Effectiveness of a Constructivist-Based Science Camp for Gifted Secondary Students

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Constructivist-based pedagogy is particularly applicable to gifted secondary students in the sciences due to the increased background knowledge of the population and the nature of the study of science. This research was an investigation of the effectiveness of a residential constructivist-based summer learning experience in aquatic biology and biomedicine for gifted secondary students. Both quantitative and qualitative approaches were used to analyze the data. Quantitative analyses showed that the program significantly increased both scientific knowledge and conceptual understanding of science among participants. There was no change in academic self-concept of the participants. Qualitative results supported these findings and demonstrated the importance of social relationships for program effectiveness. These results have implications for researchers in constructivist theory, science, and gifted education.

Keywords: *constructivism, gifted education, science education, self-concept*

Constructivism has been a philosophical and pedagogical influence in education since Piaget (1950) first introduced the term. As Vygotsky (1978) and later educational theorists have expanded on Piaget's ideas, educational practices and theories have incorporated constructivist ideas (e.g., Brown, Collins, & Duguid, 1989; Duffy & Jonassen, 1992; Holt & Willard-Holt, 2000). There has been debate, however, in current years as to the effectiveness of constructivist-based practices in the era of increased accountability for schools and teachers and of standardized testing (e.g., Kirschner, Sweller, & Clark, 2006; Windschitl, 2002). As schools, policy makers, and communities have become more concerned with measureable aspects of student achievement in the form of standardized testing (e.g., No Child Left Behind, 2001), constructivist-based practices, which tend to focus on broader definitions of learning, have received less attention in favor of more standards-based and standardized pedagogical techniques (Nowak & Plucker, 2002). Thus, with the increased emphasis on student achievement outcomes measured by standardized tests, it is important for researchers to investigate the effectiveness of constructivist-based practices in terms of these same educational outcomes. In addition, the effectiveness of programs for specific populations has not been thoroughly studied in constructivist research.

This article reports findings from a study of the intersection of two populations that are rarely investigated in this framework—secondary school students and gifted students. While constructivist theory remains at the forefront of early childhood education (e.g., DeVries, Zan, Hildebrandt, Edmiaston, & Sales, 2002), there is less emphasis on the theory in secondary schools. In addition, research about gifted and talented students has not investigated the effectiveness of constructivist-based approaches

(Nowak & Plucker, 2002). Thus, this study provides important insights into research about, and programming for, this population.

Finally, science education has a rich background in inquiry and exploratory approaches (e.g., NSTA, 2004), which can be closely connected to constructivist theory (e.g., Wheatley, 2006). This study makes these connections more explicit in the investigation of science programs for gifted secondary students.

The research questions guiding this study are as follows:

1. Does a constructivist-based science summer program significantly increase participants' academic self-concept and science knowledge?
2. Does a constructivist-based science summer program change participants' understanding of science?
3. Are there differences in the growth of academic self-concept, knowledge of science, or understanding of science, after a constructivist-based science camp, based on the gender of or class attended by the participants?

We hypothesized that the intervention would have a positive effect on the academic self-concept, science knowledge, and conceptual understanding of science of the participants, given previous research, as well as anecdotal knowledge of the program, indicated positive effects. Additionally, we hypothesized no differences within genders and between classes attended, as all students attending the class were of similar academic background and were nominated by their science teachers as highly motivated and interested in the science curriculum.

Review of the Literature

Constructivism is a theory of knowledge in which learning is conceptualized as the interpretation and meaning-making process that occurs through interactions with the social and physical environment (Piaget, 1950). Thus, constructivism theorizes that learners construct knowledge from their own experiences. Although not explicitly connected to a singular pedagogy, many educational practices may be said to be based upon this theory of learning (Wheatley, 2006). In particular, constructivist theory is linked to approaches that foster active engagement, teacher-as-facilitator of learning, collaborative learning, and investigative models (Windschitl, 2002).

