45 different RC values were obtained and ranked in descending order. There were more than 25 connections accounted by RC values between the concepts related scientific method for both groups. A number of important differences were still noted at this level regarding students' semantic networks. First, the number and strength of the connections in I-SWEEEP students' semantic networks was relatively greater as hinted by thicker lines. Second, I-SWEEEP students gave less weight to *science fair* compared to non-I-SWEEEP students.

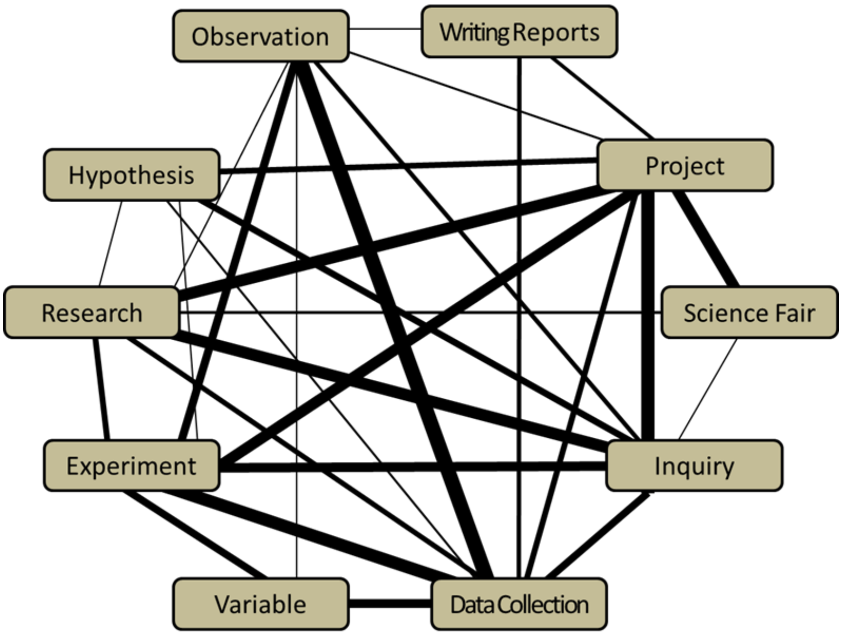

Figure 1. Semantic network for the I-SWEEEP participants with a 0.50 cut-off point

Semantic networks of both groups of students also showed some similarities. The six most important concepts (i.e., concepts that had the most number of connections with other scientific method concepts) between the two groups were very similar: *data collection*, *project*, *experiment*, *inquiry*, *observation*, and *research*, which were a quite interesting finding indeed because the overlap between two groups was significant. In terms of differences, non-I-SWEEEP participants had weaker perceptions of *variable* and *writing reports* with fewer connections with other concepts compared to I-SWEEEP participants. This would imply I-SWEEEP participation is positively associated with stronger conception of *variable* and *writing reports* within the scientific methods context. This relates to the greater number of science fair project completed at larger scales (e.g., national, international) by I-SWEEP students because the rigor and requirements of science projects gets harder. For example, more writing (almost like and academic paper) and variable manipulation (deeper research analysis) are needed for more prestigious competitions (e.g., international ones).

