Student Research, Communication, and Scientific Reasoning in a Mathematics Enrichment Program

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Introduction

Based in North Carolina, United States of America, the Summer Ventures in Science and Mathematics (SVSM) program is an intensive four-week enrichment program for rising high school juniors and seniors. Program participants are academically talented students who are selected based on their interest in science, technology, engineering and mathematics (STEM). The participants who are the focus of this paper were enrolled in a mathematics course - Mathematical Evolutions. The Mathematical Evolutions course has two major goals. First, the course explores the development of mathematics throughout history. Second, the instructors guide students through the process of conducting an academic research project and disseminating the results on a topic of interest.

In previous studies related to programs similar to SVSM, results generally showed students' increased interest in STEM career paths and ability to reason scientifically and communicate effectively (Campbell & Nickl, 2012; Kitchen et al., 2018). The uniqueness of the SVSM course which is the focus of this study is the students' research component which was couched in the "M" in STEM - mathematics. This study was conducted to investigate how a program with this particular focus impacted students' ability to engage in research, communication, and scientific reasoning. The two research questions that guided this study were:

1. How did the four-week mathematics-focused program impact the development of the partici` pants' skills in research, communication, and scientific reasoning?
2. Did students' STEM self-efficacy change pre- and post-course?

This paper provides a review of relevant research pertaining to the study, including previous work related to student research, communication, and scientific reasoning as well as STEM self-efficacy. Next, it details the research design for this study, including participant demographics, data collection methods, and data analysis methods. It provides findings related to each component of the research questions and concludes with a discussion of major implications and limitations of the study.

Literature Review

This review begins with a discussion of what constitutes student research and the global drive to involve high school students in conducting independent research projects (IRP). It also elucidates the importance of encouraging students to share the results of their research through presentations and publications. Integrating writing and communication tasks throughout the research process acculturates high school students into the world of academic mathematics while helping them to develop mathematical reasoning skills. These mathematical reasoning skills should be congruent with scientific reasoning skills, which are critical to retaining students in the STEM pipeline. Working with STEM professionals from various backgrounds during summer programs tends to help students build self-efficacy in mathematics and STEM, which, in turn, strengthens the vision students have of themselves as mathematical researchers.

Student Research

Student participation in conducting STEM research has many benefits (Society for Science & The Public, 2019). Students develop necessary critical thinking and problem-solving skills when they design their own research projects. Research shows students enhance their research skills and knowledge of the research process (Duncan et al., 2010). Heck (2010) found that students engaging in mathematics research applied both "mathematical and scientific knowledge in a meaningful way in a concrete context leads at the same time to consolidation and deepening of this knowledge" (p. 6).

In general, the process of conducting independent research projects in high school differs from most undergraduate research projects in that typically neither the high school students nor the teachers/mentors have expertise or specialized training in the content area (Walkington & Rushton, 2019). The SVSM program mentors, however, do have specialized training in the subject areas, which is an affordance of the program that makes it different from high school settings. However, Ho-Shing (2016) states "individuals become scientists when they are curious about a phenomenon in the world around them and ask questions about the real nature of that phenomenon" (p. 16), so all students and teachers can become novice scientists by engaging in inquiry. Bennett et al. (2018) describe independent research projects as "student-led, open-ended research investigations, often supported by a teacher and/or a university-based or industry-based researcher. Students have considerable control in respect to the question(s) they hope the practical work will answer and the way in which the work is undertaken" (p. 1756). Therefore, the SVSM program provides students mentoring in both content and research. Students conduct independent research projects for a variety of reasons including personal interest in a phenomenon, for entry into STEM competitions, required class projects, or through participation in a summer enrichment program.

The findings from independent research projects take multiple forms. The Institute for Research In Schools (IRIS) (n.d.), an education-focused charity in the United Kingdom, suggests that students present their research in multiple forms through an academic poster, conference presentation, and submitting their paper to an academic journal for publication. The findings of independent research projects are most often communicated through academic papers and/or presentations (Bennett et al., 2018). Communicating research findings at academic conferences is an area where students, especially nontraditional students, will need additional support. Rushton et al. (2021) suggest that conference presentations are valuable experiences for helping students see themselves as researchers and academics but require teachers to provide "support with preparing presentation and poster structure and content; rehearsing public speaking to a variety of audiences; and providing emotional support to help manage nerves and performance anxiety" (p. 28). Students can also submit their papers to academic journals dedicated to publishing the research of middle and high school students (Ho-Shing, 2016). The publication process can be confusing and difficult for students and will require robust teacher or mentor support. Additionally, students should be encouraged to seek out STEM competitions because they offer chances to practice communicating research findings. Some competitions in the United States are Science and Engineering Fairs, Junior Science and Humanities Symposia, Student Academy of Science, and the Google Science Fair. Additionally, Rushton and Reiss (2019) found that unanticipated benefits to conducting independent research projects included increased communication skills, increased confidence, and stronger evaluation skills that help student researchers discern the qualitative value of information presented to them (Phelan et al., 2017). These researchers found that "research immersion is effective in building confidence and knowledge about 'doing science'" (p. 69). Importantly, these studies show the potential for high school student STEM experiences, though too often such opportunities in schools become intentionally limited due to schooling constraints and selective placement (Weis et al, 2015); however, STEM enrichment programs have been shown to positively impact students' attitudes toward STEM and their STEM career preferences (Baran et al., 2019). This study connects these components of student STEM research through analysis of the participants' communication of their research findings, measures of their scientific literacy, and their self-efficacy in STEM.