Constructivism has long been a strong influence on early childhood education (e.g., Montessori, play-based, and center-based approaches; DeVries, et al., 2002), but has not shown the same level of influence in secondary schools (Nowak & Plucker, 2002). However, constructivism theoretically applies to learners at all levels of development, and learners in adolescence may benefit from active learning, collaborative work, and investigative approaches (Nowak & Plucker, 2002). Because secondary students have greater background knowledge and more advanced schema than students at earlier educational levels, they may be able to benefit from a constructivist-based approach. They have a more nuanced schema regarding the world, and thus, learning can be made meaningful through the exploration of these phenomena (Kamii & Ewing, 1996).

Limited research has been conducted about the academic effects of a constructivist-based teaching approach in secondary contexts. Kim (2005) found that a constructivist-based approach in sixth grade classrooms in Korea increased both academic growth and motivation, but had no effect on self-concept as compared to a traditional approach. Similarly, Hickey, Moore, and Pellegrino (2001) found significant gains in academic achievement among schools implementing constructivist-based reforms in math curricula, as compared to similar-matched schools without reforms.

Among secondary students, the gifted and talented may be the most able to benefit from constructivist-based approaches. With advanced knowledge and understanding, they are in the best position to expand upon this schema. In addition, gifted learners are better able to make connections between concepts and apply previously learned knowledge to new situations (e.g., Renzulli, 1999). This allows for assimilation and accommodation mechanisms to proceed at an accelerated rate and at a deeper level of understanding. Finally, Vygotsky's (1978) idea of zone of proximal development (ZPD) is particularly important for gifted learners, who are often not adequately challenged by school curricula. ZPD is the level of challenge between work that a student can do with help and what he or she can do independently, and thus, the level at which optimal learning occurs (Vygotsky, 1978). Under a social constructivist approach, teachers should teach gifted children at more advanced levels, given the ZPD for advanced students. In other words, in comparison to same-age peers, gifted children can often work independently at higher levels, particularly in their areas of interest or academic strength. Taken together, constructivist-based approaches may be the most appropriate for gifted learners (Nowak & Plucker 2002).

Again, few research studies have explicitly explored the efficacy of constructivist-based approaches for gifted learners. The Integrated Curriculum Model, one curricular approach with constructivist principles, has been demonstrated to increase language arts achievement, especially regarding critical thinking skills, as compared to traditional models with gifted secondary students (Van Tassel-Baska, Johnson, Hughes, & Boyce, 1996). Research by Singh (2013) showed that middle school teachers of the gifted believe constructivist-based approaches to be more effective.

Lastly, constructivist-based approaches may be particularly well suited for science education. Science, by its very nature, is an investigation of the natural environment, thus, learning occurs through the interaction with and interpretation of that environment (e.g., NSTA, 2004). Specifically, inquiry-based approaches, in which students answer scientific questions through the exploration and manipulation of their environment while working collaboratively in groups, and in which the teacher facilitates, rather than directs, learning, can be based in constructivist theory (Wheatley, 2006). There is a much more substantive base of research support as to the effectiveness of constructivist-based approaches in science (e.g., Frank, Lavy, & Elata, 2003; Kim, Fisher, & Fraser, 1999; Liang & Gabel, 2005).

Methods

This study employed a mixed-methods design, using both qualitative and quantitative methods of inquiry to answer the research questions. This approach was selected to provide both statistical interpretations to lend validity to the results in an educational landscape that increasingly relies upon quantitative data and the richness of experiences and insights that can be drawn from qualitative sources.

The instruments (including measures of academic achievement in science, academic self-concept, and conceptual understanding) were administered on the first night of the camp, prior to academic instruction, and on the last day of the camp, following the participants' group presentations of their final products. These data were collected and analyzed by the research group, as described below.

Context

The science summer learning experience studied in this project used constructivist-based approaches to science for gifted secondary school students. The approach and sample were selected deliberately to investigate the appropriateness of constructivist-based approaches for science education, secondary students, and gifted learners. The data collected from this study involved a residential summer learning experience situated at a regional state university in the southern United States. The goals of the camp included students actively participating in scientific hands-on experiences in the STEM areas to learn content; engaging in activities that helped them understand the nature of science through problem-solving; and making connections between the STEM content areas in creating solutions to real-world problems. The camp focused on the development of scientific understanding and application of knowledge through experiential learning in one of two topics: aquatic biology and biomedicine. Both curricula were designed to give participants experience communicating their ideas in science and modifying conceptions based on new information and data shared during presentations.