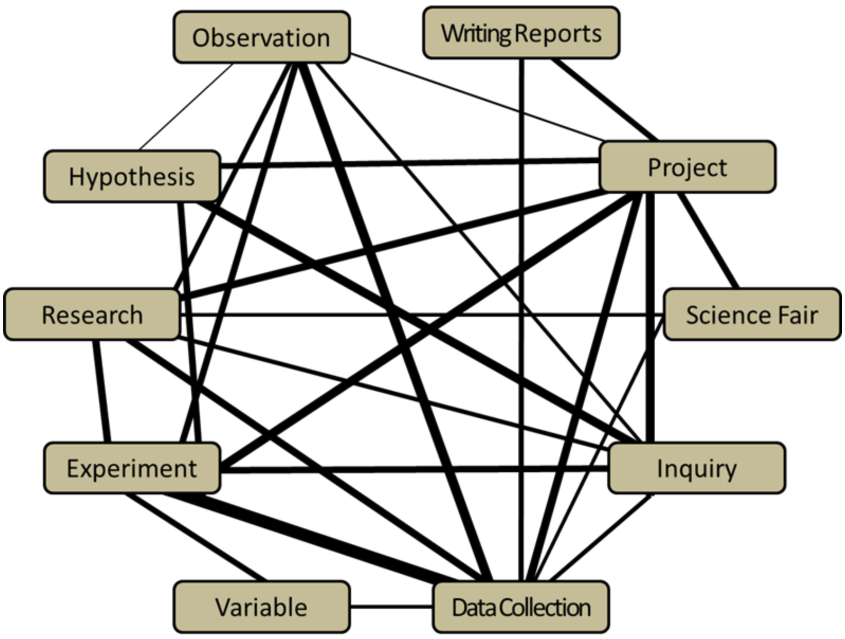

Figure 2. Semantic network for the control group students with a 0.50 cut-off point

We also compared the number of science fair participations for the two groups of students. We asked their participation in school-wide, regional (city/state/region), national, and international science fairs or competitions. As **Table 2** illustrates, the differences were significant except for school-wide participation. I-SWEEEP students participated in science fairs a lot more than the control group students. This provides strong support for the argument that I-SWEEEP students had been exposed to more scientific inquiry through science projects. This explains why I-SWEEEP students had stronger conceptualizations of scientific method.

Table 2. Descriptives and Independent Samples t-Test for Different Types of Science Fairs Students Participated

Competition	I-SWEEEP (n=164)			Control (n=199)					
	Mean	SD	Max[a]	Mean	SD	Max[a]	Mean Δ	SE of Δ	Cohen's d
School-wide	2.66	3.12	30	2.12	3.24	25	0.517	0.334	NA
Regional	2.91	2.85	8	1.12	1.78	16	1.791*	0.251	0.77***
National	0.92	1.77	4	0.23	0.67	14	0.692*	0.144	0.54**
International	0.87	1.11	2	0.11	0.37	6	0.759*	0.089	0.97***

Notes. [a]Minimum value for all is 0. *p < .001. ** Medium effect size. ***Large effect size.

Gender Differences

The second research question was about comparing perceptions of male and female I-SWEEEP participants. Results showed several differences and commonalities between males and females.