Student Communication

In terms of student communication, SVSM classroom practices were based on research about writing in mathematics disciplines and the interplay between genre and discourse communities. During the program, instructors helped students understand the role of audience and purpose in scientific communication by examining how different publications presented the same research findings. Likewise, instructors reviewed the common conventions of various scientific genres and workshopped students' writing in individual conferences. Writing-to-learn activities in mathematics classrooms can have positive impacts on mathematics understanding and performance (Harbaugh et al., 2007; Ntenza, 2006; Pugalee, 2005). Relatedly, research also suggested that science teachers should use social modeling and collaborative-learning activities to improve students' motivation, achievement, and interest in science careers (Bryan et al., 2011).

The concept of genre proves especially salient for helping students become acculturated into scientific discourse communities. Instructors aimed to help students understand that the genre of the scientific article is itself an action, an agreement between authors, editors, and readers about how new knowledge is made and accepted (Miller, 1984; Bazerman, 1988; Latour & Woolgar, 1986) . By learning the genre conventions of the scientific article, students are better equipped to participate in the broader social networks that comprise the scientific endeavor. As Henze (2013) argues, "genres are one of the things technical communicators use to fulfill a specific type of purpose within a particular, recognizable, and recurring situation" (p. 339).

SVSM Instructors also modeled Aristotelian rhetoric, as detailed in his 4th century BCE work *On Rhetoric,* to help students recognize how formal writing persuades readers with *logos* or logic, *pathos* or an appeal to emotion (or its absence), *ethos* or the credibility of the authors, and *forums* or the places of publication (see Aristotle, 1991). The Aristotelian proofs served as a way for us to teach the rhetoricity of the standard genres of scientific communication by helping us illustrate how their persuasive potential is a function of *ethos* as well as rote *logos*. For instance, instructors had students examine how the presentation of scientific results changes across different forums. Students examined a series of publications about recent research that uses mathematics to examine the dental morphology of a new species of hominid, homo naledi. The publications included academic research reports, university research newsletters, and popular science articles. Students had to determine how the authors generated ethos, or credibility, for non-expert audiences who lacked the disciplinary expertise to understand the research's underlying logos. Likewise, students had to review the function of various genres, such as research notebooks, research/grant proposals, progress reports, and conference posters, across the scientific research process. Students were taught that the rhetorical function of these genres is contextual. These lessons allowed us to discuss the formatting and citation requirements for the students' documents—a research report and poster. By framing document requirements in terms of conventions, instructors helped students to understand that these minute details help generate ethos for their documents, an ethos independent of the logos of their research designs and mathematical analyses.

Instructors' pedagogical approach was well aligned with scholarship about scientific texts' rhetoricity. Gross argues that while Aristotle limited the scope of his rhetoric to the political and judicial realms—i.e., he avoided discussion of scientific proofs and *apodeixis* within *On Rhetoric* (ca 4th century BCE)—those who study modern rhetoric should expand it to include scientific texts and the social networks that produce them (Gross, 1990; Gross & Harmon, 2014). As Gross (1990) explains, the acceptance of science results depends upon *ethos*: "All scientific papers are embedded in a network of authority relationships: publication in a respected journal; behind that publication, a series of grants given to scientists connected with a well-respected research institution; within the text, a trail of citations highlighting the paper as the latest result of a vital and ongoing research program" (p. 13). Likewise, Winsor (2003) argues that engineering writing functions in the same way: "Texts function not only to record and share what is already known but, perhaps more importantly, to help writers and readers generate and agree on what is to count as knowledge" (p. 5). By understanding the standard genres and practices of scientific discourse communities, students are better prepared to produce research that "count[s] as knowledge" for their readers (Winsor, 2003, p. 7).