Participants who chose the aquatic biology curriculum were put into research teams to learn about methods of assessing the health of bodies of water. Teams visited lakes on campus to take water samples to examine parameters such as pH, temperature, and turbidity, as well as to perform bioassays. Upon completion of their data analysis, the teams created watershed remediation plans designed to improve the health of the water bodies (with data analyses to justify their plans). They presented these plans for evaluation and peer critique during the last session of the camp.

For the biomedical curriculum, participants were also part of research teams tasked with understanding the mammalian body through macroscopic, microscopic, and molecular assays. Beginning with a dissection of cats, teams learned the morphological and cellular differences between organ systems. They also learned the theory and methods underlying the polymerase chain reaction, including the use of reverse transcription as means to examine the relationship between the structure and function of different organ tissues. Working in their research teams, participants presented their data to their peers for discussion and critique.

The camp also integrated engineering into both paths of study, through facilitated laboratory work, in which participants used scientific inquiry in collaborative groups to investigate topics of interest. These activities were hands-on and problem-based, and centered on robotics using LEGOs. For example, teams were tasked with creating a LEGO robot that could be programmed to pick up an object, move it, and set it down. The process was iterative, with teams programming, testing, and re-programming their robots based upon their experiences. Other activities included visits to the labs used by UNF engineering clubs.

The summer science camp is part of a larger consortium of regional high schools from rural areas. These schools partner with non-profit agencies to provide enriching science experiences beyond the resources that could be provided by any one school. This combination of resources, and outside funding, facilitate science experiences throughout the school year and includes the 2-week summer program.

Table 1

Demographic Data

	N	Percent
Program		
Biomedical	7	46.7
Water Ecology	8	53.3
Age		
16	1	6.7
15	12	80.0
14	2	13.3
Grade Entering in Fall		
10th	15	100.0
High School		
School A	3	20.0
School B	5	33.3
School C	1	6.7
School D	2	13.3
School E	2	13.3
School F	2	13.3
Number of High School Science Classes Completed		
1 Class	13	86.7
2 Classes	1	6.7
3 Classes	1	6.7
Ethnicity		
White	10	66.7
Black/African American	1	6.7
Asian/Pacific Islander	2	13.3
Hispanic/Latino(a)	2	13.3
Gender		
Male	4	26.7
Female	11	73.3

Sample

Students were selected to participate in the larger consortium and the summer science camp by their high school teachers because of their high achievement in the areas of mathematics and science. These nominated students were categorized as gifted based on teacher recommendations and documented success and academic achievement in science classes. Of the 30 students who participated in the program, parental permission to participate in the research study was obtained for 15 (50% participation). The 15 participants ranged in ages from 14 to 16 years old (see Table 1). They had all completed at least one high school science class, and were all entering grade 10. In general, the high school science class completed by participants was either honors or advanced Biology or Physical Science, but there was great variation between schools as to the curricula for these classes. The participants came from six high schools from the surrounding counties of the university, primarily from rural areas with limited access to more advanced science courses. The sample was primarily White (66.7%), with few Black (6.7%), Asian (13.3%), or Hispanic (13.3%) students. More female (n = 11) than male (n = 4) students participated (see Tables 1 and 2). There were no known demographic differences between the group of students who had permission to participate in the study and those students who did not have permission to participate.