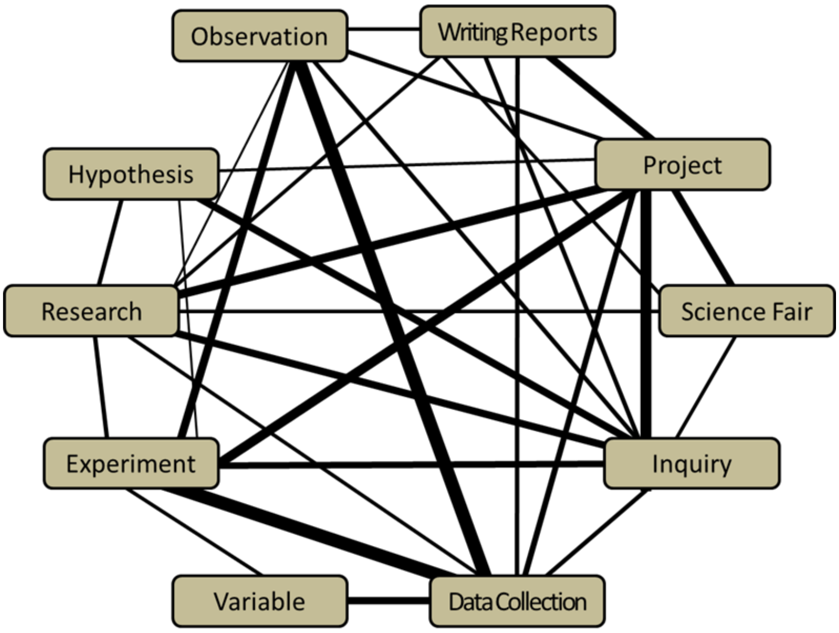

Figure 3. Semantic network for male students who participated in I-SWEEEP

Overall, male participants had a more complex conception of scientific method. They perceived scientific method concepts as a lot more interconnected than their female peers. The number and strength of connections between concepts was considerably greater and stronger for male participants (30 vs. 20). In terms of the individual concepts, one of the evident differences was that *writing reports* was not connected to any scientific method concept for female students. However, it was an important concept for male students. Female students perceived *science fair* as relatively less important scientific concept than the male participants thought.

On the other hand, both male and female participants thought that *research*, *inquiry*, *project,* and *experiment* were very important concepts in the scientific method context; they had the most number of connections and the strongest connection (i.e., bigger RC value). In addition, *data collection* and *hypothesis* were moderately connected to other concepts for both male and female participants. Finally, *variable* was perceived as relatively less important concept among all scientific method concepts by both male and female participants.

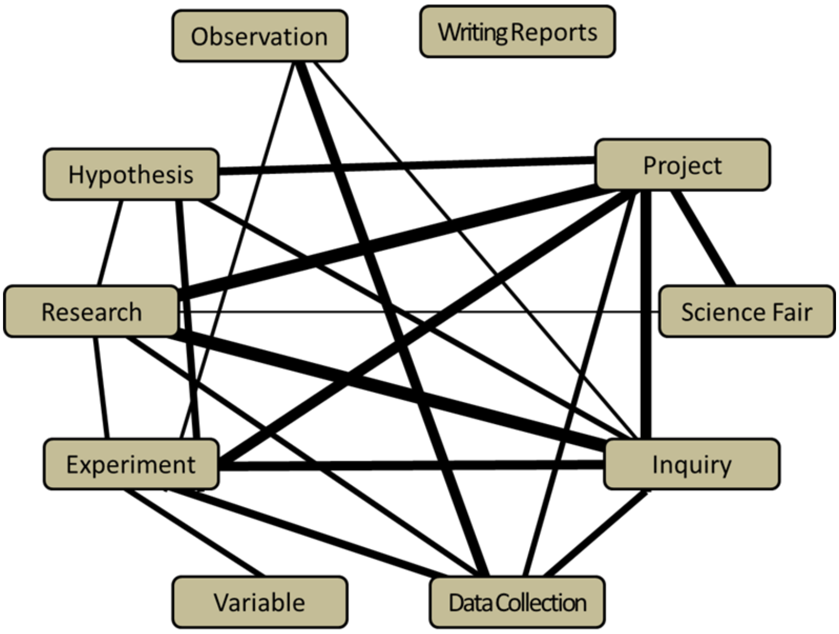

Figure 4. Semantic network for female students who participated in I-SWEEEP

Differences by Participants' Geographic Region

The third research question is about comparing I-SWEEEP participants from different geographic regions. Three regions were identified: America, Asia, and Eastern Europe. Most of the participations from the Americas were from the U.S. but there were a few from Canada and Central and South American countries. All of the European participants were from Eastern Europe. Results of analysis comparing students from different regions showed several differences and commonalities between regional groups. Overall, participants from the Americas had a more complex conception of scientific method with stronger connections among stimulus words. Participants from the Americas perceived scientific method concepts as a lot more interconnected than their peers from other geographic regions. Not only the number of connections between concepts was the highest for participants from the Americas, the connections were also the strongest. The lowest number of connections and relatively the weakest ones belonged to participants from Eastern Europe. There were several other differences among regional groups in terms of conceptualizing scientific method. In terms of the individual scientific method concepts, one of the evident differences was in the concepts that did not connect to other concepts. The concept *variable* did not connect to other concepts for participants from Eastern Europe. Similarly, *writing reports* concept was disconnected to other scientific method concepts for participants from Asia.