Student Scientific Reasoning

It is well established that, while the United States leads the race in STEM research and development, a relatively low percentage of students enter STEM fields (Van Tuijl & van der Molen, 2016; National Science Board, 2006) . Researchers are just beginning to study the reasons why K-12 students do not matriculate into the STEM fields upon entering the university as well as why a large percentage of first-year STEM students transfer into other fields. One plausible reason is that STEM advances have changed the focus and the methods of the sciences leaving many students lacking the basic reasoning and thinking skills critical in STEM fields (Borge, 2016; Ernst & Glennie, 2015). Duschl et al. (2016) argue that this type of quantitative and model-based reasoning supports a systems-thinking approach by explaining that both the mechanisms and interactions of systems support the idea that model-based reasoning and quantitative/scientific reasoning occur within systems thinking. Such reasoning involves interactive processes of analyzing, modeling, communicating, evaluating, and redesigning models to explain scientific phenomena or processes. The Next Generation Science Standards (n.d.) argues that "Science is a quantitative discipline, which means it is important for educators to ensure that students' learning in science coheres well with their learning in mathematics." Elrod (2014) argues that quantitative reasoning is different from a focus on mathematics as it involves complex reasoning and decision-making processes that are embedded within disciplinary and real-world contexts. These conceptualizations emphasize the broad nature of scientific literacy emphasizing the ability to engage with science and mathematics related issues and with the ideas of science and mathematics (Drijvers, 2020). According to research from Polat and colleagues (2017), students who have good mathematical understanding are more positive in their science literacy.

Scientific reasoning underscores students' understanding of correlation, necessity, and sufficiency in understanding scientific data (Coleman, 2015). Scientific reasoning includes hypothetical-deductive reasoning, control of variables, proportional reasoning, correlation reasoning, and probabilistic reasoning (Ding et al., 2016; Lawson, 2004). In addition, Harel and Soto (2017) argue that there is another type of mathematical reasoning to consider referred to as structural reasoning. Structural reasoning is defined by Harel and Soto (2017) as "combined ability to: (a) look for structures, (b) recognize structures, (c) probe into structures, (d) act upon structures, and (e) reason in terms of general structures, (f): the ability to see (be aware of) how a piece of knowledge acquired resolves a perturbation experienced" (p. 226). Student research reports are intended to demonstrate scientific reasoning and mathematical reasoning as described in this literature reflecting a broader conceptualization of scientific literacy as interconnected with mathematical literacy.

Self-Efficacy in STEM

Researchers have determined that self-efficacy significantly affects academic achievement (Bandura, 1997; Lent et al., 1984; Sandholtz & Ringstaff, 2014; Stronge et al., 2011). Bandura (1997) describes self-efficacy as one's beliefs in their capabilities to organize and execute a course of action. Based on his foundational work in this area, Bandura (1997) determined that the level of self-efficacy is related to whether a task will be initiated, the effort levels, and the degree of persistence necessary to complete the task even when faced with roadblocks. Bandura (1997) emphasizes that self-efficacy belief is multidimensional and domain or context specific. Street et al.'s (2022) study of secondary students participating in a series of lessons on new mathematical content over a two-week period, found that students' mathematical self-efficacy, even over a short duration activity, initially led to sharp increases in students' self-efficacy. The initial sharp increase plateaued and the authors also noted that the more challenging the activity, the greater the changes in self-efficacy (Street et al., 2022). The nurturing of students' interest in mathematics at an early age, through fun, challenging, and enjoyable mathematical tasks as well as STEM classes positively influences students' mathematical self-efficacy (Wang, 2013).

Mathematics-Specific Enrichment Programs

Research about other mathematics enrichment programs informed this study. Alumni of the Pennsylvania Governor's School summer STEM programs indicated that the following factors affected future educational and career development in STEM: collaborative college-level curriculum, mentorship, camaraderie, and engagement in research (Campbell & Nickl, 2012). This is supported by Kitchen et al. (2018) in their study involving 27 colleges and universities participating in National Science Foundation STEM grants. They found that high school students participating in summer STEM programs were 1.4 times more likely to pursue STEM careers. The study highlights the malleability of high school students regarding their future aspirations and encourages funding of summer programs that promote hands-on, relevant learning experiences (Kitchen et al., 2018). Student engagement in STEM can be enhanced by implementing interventions that target math and reading for co-developing STEM literacy. Binns, et al. (2016) gauged the perception of students' interest in STEM fields before and after an academic summer enrichment program. The results indicate that students' interest in STEM fields increased as a result of the program (Binns et al., 2016). Similarly, Saw et al. (2019) found that STEM program participation positively correlated with elevated interests in math careers and positive attitudes toward mathematics but also found that these programs saw negligible correlation in the same areas for science.

Materials and Methods

Participants

The participants in the Mathematical Evolutions Class included 20 students with 7 identifying as Asian, 3 as Black or African American, 1 as Hispanic, 5 as White, and 4 as Unknown or declined to identify. Eleven students identified as female and 9 as male. Additionally, 4 of the students identified as Underrepresented Minorities (URM) and 16 of the students were non-URM. One student reported that they were considered in financial need and none of the students reported any learning or physical disabilities.