Table 2

Descriptive Statistics

	Range	*M*	*SD*
Age	[14, 16]	14.93	.458
Number of High School Science Classes Taken	[1, 3]	1.20	.56
Pre-Intervention General Self-Concept	[5.33, 7.00]	6.39	.52
Post-Intervention General Self-Concept	[5.25, 7.00]	6.47	.59
Pre-Intervention Science Self-Concept	[4.25, 7.00]	6.27	.69
Post-Intervention Science Self-Concept	[4.50, 7.00]	6.29	.67
Pre-Intervention Science Knowledge-Aquatic Bio	[10, 24]	18.60	3.81
Post-Intervention Science Knowledge-Aquatic Bio	[13, 25]	21.40	2.92
Pre-Intervention Science Knowledge-Biomedical	[7, 17]	10.87	3.15
Post-Intervention Science Knowledge-Biomedical	[6, 17]	12.80	3.14
Pre-Intervention Science Knowledge-Total	[19, 40]	29.47	5.85
Post-Intervention Science Knowledge-Total	[19, 40]	34.20	5.21
Pre-Intervention Concept Map Frequency	[3, 12]	6.00	2.75
Post-Intervention Concept Map Frequency	[4, 17]	8.20	3.41
Pre-Intervention Nature of Science Understanding	[0, 2]	1.00	.84
Post -Intervention Nature of Science Understanding	[0, 6]	2.53	1.64
Pre-Intervention Concept Map Complexity	[8, 77]	24.20	22.01
Post -Intervention Concept Map Complexity	[12, 94]	38.13	28.17

Instrumentation

The research questions were answered through a series of quantitative and qualitative instruments administered on the first night of the summer camp, prior to participation in any learning activities. These instruments were re-administered on the final day of the camp, after each group of students presented the results of their science investigations. Three instruments were given to students: a Science Content Test, the *Perceived Challenges and Self-Concept Scale*, and a Science Research Concept Map.

Science content test. Science content knowledge was assessed through a content area test. This assessment was constructed by university faculty with expertise in assessment and science education. The 44 items were taken from the released Texas state assessment measures (STAAR Science 8 and Biology End of Course Exam; Texas Education Agency, 2015). Items were chosen for their applicability to the two areas of concentration in the camp (aquatic biology, $n = 26$; biomedicine, $n = 18$). The students were given 45 minutes to complete the assessment, and all participants were able to complete the assessment in the given time frame.

Perceived Challenge and Self-Concept Scale. General academic self-concept and science self-concept were assessed with the Perceived Challenge and Self-Concept Scale-Revised (Wilson, 2014). This instrument is designed to measure academic self-concept in three content area domains (science, mathematics, and humanities) and general academic self-concept, without references to social comparisons. Thus, questions focus on perceptions of academic success (e.g., *"I make good grades in science"*) and learning (e.g., *"I am good at understanding science"*). It has been specifically developed for gifted, secondary school students (Wilson, 2014). The entire instrument consists of 36 items, but only data from the science ($n = 9$) and general ($n = 9$) subscales were used in the analyses for this study, as they represent relevant domains for the research questions of interest. Students were given 15 minutes to complete the instrument and all participants answered all of the questions on the survey in this amount of time.

Science research concept map. Finally, to assess the understanding of the nature of science of the students, participants were asked to complete a concept map with the term "scientific research" in the center. A concept map is a graphic organizer that allows participants to document ideas related to one concept and illustrate the connections between ideas and overall organization of their schema regarding the concept. Students were instructed to complete the concept maps by adding as many ideas as they could to the center concept, including connections between ideas, to illustrate their understanding of the concept. After instructions were given, students had 15 minutes to complete the concept map. Students were generally familiar with concept maps as a tool for organizing ideas through classroom instruction, although this varied across students and school instruction.

Data Analysis

The data was analyzed with both quantitative and qualitative methodology. The science content knowledge and self-concept data were analyzed using a paired-sample *t*-test analysis to detect statistically significant differences between pre- and post-intervention means. Additional *t*-tests were conducted to compare growth scores of science content knowledge and self-concept between genders and class (biomedicine and aquatic biology) attended. Growth scores were calculated by taking the difference between pre- and post-intervention scores for each participant. In addition, for each comparison, an effect size (Cohen's *d*) was calculated, as well as a 95% confidence interval around the effect size. This was done to account for the relatively low sample size ($n = 15$) and to inform future, larger scale research studies. The effect size can be interpreted using the guidelines from Cohen (1992), but any interpretation should include a consideration of the confidence interval, particularly if the confidence interval includes 0, in which case there can be no interpretation of an effect.