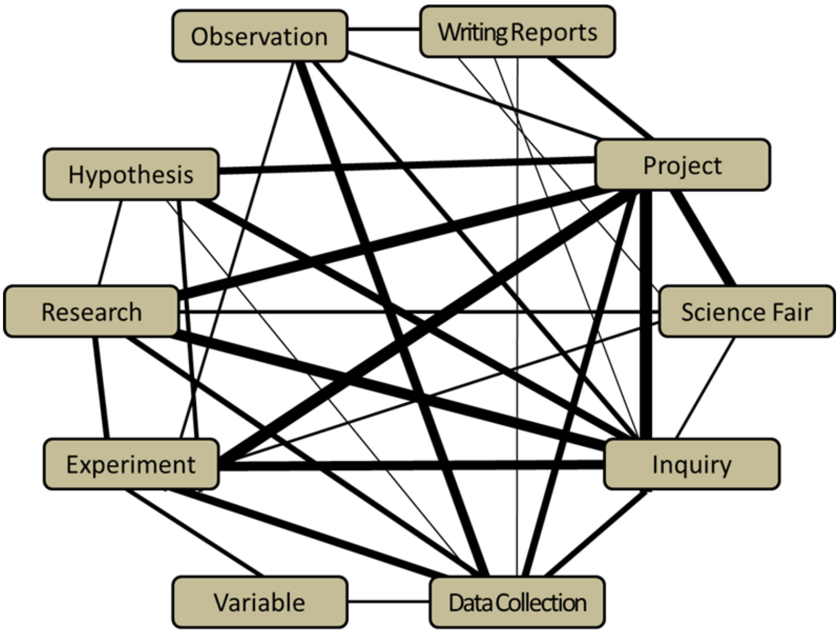

Figure 5. Semantic network for I-SWEEEP students representing Americas

The second type of difference was about the strongest perceptions within the scientific method context. The strongest perception indicates concepts that have the most connections with other scientific method terms. Results indicated that all participants highly valued *inquiry* and *experiment*. Participants from the Americas and Eastern Europe thought *data collection* was also among the most important scientific method concepts. Participants from Asia, on the other hand, found *research* more important than *data collection*.