All the students selected to attend SVSM undergo a rigorous application and screening process. The application for this very competitive program includes an online questionnaire, series of essay questions, letters of recommendations, and submission of educational transcripts. Completed student portfolios are then reviewed by STEM specialists and only students with strong backgrounds in STEM classes, extracurricular STEM experiences, and a strong desire to pursue STEM subjects in college are accepted as participants for SVSM. Furthermore, students must also complete an online pre-attendance research class to be accepted into the SVSM program.

Data Collection and Analysis Methods

A mixed methods approach was employed to address the research questions. Both quantitative and qualitative data were collected and analyzed using three data points. Firstly, the Test of Scientific Literacy Skills (TOSLS) was a survey administered at the conclusion of the program and was chosen since it could help illustrate the participant's scientific literacy as a result of the program, thereby addressing research question one. Secondly, students' research papers, posters, and oral reports were collected and analyzed using evaluation guidelines following the judging criteria for the Junior Science and Humanities Symposia research competition. The authors analyzed student research reports using these judging criteria and the coding schema as detailed below, which also addressed research question one. Finally, the S-STEM survey was used to analyze participants' STEM self-efficacy, pre- and post-test, to address research question two.

TOSLS was intended for undergraduate science courses and provides data on nine skills and was administered at the end of the program (Wang, 2013). The developers of the TOSLS found that it is "sensitive enough to detect pre- to post-semester learning gains" (Gormally et al., 2012, p. 374) for university classes which indicates this to be a useful tool to use for the month-long, intensive, SVSM summer program. Developers reported internal reliability above .73 for results of an exploratory factor analysis indicating one factor (scientific literacy) rather than two or three factors (Gormally et al., 2012). Correspondence between the TOSLS items and the National Research Council and Project 16's scientific literacy goals was used for validity. The scientific literacy goals were developed via a survey of biology faculty, expert educator reviews, student interviews, and statistical analysis.

The student papers, reports, and oral presentations were analyzed following qualitative procedures of searching for themes using a compare and contrast process focusing on the heterogeneity and homogeneity of the responses (Gay & Airasian, 2003). This procedure allowed for the identification of written units which were usually one or more sentences. The coding scheme was then applied to these units providing a characterization of the students' written products. Features of each report were categorized as belonging to one of seven forms or genres of student report writing (Wellington & Osborne, 2001). These categories included Classification, Decomposition, Descriptions of Functions or Processes, Listing of Properties, Explanation, Experimental Accounts, and Argumentation (Wellington & Osborne, 2001). The coding scheme was developed based on previous work of Shield and Galbraith (1998) and Huang et al. (2005). Shield and Galbraith's (1998) coding scheme, applied to expository writing of eighth graders, focused on explanation elaborations, aspects of mathematics and levels of language. Huang et al.'s (2005) research focused on knowledge structures evident in student discourse in secondary mathematics classrooms. Though the codes developed were used in verbal discourse, the applicability to written work is promising as a mechanism for illuminating and analyzing students' mathematical knowledge structures. The coding system includes higher level structures such as classification, principles, and evaluation whereas lower-level structures include description, sequence, and choice. Other possible codes include goal statements, description (general and particular), justification, link to prior knowledge or experience, examples, conclusions/results (empirical, theorems/definitions), exemplars (symbolic representation, diagram, graph, conventions, tables, procedures), and aspects of mathematics (theoretical, logical, algorithmic, methodological). Researchers first independently coded one paper to determine baseline inter-rater reliability. Differences were discussed and resolutions reached. Pairs of researchers then coded the remaining papers. Using various methods to determine the quality of the students' products will address Bennett et al.'s (2018) concerns that "the wide variety of outcome measures points to one of the most prominent features of research into the impact of [independent research projects], which is the very disparate approaches to judging the impact of IRPs" (p. 1766). Examining the students' research from multiple perspectives provided a nuanced understanding and representative report on the impact of individual research projects within a mathematics enrichment program.

The S-STEM survey contains items that provide information on constructs related to students' attitudes toward science, technology, engineering, and mathematics subjects (Friday Institute for Educational Innovation, 2012). More specifically, the instrument contains items related to attitudes toward math (Friday Institute for Educational Innovation, 2012). The Middle/High School S-STEM version was used in this study. The attitudes constructs were adapted from survey work with a middle school engineering program (Erkut & Marx, 2004). Validity and reliability were developed through multiple pilot studies which applied exploratory factor analysis through principal axis factoring and promax rotation. Correlations with item loadings above .40 considered significant (Unfried et al., 2015). Results from the pilot studies demonstrated a clear factor structure with each section representing a single construct. The reliability levels using Cronbach's Alpha were above 0.86 for mathematics attitudes, 0.86 for science attitudes, 0.82 for Engineering and technology attitudes (Erkut & Marx, 2004). Differential item functioning was used to determine internal validity. These tests indicated that students at different grade levels comprehended the surveys similarly. Further, the results also showed that measurement invariance was consistent across the grade levels.