The data from the concept maps was analyzed in four different ways. First, the frequency of the ideas included was analyzed (e.g., by counting each circle included in the concept map). Second, each map was scored according to the nature of science understanding domains developed, using a VNOS framework from the VNOS-C questionnaire (Abd-El-Khalick et al., 1998) (see Table 4 for a description of each domain). These constructs were useful because they were consistent with the key science education reform documents that served as consensus definitions of the nature of science for students (e.g., AAAS, 1989; 1993, & NRC, 1996). Each domain was scored as 0 (not mentioned), 1 (naïve understanding), or 2 (sophisticated understanding). Thirdly, the concept maps were scored using guidelines adapted from Novak. These guidelines assessed the complexity of each student's schema. The rubric used in the study is shown in Table 3. Finally, the data from each participant's pre-intervention map was directly compared with the post-intervention concept map, and qualitative notes were taken.

Each map was independently scored by two researchers, then scores were compared and discussed until consensus was reached. Each map was scored twice (once by each member of the research team) on each of the three measures (frequency, VNOS, and Novak guidelines). When there was a discrepancy in scores (which occurred for less than 10% of the maps, across all three analyses), the researchers discussed the difference and an agreed-upon score was recorded. Notes on direct comparisons between concept maps were analyzed and themes were developed. The themes, identified independently by each of the researchers, included changes to the conceptual framework or understanding, inclusion of more or less detail, and use of scientific language.

Table 3

Complexity of Understanding Scoring Guide

Criteria	Description	Score
Concepts	Objects, events, situations, or properties designated by a label or symbol.	1 point for each concept connected to at least 1 other concept by a proposition.
Groupings	Ways concepts can be linked or joined together. There are 3 types of groupings: 1. Point groupings: a number of single concepts emanating from one concept 2. Open groupings: three or more concepts that are linked in a single chain 3. Closed groupings: concepts that form a closed system (a loop)	Point groupings: 1 point for each concept in the group Open groupings: 2 points for each concept in the group Closed groupings: 3 points for each concept in the group
Hierarchy	Concepts on a map can be represented as a hierarchical structure in which the more General and inclusive concepts are at the top of the map; the specific and exclusive concepts are at the lower end of the map	5 points for each valid level of the hierarchy.
Cross Links	Show meaningful connections between one segment of the concept hierarchy and another segment, and indicate whether the relationship shown significant and valid	10 points for each cross link that is both valid and significant; 2 points for each cross link that is valid but does not illustrate synthesis between concepts or propositions; unique or creative cross links might receive special recognition or extra points.
Proposition	Connecting word(s) and phrases written on the line joining any two concepts to signify a relationship. • Simple Proposition is a simple English word or phrase • Advanced Proposition is a phrase or statement that is composed of technical or scientific word(s).	• Simple Propositions score 1 point for each word or phrase; .5 points for repeated use of Simple Propositions • Advanced Propositions score 2 points for each proposition; 1 point for repeated use of Advanced Proposition

Adapted from Novak & Gowin (1984), Cronin, Dekker, & Dunn, (1982), and Center for Teaching (2014).

Table 4

Nature of Science Understandings

Criteria	Description	Score
Tentativeness	Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. All other aspects of NOS provide rationale for the tentativeness of scientific knowledge.	0= Not observed 1= Naïve 2= Sophisticated
Empirical Basis	Scientific knowledge is based on and/or derived from observation of the natural world.	0= Not observed 1= Naïve 2= Sophisticated
Subjectivity	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent, yet also contributes to change in science when previous evidence is examined from the perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what and how scientists do their work.	0= Not observed 1= Naïve 2= Sophisticated
Social/ Cultural Embeddedness	Science is a human endeavor and, as such, is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.	0= Not observed 1= Naïve 2= Sophisticated
Theories and Laws	Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed and perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.	0= Not observed 1= Naïve 2= Sophisticated

From Lederman, Adb-El-Khalick, Bell, & Scharwartz, 2002

Results

Overall, the results of the quantitative analyses indicate that participants showed a significant increase in science knowledge and conceptions of science, but no significant difference in academic self-concept (see Tables 5 and 6). The qualitative analyses revealed a deeper conception of scientific knowledge and an appreciation of the interactive nature of the science learning experiences.