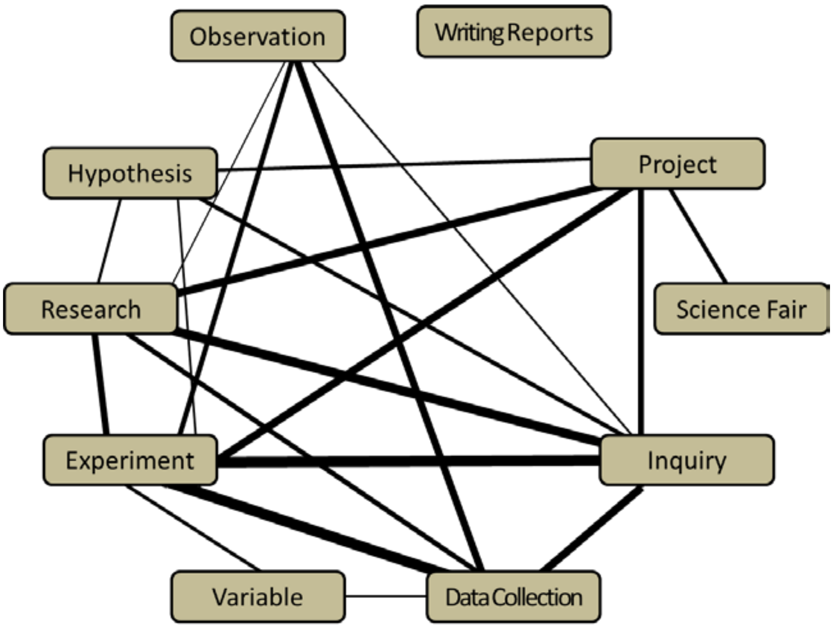

Figure 6. Semantic network for I-SWEEEP students representing Asia

The third type of difference was about the concepts that connected to only a few other concepts or that had relatively weaker connections for some groups of students whereas, for other groups of students, the same concepts connected to several others or had relatively stronger connections. Participants from Eastern Europe participants thought *research* was not related to any concept other than *data collection*. However, participants from the Americas and Asia thought *research* was associated with most of the concepts in the context of scientific method. The strong connection between *research* and *inquiry* was noticeable for participants from the Americas and Asia but did not exist for participants from Eastern Europe. Moreover, *experiment* and *hypothesis* connected to each other for participants from the Americas and Asia but did not connect to each other for participants from Eastern Europe. The concept *science fair* had connections to several other scientific method concepts for participants from America whereas it had only one connection (to *project*) for participants from Asia and Eastern Europe. Participants from the Americas also thought that *project* and *experiment* were strongly related compared to their counterparts from Asia and Eastern Europe who did not think the two concepts were not much related to each other.

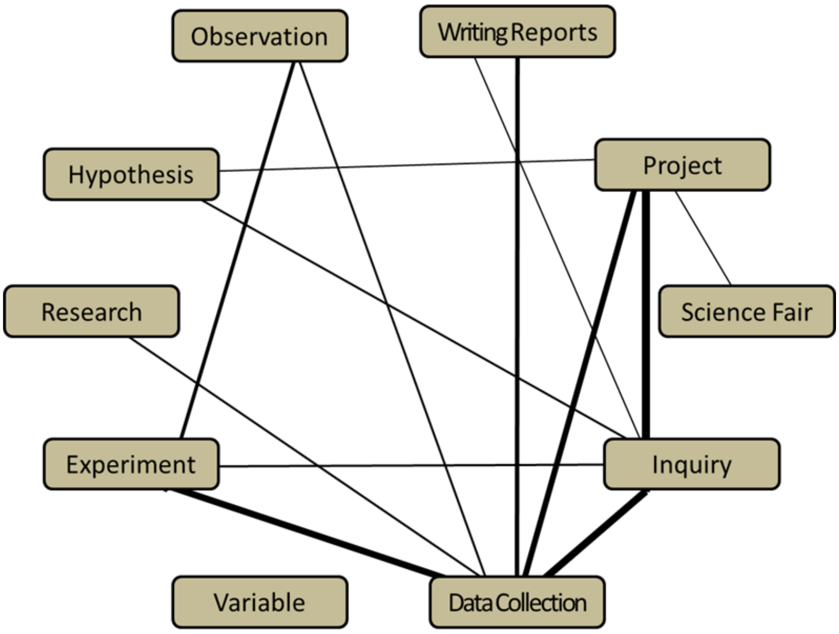

Figure 7. Semantic network for I-SWEEEP students representing Eastern Europe

There were some similarities among participants from different geographic regions. *Experiment*, *inquiry*, and *data collection* were perceived very important scientific concepts for participants from all geographic regions. *Variable* was among the relatively less important concepts for participants from all geographic regions.

DISCUSSIONS

Research suggests that in-and out-of-class science projects can equip the 21st century generation with the knowledge of nature of science and scientific inquiry (e.g., Bell et al., 2003; NRC, 1996). Building on the previous research, we first examined how both I-SWEEEP and non-I-SWEEEP students conceptualized the scientific method that is considered as integral to the scientific literacy (Lederman et al., 2014; NRC, 1996; OECD 2015). Doing science and being actively involved in the scientific processes (i.e., getting acquainted with scientific method) are promising ways to understand the nature of science and develop scientific literacy (Lederman, 1992; Trautman et al., 2002). This study provides insights into how participation in a science Olympiad, gender, and geographic region relate to students' understanding of scientific method as a proxy for scientific literacy.