Discussion of Results

Results show that students' scientific research, communication, literacy, and self-efficacy developed over the course of the four-week enrichment experience. The student projects varied widely in terms of clearly articulating research problems and demonstrating creativity and originality. Students who identified research topics earlier in the program tended to have fewer issues stating clear and compelling research problems. In terms of student communication, the majority of student participants succeeded well in aspects of the project that were heavily supported by either mentoring or templates. Students struggled with producing appropriate figures and tables, as well as identifying credible sources. Regarding student scientific literacy, the results show that students understand the scientific process and have the ability to apply mathematical principles to data. On the other hand, students displayed some lack of understanding of appropriate data interpretation. The STEM Self Efficacy test results showed that by the end of the program students recognized the need to manage their time and prioritize high stakes assignments and homelife expectations. More importantly, because all the students engaged in scientific research to study mathematical concepts, students began to understand the relationship between the STEM subjects and to see science and mathematics as foundational to all subjects including technology and engineering.

Student Research

The assessment tool used to evaluate the quality of student written research reports was the 2019 Junior Science and Humanities Symposium (JSHS) paper rubric. The JSHS competition is in its 62nd year of regional and national competition and is supported by the Department of Defense, Tri-Services, Army, Navy, and Air Force Research Offices. The JSHS rubric for written paper submissions assesses on a 100-point scale for the following items: Statement of Research Problem (15 points); Creativity and Originality (15 points); Research Design, Procedures, Results (15 points); Discussion and Conclusions (25 points); Written Report (20 points) and, Citing Sources of Information (10 points).

Our assessment shows that scores for the Statement of the Research Problem category varied widely across students' written research reports, ranging from 5 to 14 points achieved on a 15-point scale. The mean value in this category was 11, or 73% percent of the maximum possible score. Of the 20 projects, 14 were rated at or above the mean. In a few projects, the research problem was vaguely developed or stated. Examples of vaguely developed problem statements included

- "How do personal opinions on GMOs change after being exposed to a small amount of educational information on GMOs?";
- "How in touch Magic: The Gathering players are with probability related to the game";
- and "This research focuses on the parenting style preferences of 18+ year old college students."

In the strongest projects, the statement of the research problem was clearer. Examples include

- "The research purpose is to find out to what degree repetitive lyrics contribute to Billboard Hot 100 Success"
- and "The aim of this study is to find whether there is a difference in recovery methods after practice in high school-aged swimmers and to find which type of recovery is the best for performance."

In the evaluation of the Research Design, Procedures, and Results category, the mean was 9.4 out of a possible 15, or 63% of the maximum possible score.

Not surprisingly, these high school research projects also varied widely in demonstrations in the Creativity and Originality category, with scores ranging from 4 to 13 on a 15-point scale. The mean value was 9.45, or 63% of the maximum possible score, with 12 of the 20 ranked at or above the mean.

Another key indicator of the quality of the research appears to be how quickly the students were able to arrive at a firm topic. Students who were still exploring research topics at the mid-point of the four-week program were much less likely to be able to articulate a strong statement of the research problem. Those who made topic selections earlier were stronger. Positive examples include a research project to determine whether there is a difference in reading comprehension of elementary-aged students when using electronic or paper media; a study that examined the top demographic indicators of voter shift between the last two presidential elections; and research into the correlation between an individual's cognitive bias and their financial investment practices.

One student who began writing with a template, the LaTeX document preparation system, met the requirements of the assignment and scored better than most peers on the rubric. This student's writing also included more citations, levels of hierarchy, and visualizations than the papers of students who wrote without a template.

Student Communication

An examination of students' projects indicates how mentor support and templates facilitated scientific communication though students still struggled with producing figures and identifying credible sources. In instructor evaluations of the set of 20 student projects, the students ranked highest in their ability to (1) identify and state a research problem, (2) cite sources of information, and (3) write the final report. The mean scores across these categories were 73% of the possible score. The students' final papers were scored slightly lower in their (1) presentation of creativity and originality, (2) research design, procedures, results, and (3) discussion and conclusions. The mean scores across these categories were 63% of the possible score.

The implications are that the majority of student participants succeeded well in aspects of the project that were heavily supported. Each student worked closely with a faculty mentor to identify and state their research problem beginning in week one. The writing of the final report was supported by two three-hour workshops with two technical communication faculty members, who also tutored each student in the revision process on a rough draft during the final week. The student projects demonstrated somewhat less success, according to the JSHS rubric, in displaying creativity and originality (9.45 out of 15 points), defining clear research designs and procedures (9.5 out of 15 points), and discussing the importance of their conclusions (15. 7 out of 25 points). The relatively lower mean scores in these categories point to the difficulty of rapid acculturation into a scientific discourse community. Creativity and the ability to articulate a research problem may depend, in part, upon an understanding of previous research in a field, something that few secondary students will possess coming into such a program. Although some students had completed extended research projects in the past, conventional research designs and procedures within a discipline were also new to most students. Consequently, students demonstrated more difficulty in discussing the importance of their conclusions convincingly. The strongest exhibit of student writing in a final paper scored 87 out of 100 possible points on our rubric. The weakest scored only 29 points.