Table 5

Compared Means, Pre-Intervention and Post-Intervention

	M	*SD*	*t*	*d*	*CI* of *d*
General Academic Self-Concept			.91	.14	[.58, .86]
Pre-Intervention	6.39	.52			
Post-Intervention	6.47	.59		.03	[-.69, -.74]
Science Academic Self-Concept			.26		
Pre-Intervention	6.27	.69			
Post-Intervention	6.29	.67			
Science Knowledge- Aquatic Biology			4.91**	.82	[.06, 1.55]
Pre-Intervention	18.60	3.81			
Post-Intervention	21.40	2.92			
Science Knowledge- Biomedical			3.33	.62	[-.13, 1.33]
Pre-Intervention	10.86	3.16			
Post-Intervention	12.80	3.14			
Science Knowledge- Total			4.94**	.85	[.08, 1.58]
Pre-Intervention	29.47	5.85			
Post-Intervention	34.20	5.21			
Concept Map Frequency			3.12	.71	[-.05, 1.43]
Pre-Intervention	6.00	2.75			
Post-Intervention	8.20	3.41			
Nature of Science Understanding			4.38*	1.17	[.37, 1.91]
Pre-Intervention	1.00	.85			
Post-Intervention	2.53	1.64			
Concept Map Complexity			1.92	.44	[-.30, 1.15]
Pre-Intervention	27.0	22.01			
Post-Intervention	38.13	28.17			

Note. ** indicates $p<.01$, * indicates $p<.05$ after Bonferroni adjustment, $df=14$

Table 6

Frequency of Coding for Concept Maps

	Pre-Intervention	Post-Intervention
Tentativeness		
Not Observed	13	10
Naïve	2	1
Sophisticated	0	4
Empirical Basis		
Not Observed	7	9
Naïve	8	9
Sophisticated	0	2
Subjectivity		
Not Observed	15	14
Naïve	0	1
Sophisticated	0	0
Social/Cultural Embeddedness		
Not Observed	15	7
Naïve	0	8
Sophisticated	0	0
Theories and Laws		
Not Observed	14	14
Naïve	1	1
Sophisticated	0	0

Scientific Knowledge

Science knowledge, as assessed by the Science Content Test, showed significant differences from the pre-intervention and post-intervention time periods (t = -4.94; see Table 5) with a strong effect (d = .85, CI = [.08, 1.58]). The mean number of items (out of 44) was 29.47 prior to the camp, and 34.20 after the camp. Thus, our hypothesis was supported that participants had an increase in scientific knowledge after their participation in the learning experiences. These results were consistent across the subtests of biomedicine (t = -3.33; d = .62) and aquatic biology (t = 4.91; d = .82).

Academic Self-Concept

On the other hand, participants showed no significant change in science academic self-concept ($t = 0.26$) or general academic self-concept ($t = 0.91$), as based upon the *PCSC-R* with little or no effect, and with confidence intervals around d including zero for the analyses. Our initial hypothesis was not supported, but this result might be due to the fact that the participants entered the camp with a relatively high self-concept in all areas, ranging from 6.27 to 6.39 on a 7-point scale (see Table 5).

Conceptual Understanding

Participants' conceptions of science, as assessed by concept maps, were analyzed both quantitatively and qualitatively. The results of these analyses were mixed, providing partial support for our initial hypothesis. First, the frequency of ideas written on each concept map was counted and compared pre- and post-intervention. The mean at the conclusion of the camp was 8.20 words, which was significantly ($t = 3.12$) higher than prior to the camp ($M = 6.00$; see Table 5). This represents a strong effect ($d = .71$), but the confidence interval includes zero (CI = [-.05, 1.43]).