With respect to the differences between the I-SWEEEP and non-I-SWEEEP students, the differences may stem from two main reasons: (a) the fact that I-SWEEEP students went through a more rigorous process of doing science and (b) they also utilized I-SWEEEP framework for doing science (I-SWEEEP, 2014). However, the differences cannot be attributed only to I-SWEEEP Olympiad. When the number of participation in different science fairs was compared between the two groups, it was found that I-SWEEEP students had significantly higher rates of participation. This is not an I-SWEEEP effect per se because the participations occurred in the past but we can confidently argue that doing more science fair projects which expose students to doing science and enacting scientific method naturally result in stronger conceptions of scientific method.

Second, we studied how I-SWEEEP participants' perceptions of scientific method varied by their genders and regions they came from. It was found that I-SWEEEP participants' semantic network had stronger connections compared to non-I-SWEEEP participants. This implies that participation in I-SWEEEP[3] might have helped participants develop stronger conceptions of scientific method. This is an expected outcome because research indicates that most science fair projects utilize a structured approach of scientific method (Watson, 2004). On the

[3] We should note that, participation in I-SWEEEP is not only attending to the Olympiad but also includes all the work leading up to attending, namely, all the science project development process.

other hand, results showed that I-SWEEEP students placed less importance to *science fair* term that has fewer connections compared to non-I-SWEEEP participants. Although, it may seem contrary to the expected and aforementioned finding about stronger conceptions of I-SWEEEP participants, it is possible that genuine research practice that I-SWEEEP students experienced conceivably made them care more about rigorous research projects and less about the competition aspect. During this research experience it is more likely that I-SWEEEP students interacted with high caliber researchers from higher education and medical institutions whereas non-I-SWEEEP students might not have had similar opportunities. Thus, non-ISWEEEP students might have had science fair oriented conceptions of scientific method (doing science for the sake of science fair). Both groups showed some similarities in *data collection*, *project*, *experiment*, *inquiry*, *observation*, and *research*. This might be a sign of non-linear perception of scientific method (Reiff et al., 2002) where students may jump and re-visit each term depending on need and/or its role in the project. Moreover, although, there is no certain information about the degree of encouragement of doing science projects at survey participants' schools, considering control students were from the same school as I-SWEEEP students, it is very likely that these schools organize science fairs to choose their top project(s) for submission to I-SWEEEP. This may be the reason for the similarities between the two groups of students. It was interesting to see that control group students have only few connections for *variable* and *writing reports* with any other steps in the scientific method. This is problematic as students need to understand that *variable* is very essential part of doing research; and not knowing how to relate it to other parts of your research might risk success of your research (Trochim, 2006) because you need to know what you are manipulating or controlling. Likewise, *writing reports* is usually the final stage of research. This is the part that lets your research reach to a broader audience. Therefore, writing a clear, effective, and precise report is crucial (Trochim, 2006). Thus, having few connections with other parts of the research might imply students' lack of comprehensive understanding of what doing a research entails.

Findings related to the second research question revealed that male I-SWEEEP participants had a much more complex understanding of scientific method with a lot more interconnectedness among scientific method terms. This is an interesting finding because in both 2009 and 2012, Programme for International Student Assessment (PISA) results indicated that boys and girls perform similarly in science (OECD, 2012). However, research consistently showed that male people earned a higher proportion of degrees in many science and engineering fields in the last decade (NSF, 2013). This trend continues in the most recent PISA 2015 test results where boys were found to be more interested than girls in physics, chemistry, and engineering, while girls were found to be more interested in health-related topics (Anderson, 2016). Although the number of boys and girls working in a science-related occupation rate increased from 20% to 25% and 24% respectively when they are 30, less than 1% of girls indicated pursuing a science career that is about information technology (Anderson, 2016). The existing research explains the situation by suggesting that girls inherently have lower self-perceptions of their academic ability in science even when they actually outperform boys (Meece & Eccles, 1993). In other words, they conform to gender stereotypic roles (Wigfield, Eccles & Pintrich, 1996). Therefore, our finding might be related to this, in a way, a chronic stereotype problem rooted in female students' mindset rather than any academic difference between two groups.