The distribution of rankings for the students' posters and oral presentations were similar to those of the final reports. The posters were designed from a common template provided by the instructors. Consequently, they were more uniformly complete when compared with posters from the previous summer when a template was not provided.

We used the Junior Science and Humanities Symposium (JSHS) Poster Rubric to evaluate the quality of poster student submissions which scored each component on a 5 point scale. The poster rubric category scores included evaluations of the students' abilities to (1) identify and state a research problem (mean 3.4 or 69% of the possible score), (2) display creativity and originality (mean 3.3 or 67% of the possible score), (3) exhibit clear research design, procedures, results, (mean 3.6 or 72% of the possible score) and (4) present discussion and conclusions (mean 3.5 or 70% of the possible score). Faculty evaluations of the students' recorded presentations led to an overall mean score of 73 percent of the possible score, indicating that for this group, science communication through speaking was equally as challenging as writing the final paper and composing an effective poster.

A closer examination of the students' citations, figures, and tables reveals distinctions between student and professional understanding of how these elements of the writing generate ethos. For this group, the mean paper ran 12.1 pages and cited 5.6 sources. The sources ranged in type from scholarly to popular or journalistic. On average, 39 percent of the sources cited were scholarly, representing fewer than one scholarly source per paper. Sixty-one percent of sources that the students cited were popular or journalistic.

The student papers were also less well illustrated than professional research articles. The mean was 5.25 illustrations per paper. Of 105 student-authored illustrations, 80 percent were figures and 20 percent were tables. Twelve of twenty students were also less than successful in carefully following the American Psychological Association (APA) guidelines for presenting figures and tables. This points to their novice status in designing visuals to support the key claims of their scientific writing.

A small set of students extended their scientific communication efforts further to submit their paper for publication consideration. Three of the students submitted their research papers to The Journal of Emerging Investigators, an open-access journal run by Harvard graduate students that publishes original research conducted by middle and high school students. This journal provides young scientists, under the guidance of an advisor or teacher, the opportunity to submit and gain feedback on original research and to publish findings in a peer-reviewed scientific journal. With guidance and close mentorship, all three students completed the submission and revision process and their research papers have appeared in recent issues of the journal.

Item Number	Item Descriptor	Mean
5	*Identifying Valid Scientific Course of Action*	3.8
7	*Interpreting Graphs*	1.80
18	*Making Conclusions Given a Graph*	1.75
23	*Calculating a Percent Given a Scientific Context*	3.75

Table 1. Selected Items from TOSLS Survey

Student Scientific Literacy

To address how students' scientific literacy was impacted by the SVSM experience, the authors examined the responses to the Test of Scientific Literacy Skills (TOSLS), which was administered as a post-test at the conclusion of the program. Each question was scored out of a possible 4 points. Table 1 shows selected items from the results, including the two highest scoring items and the two lowest scoring items. The results suggest that students understand the scientific process and have the ability to apply mathematical principles given data. On the other hand, though, students displayed a lack of understanding of the interpretation phase of the said data, showing a potential weakness in their ability to reason both scientifically and mathematically.

Responses to the Summer Ventures Survey were also analyzed in order to find qualitative information regarding students' advancements in scientific literacy as a result of the program. Several students commented on the positive impact of the Mathematical Evolutions coursework. One commented "I was most satisfied with the information I gained on mathematical proofs and how they started out throughout history because it broadened my understanding of the area." Another commented that "Learning about ancient mathematics brought me the most satisfaction, as I derived the most joy from solving and learning about ancient math." Additionally, students commented on how the research project promoted perseverance in problem solving. As one student wrote, "My biggest challenge was that I was set on learning theoretical probabilities of a difficult problem, eventually I had to move to solving the problem from an experimental standpoint because I didn't have enough time." This student demonstrates how the research project placed students in the position of making decisions related to their scientific process. Also, in the realm of perseverance, another student remarked that "I am capable of doing higher level math without having to rely on others as much as I thought," reflecting an increase in students' mathematical confidence.

STEM Self-Efficacy Results

To address research question two -- *Did students' STEM self-efficacy change pre - and post-course?* -- the authors employed the Student Attitudes Toward STEM (S-STEM) Survey which was given pre and post participation in SVSM. To analyze the data, the authors used a paired samples two-tailed T-test to compare students' attitudes. Of the 60 items on the S-STEM Survey, only four items indicated statistically significant changes in student attitudes by participating in SVSM, as summarized in Table 2.