In examining the participants' understanding of the nature of science , the mean score was 1.00, based on the VNOS scale, prior to the beginning of camp, and increased to 2.53 at the end of the camp, representing a significant change ($t = 4.38$) with a strong effect ($d = 1.17$; $CI =$ [.37, 1.91]; see Table 5). The most common domain in both the pre- and post-intervention concept maps was *Empirical Basis* (see Table 6). The post-intervention data included *Social/Cultural Embeddedness* and *Subjectivity*, both of which were not observed in the pre-intervention data. There was an increase in the observations of *Observations and Inferences* and *Tentativeness* after the camp (see Table 6).

In examining the complexity of the participants' understanding of the scientific research using the rubric based on Novak's research (see Table 3), there was no significant difference in scores (t = 1.92) from the beginning of the camp (M = 27.0) to the end of camp (M = 38.13). There was large variability between students (SD = 22.01; 27.17; see Table 5). Although the effect size was moderate (d = .44) the confidence interval included zero (CI = [-.30, 1.15]).

Gender

We also examined results to see if there were gender differences in the change from pre- to post-intervention in the outcome variables (self-concept, science knowledge, and conceptual understanding). There were significantly more female (n = 11) than male (n = 4) participants in the sample, which was not representative of the overall population of students at the camp. There were no statistically significant differences between the genders for general academic self-concept (t = -2.00), science self-concept (t = -0.18), science knowledge (t = 0.16), frequency of ideas on the concept map (t = 0.46), nature of science understanding (t = 0.36), and concept map complexity (t = 1.77; see Table 7). The effect sizes ranged from large (d = -1.77) to small (d = .09), but all confidence intervals around the effect sizes included zero.

Table 7

Compare Change (Pre-Intervention – Post-Intervention) By Gender

	M	*SD*	*t*	*d*	*CI* of *d*
General Academic Self-Concept			-2.00	-1.17	[-2.31, .11]
Male (*n* = 4)	-.1597	.25			
Female (*n* = 11)	.1512	.27			
Science Academic Self-Concept			-.18	-.11	[-1.25, 1.04]
Male (*n* = 4)	-.0045	.36			
Female (*n* = 11)	.0341	.34			
Science Knowledge- Aquatic Biology			.21	.77	[-.45, 1.90]
Male (*n* = 4)	3.00	.82			
Female (*n* = 11)	2.72	2.58			
Science Knowledge- Biomedical			.07	.12	[-1.03, 1.26]
Male (*n* = 4)	2.00	1.41			
Female (*n* = 11)	1.91	2.54			
Science Knowledge- Total			.16	.09	[-1.06, 1.23]
Male (*n* = 4)	5.00	2.00			
Female (*n* = 11)	4.64	4.24			
Concept Map Frequency			.46	.27	[-.90, 1.40]
Male (*n* = 4)	2.75	2.23			
Female (*n* = 11)	2.00	2.97			
Nature of Science Understanding			.36	.21	[-.95, 1.35]
Male (*n* = 4)	1.75	.96			
Female (*n* = 11)	1.45	1.51			
Concept Map Complexity			1.77	1.03	[-.22, 2.17]
Male (*n* = 4)	26.50	31.6			
Female (*n* = 11)	5.27	15.8			

Note: No significant differences ($p<.05$ after Bonferroni adjustment)

Class Attended

The camp was divided into two content courses. In the sample, seven students attended hands-on classes based on biomedicine. The other eight students participated in investigations related to Aquatic biology. There were no significant differences in the change of general academic self-concept (t = -0.469) or science self-concept (t = -0.791) between the groups (see Table 8). The aquatic biology students had significantly more growth in the aquatic biology questions than the biomedical group (t = -2.709), which represents a strong effect (d = -1.40; *CI*

= [-2.44, -.20]). However, there was no significant difference between the groups for the change in biomedical knowledge (*t* = -1.581). Overall, the aquatic biology students showed more growth in scientific knowledge (*t* = -2.712), with a strong effect (*d* = -1.41; *CI* = [-2.45, -.21). There were no significant differences between the group on the frequency of ideas on concept maps (*t* = -1.025), understanding of the nature of science (*t*=0.098), or complexity of understanding of scientific research (*t* = 0.686; see Table 8).