For the third research question, we found that participants from the Americas—mostly from the United States—had the most complex conception of scientific method with several stronger connections among stimulus words. This may indicate that students from the Americas had more opportunities to learn about and apply scientific method principles to their projects where academic science competitions are plenty and date back to the 1950s (Student Science, 2016). It was interesting to see that participants from Eastern Europe had the least complex semantics map where there were only 13 connections compared to the participants from the Americas (30) and Asia (20). This may be related to their understanding of scientific literacy where Eastern Europe students scored below average in 2009 PISA science test while students from Asia and the Americas scored above average. However, we definitely need more evidence to make better interpretation of the results. Third question also revealed that all I-SWEEEP participants considered *experiment, inquiry,* and *data collection* steps very central to their understanding and application of scientific method. Given that most of the participants from the Americas are from the United States, it should not be surprising to see this result because all these concepts are explicitly recommended by the Next Generation Science Standards (2013) to be incorporated in high school science.

This study adds to what is known about science fairs and how they impact students' perceptions of scientific method as well as about gender differences and differences due to the geographic locations in terms of students' perceptions of scientific method. The findings may have implications for science curricula and teaching. For example, affordances of science fairs as illustrated by this study's results, include developing stronger conceptualization of scientific method. Variable and writing concepts in the context of scientific method were significantly stronger for I-SWEEEP participants suggesting that standards or curricula that emphasize these concepts should consider providing students with more opportunities for participating in science fairs. Based on gender differences (i.e., females having more superficial conceptions of scientific method) is also very telling. This results may even explain why females are underrepresented in science fields. We argue that female students should be provided with even more opportunities for and should be encouraged more for doing science and participating in science fairs. Science teachers should also keep in mind geographic differences in scientific method conceptions especially if they have international students in their classes so that they can differentiate instruction and scaffold these students to develop stronger conceptions of scientific method (e.g., engaging them more in scientific processes or giving them extra responsibilities for science projects). These implications illustrate why this study and other alike are important in addressing diversity and inclusion issues in school science and achieving science for all.

LIMITATIONS AND IMPLICATIONS

We should interpret the result of this study with caution as the study has some limitations. One of the limitations of the study is that most of our participants were from the United States. This partially limited our chance to get a better picture of International perspective on the high school students' conceptions of scientific method. We could overcome this by conducting face-to-face or phone interviews with randomly selected students from each participating region. Another limitation of the study was the type of data we obtained. We had only one data source, WAT survey, which may have its own limitations in identifying students' real understanding of scientific method or doing science. We could supplement WAT with other mean(s) of measuring students' understanding of scientific method and doing science better. Last but not the least, the methodology of RC does not allow us to control for several confounding factors at once. This is why the sample for gender and regional differences were narrowed to only I-SWEEEP participants. However, the sample size did not allow for any further controlling of other factors (e.g., controlling for gender when looking at regional differences).

Despite its limitations, the findings of this study showed that science project competitions such as I-SWEEEP and science project involvement have a capacity to help cultivate a complex understanding of the scientific method as documented by more interconnections among important concepts within the context of scientific method. This study contributes to existing literature by providing valuable information on developing stronger conceptions of the scientific method, particularly where there is limited research on the role of science project involvement and science Olympiads in this effort. Considering the importance of STEM education and the need for a qualified STEM workforce in the future, it is important that educators invest more effort and energy to increase the involvement of students in activities in the same vein as I-SWEEEP type competitions. In addition, the promising results of this study deserve the attention of other researchers who have opportunities and skills to conduct further studies to confirm and/or extend the findings presented herein.

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APPENDIX A

This provides a sample RC calculation for a pair of stimulus words (*data collection* & *observation*) for males in the experimental group. The table below is a rank order of first 5 words for the stimulus word *data collection* and their corresponding rank order for the stimulus word *observation*. In original calculations first 25 words were used.