Due to the rigorous registration process, only students with a strong interest in STEM were accepted to participate in SVSM. As a result of this self-selection process followed by STEM specialists selecting the most STEM focused students from the applicant pool, it is understandable that only four of the S-STEM survey questions showed a statistically significant change based on participation in SVSM. Because this iteration of SVSM was an online class due to COVID restrictions, question 35—*I am confident I can manage my time wisely when working on my own* ($p<.05$); and question 36—*When I have many assignments, I can choose which ones need to be done first* ($p<.05$) showing a statistically significant change are not surprising. The online SVSM class had three aspects, mathematical research; writing clear and effective research papers; publishing research in a journal and sharing research at STEM competitions. These three time-consuming aspects were competing for students' time while working at home. This required students to manage their time and prioritize high stakes assignments and homelife expectations. Because all the students engaged in scientific research to study a variety of mathematical concepts, students began to understand the relationship between the STEM subjects and see science as foundational to all subjects including mathematics, technology,

Item Number	Item Descriptor	p-value Range
13	I *will need science in my future work*	$p<.05$
21	*I am interested in what makes machines work*	$p<.01$
35	*I am confident I can manage my time wisely when working on my own*	$p<.05$
36	*When I have many assignments, I can choose which ones need to be done first*	$p<.05$

Table 2. Statistically Significant Items from S-STEM Survey

and engineering. This could explain question 13—*I will need science in my future work* ($p<.05$) showing a statistically significant change by participating in SVSM.

Implications

This research demonstrates the utility of independent student research projects within a mathematics enrichment program. The program provided highly motivated students with the opportunity to engage in a full cycle of the research design and implementation. Students were able to engage successfully in authentic inquiry and problem solving throughout this process, advancing students' scientific literacy beyond the typical classroom setting. This research also highlights how mentorship and templates quickly facilitated students' ability to communicate the results of their independent research. However, based on the scoring of students' work using the JSHS rubrics, it appears that even STEM-inclined high school students require additional support with identifying credible sources and designing rhetorically effective figures and tables.

Though the survey only identified STEM self-efficacy beliefs about the usefulness of science and project management skills, some students indicated a clear desire to continue in the STEM pipeline. One student wrote, "SVSM has confirmed my thoughts of going into a career in the STEM field. This is because it has allowed me freedom to explore my interests, and therefore I am certain I want to be in STEM because I have now tried it out". This suggests that SVSM and other enrichment programs serve a useful function by providing direct research experience for high school students, experience which may make them more confident in their abilities to continue in STEM when they enter university settings and, looking beyond, as they contribute to contemporary society in adulthood.

The results of the study contribute to the literature outlined in the Literature Review in two distinct ways. First, the research work of participants exhibits how scientific reasoning, as presented by Duschl et al. (2016), developed as a result of undergoing the research project process. That is, the students were able to analyze, model, communicate, and evaluate a phenomenon of choice (Borge, 2016). Second, the results demonstrate how participants can engage in a STEM research project of this magnitude that is couched in the "M," mathematics. This aligns with work related to previous summer programs, though offers a unique take away because of this mathematics focus (Campbell & Nickl, 2012; Kitchen et al., 2018).

Although students showed positive changes in mathematics-focused research, communication, and scientific reasoning skills, this study had limitations that may have affected the outcomes. The primary limitation for this study is that this iteration of SVSM took place during the COVID-19 pandemic and the students were all taking classes virtually. This limited instructor interactions with the students. Typically, instructors have access to the students for the entire day as well as on evenings and weekends when some of this intensive writing work is completed. However, during COVID-19 the only interaction with students was by Zoom for approximately four hours per day. Additional limitations were that the students attending SVSM are highly motivated students who have previous experiences in STEM and have a predisposition to engage in STEM related research. Thus, the results of this study should not be extrapolated to all high school aged students. Finally, a four-week program in a virtual environment may not have been substantial enough for changes in students' STEM self-efficacy. The Zoom virtual SVSM replaced the typical face to face environment of SVSM where motivated students live together, interact with faculty on campus, navigate the college environment, and use university resources. The lack of interaction of SVSM students outside of the Zoom meetings undoubtedly affected the stagnant self-efficacy results..

Recommendations and Conclusion

Research into a four-week STEM enrichment program for high school students demonstrated that independent research projects offer a useful avenue for helping students understand the scientific research process. Students in the program were able to work from their curiosity and interests to frame researchable questions. While students demonstrated a solid understanding of the research design process, they sometimes struggled with identifying analysis procedures to provide results that were clearly aligned to the research problem or hypotheses. Students also reported on key related studies from the literature; however, these were not always synthesized to provide a context of the contributions to the study being undertaken, and the majority of sources were not scholarly. The four-week experience contributed positively to students' scientific reasoning as indicated by measures of the Test of Scientific Literacy, but students demonstrated little development in their use of statistics and data to reason about problems.