	Data Collection		***Observation***	
	Frequency Rank Order	***Weight***	***Frequency Rank Order***	***Weight***
Experiment	1	**25**	15	**11**
Measurement	2	**24**	11	**15**
Analysis	3	**23**	149	**0**
Calculation	4	**22**	21	**5**
Investigation	5	**21**	22	**22**
Collecting data	6	**20**	2	**24**
Conclusion	7	**19**	6	**20**
Changing	8	**18**	17	**9**
Problem Solving	9	**17**	8	**18**
Design	10	**16**	22	**4**
Observing	11	**15**	5	**21**
Difficult	12	**14**	25	**1**
Research	13	**13**	10	**16**
Recording	14	**12**	81	**0**
Important	15	**11**	18	**8**
Tools	16	**10**	59	**0**
Gathering	17	**9**	68	**0**
Reading	18	**8**	120	**0**
Advancement	19	**7**	24	**2**
Careful	20	**6**	16	**10**
Quantitative	21	**5**	30	**0**
Qualitative	22	**4**	50	**0**
Creativity	23	**3**	9	**17**
Query	24	**2**	27	**0**
Literature Review	25	**1**	33	**0**
Science	26	**0**	23	**3**
Learning	27	**0**	102	**0**
Search	28	**0**	53	**0**
…				

The most frequent word in the list for *data collection* (experiment) contributes the most points (25) to the RC calculations.

$$\mathrm{RC} = \frac{(25,24,23,22,21)\cdot(11,15,0,5,22)}{(25,24,23,22,21)\cdot(25,24,23,22,21)}$$
$$= \frac{(25\cdot 11)+(24\cdot 15)+(23\cdot 0)+\cdots+(3\cdot 17)+(2\cdot 0)+(1\cdot 0)+(0\cdot 3)+(0\cdot 0)+\cdots}{(25^2+24^2+23^2+\cdots+2^2+1^2)}$$
$$= \frac{275+360+0+\cdots+51+0+0+0+\cdots+0}{(25^2+24^2+23^2+\ldots\ldots+2^2+1^2)} = \frac{4158}{5525} = .75$$

RC is the rate of overlap in responses which is the amount of overlap for a certain group divided by the max possible overlap (a perfect overlap).

APPENDIX B

1. What is your gender?
   1. Male 2. Female

2. How old are you?
   1. ----

3. What grade are you?
   1. 9th 3. 11th
   2. 10th 4. 12th

4. Which country are you participating from?
   1. ----

5. Please state how many times you have participated (1, 2, ..., or 0) in the following types of science fairs so far including I-SWEEEP (Put an approximate number to best of your knowledge)
   1. International:…………….. 3. Regional and State wide:..
   2. National:………................. 4. School wide:………………

6. Which of these best describes your ethnicity/race?
   1. White 5. American Indian or Alaska Native
   2. Black or African American 6. Other…
   3. Latino/Hispanic
   4. Asian/Pacific Islander

7. How many hours do you think you spent on each of the following parts of your project?
   1. Literature Review:…….. 3. Analysis:………………
   2. Lab work/Experiment:… 4. Writing Reports:………

8. **Now, we want you to choose ten words that a stimulus word reminds you in the context of SCIENTIFIC METHOD. Stimulus word will be given in each question.**

Also, please DON'T SPEND <u>NO MORE THAN 2 MINUTES</u> ON EACH PAGE!!!

INQUIRY: Please type five words that INQUIRY reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

DATA COLLECTION: Please type five words that DATA COLLECTION reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

SCIENCE FAIR: Please type five words that SCIENCE FAIR reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

WRITING REPORTS: Please type five words that WRITING REPORTS reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

EXPERIMENT: Please type five words that EXPERIMENT reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

PROJECT: Please type five words that PROJECT reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

VARIABLE: Please type five words that VARIABLE reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

RESEARCH: Please type five words that RESEARCH reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

OBSERVATION: Please type five words that OBSERVATION reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

HYPOTHESIS: Please type five words that HYPOTHESIS reminds you in the context of scientific method.
1. … 3. … 5. …
2. … 4. …

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