Further research should examine how best to support students in identifying credible information and producing rhetorically effective figures. Students' understanding of how multiple representations convey conclusions connecting to the data analysis is a critical next step in improved academic writing. The study also highlights the critical nature of supporting scientific communication as part of student STEM-focused research. Additional research on how students frame findings from data would provide needed perspectives on effective communication of STEM research.

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Junior Science & Humanities Symposium
Judging Score Sheet

Name of Student: ________________________ **Name of Judge**: ____________________________

JSHS recognizes students for original research achievements in the sciences, technology, engineering or mathematics (STEM). The overall test is that students demonstrate valid investigation and experimentation aimed at discovery of knowledge. The judging criteria and scoring for JSHS are presented. A total score of 30 points is assigned using the below scale and serves as the basis for discussions among the judging team. Rank each students' oral presentation using the following criteria and weights:

5 = Superior 4 = Excellent 3 = Good 2 = Satisfactory 1=Fair

Judging Criteria	Suggested Weight
Statement and identification of research problem • Is the problem clearly stated? • Does the presenter demonstrate understanding of existing knowledge about the research problem?	1 2 3 4 5

Scientific thought, creativity/originality
• Student demonstrates his or her individual contributions to and understanding of the research problem
• Appropriate duration of collection and data analysis
• Innovation of Original Concept and Scientific Thought/Process
  ○ Standard Protocol/Design
  ○ Innovative Protocol/Design
	1 2 3 4 5

Research design, procedures (materials & methods), results **1. Science** • Appropriateness of research design and procedures • Process skills demonstrated by the student in the solution to the research problem and/or the research design • Identification and control of variables • Reproducibility **2. Engineering, computer science, technology** • Workable solution that is acceptable to a potential user • Recognition of economic feasibility of solution • Recognition of relationship between design and end product • Tested for performance under conditions of use • Results offer an improvement over previous alternatives	1 2 3 4 5
Discussion/Conclusions • Clarity in stating conclusion • Logical conclusion that is relevant to the research problem and the results of experimentation or testing • Recognizes limits and significance of results • Evidence of student's understanding of the scientific or technological principles • Theoretical or practical implications recognized • What was learned?	1 2 3 4 5
Skill in communicating research results-- Oral Presentation and written report • Clarity in communicating research results to non-specialized audience and to judges • Definition of terms as necessary • Appropriate use of audio-visuals • Response to questions from audience and judges	1 2 3 4 5
Includes References/Bibliography and acknowledges major assistance received	1 2 3 4 5
Total Score	

Junior Science & Humanities Symposium
Judging Score Sheet- Poster Session

Name of Student: ____ Student Poster Number: _________Judge Name: ____________________________

JSHS recognizes students for original research achievements in the sciences, technology, engineering or mathematics (STEM). The overall test is that students demonstrate valid investigation and experimentation aimed at discovery of knowledge. The judging criteria and scoring for JSHS are presented. A total score of 30 points is assigned using the below scale and serves as the basis for discussions among the judging team. Rank each students' poster presentation using the following criteria and weights:

5 = Superior **4 = Excellent** **3 = Good** **2 = Satisfactory** **1=Fair**

Judging Criteria	Suggested Weight
All posters must include: • Title • Abstract • Hypothesis/Engineering Design • Methods and Procedures • Data Analysis • Results/Conclusion • Bibliography/References • Acknowledgement Are Allowed BUT Not Required	1 2 3 4 5
Statement and identification of research problem • Is the problem clearly stated? • Does the presenter demonstrate understanding of existing knowledge about the research problem?	1 2 3 4 5

Scientific thought, creativity/originality
• Student demonstrates his or her individual contributions to and understanding of the research problem. Please note that mentored projects and non-mentored projects are to be judged equitably. Confirm student understanding of project research/components if mentored.
• Appropriate duration of collection and data analysis
• Innovation of Original Concept and Scientific Thought/Process
  ○ Standard Protocol/Design
  ○ Innovative Protocol/Design
	1 2 3 4 5

Research design, procedures (materials & methods), results **1. Science** • Appropriateness of research design and procedures • Process skills demonstrated by the student in the solution to the research problem and/or the research design • Identification and control of variables • Reproducibility **2. Engineering, computer science, technology** • Workable solution that is acceptable to a potential user • Recognition of economic feasibility of solution • Recognition of relationship between design and end product • Tested for performance under conditions of use • Results offer an improvement over previous alternatives	1 2 3 4 5
Discussion/Conclusions • Clarity in stating conclusion • Logical conclusion that is relevant to the research problem and the results of experimentation or testing • Recognizes limits and significance of results • Evidence of student's understanding of the scientific or technological principles • Theoretical or practical implications recognized • What was learned?	1 2 3 4 5
Skill in communicating research results-- Poster Presentation **Clarity in communicating research results to non-specialized audience and to judges** • Effective use of tables and/or figures in presenting data • Accuracy of spelling and grammar • Neatness and organization of poster • Response to questions from judges	1 2 3 4 5
Total Score	