Table 8

Compare Change (Pre-Intervention – Post-Intervention) By Class Attended

	M	*SD*	*t*	*d*	*CI* of *d*
General Academic Self-Concept			-.469	-.24	[-1.24, .79]
Biomedical (*n* = 7)	.0292	.36			
Aquatic Biology (*n* = 8)	.1024	.25			
Science Academic Self-Concept			-.791	-.41	[-1.41, .64]
Biomedical (*n* = 7)	-.0536	.38			
Aquatic Biology (*n* = 8)	.0915	.33			
Science Knowledge- Aquatic Biology			-2.709*	-1.40	[-2.44, -.20]
Biomedical (*n* = 7)	1.43	1.72			
Aquatic Biology (*n* = 8)	4.00	1.92			
Science Knowledge- Biomedical			-1.581	-.82	[-1.82, .28]
Biomedical (*n* = 7)	1.00	2.58			
Aquatic Biology (*n* = 8)	2.75	1.67			
Science Knowledge- Total			-2.712*	-1.41	[-2.45, -.21]
Biomedical (*n* = 7)	2.42	2.76			
Aquatic Biology (*n* = 8)	6.75	3.32			
Concept Map Frequency			-1.025	-1.55	[-2.60, -.31]
Biomedical (*n* = 7)	1.42	3.59			
Aquatic Biology (*n* = 8)	2.87	1.64			
Nature of Science Understanding			.098	.05	[-.97, 1.06]
Biomedical (*n* = 7)	1.57	1.81			
Aquatic Biology (*n* = 8)	1.50	.93			
Concept Map Complexity			.686	-.36	[-1.36, .68]
Biomedical (*n* = 7)	6.57	18.96			
Aquatic Biology (*n* = 8)	14.75	25.13			

Note: ** indicates $p<.01$, * indicates p<.05 after Bonferroni adjustment

Qualitative Analysis

In examining the concept maps of participants using qualitative methods, several themes emerged. In conceptualizing "scientific research," many students referred to the traditional scientific method, including a linear progression from "hypothesis" to "data collection" to "conclusions." This conceptualization was present in both pre-intervention and post-intervention data; however, more tentativeness and subjectivity were added in the post-intervention concept maps. For example, one participant included the replication of "collect- analyze- organize- present- teach" in the post-intervention concept map. Several of the students who did not have any observable characteristics of the VNOS criteria in pre-intervention concept maps (as well as one participant in the post-intervention data) conceptualized the nature of science as discrete disciplines (e.g., "Biology," "Chemistry," and "Physics"), rather than broader themes of scientific inquiry.

In direct comparisons of pre-intervention and post-intervention maps for each participant, the growth of understanding was evident (see Table 6). Participants consistently added more detail and made more connections between ideas in their concept maps. This included a change from point groupings in the pre-intervention stage to a greater number of students using open and closed grouping after the intervention. In addition, there were more instances of crosslinks to connect ideas and increased number of levels of hierarchy in the post-intervention concept maps.

In their understanding of scientific concepts and the nature of sciences, participants used more technical vocabulary and incorporated the importance of sharing their findings as part of the scientific process. Some participants did not follow the instructions to map "scientific research," but instead demonstrated their knowledge of domain-specific concepts, but even in these instances they demonstrated a deeper knowledge of scientific concepts, such as cellular

Biology. In these instances, the maps illustrated deeper content understandings and schema, although these were not reflected in the quantitative analyses. In addition, more participants indicated a deeper understanding of subjectivity and tentativeness in their concept maps after the intervention. Overall, the students demonstrated deeper levels of conceptual understanding of science through their concept maps.

Discussion

These results show preliminary support for the continued benefits of a constructivist-based summer program for gifted secondary school students. This pilot study demonstrates the need for expanded studies on the effectiveness of these programs, as well as the development of valid instruments to measure the complexity of the growth in understanding of science for this population. For each of the domains of interest, we discuss the specific findings and implications of those findings.

Self-Concept

There were no significant changes in either the general or science self-concept from before the camp to after the camp for the participants (see table 5). In addition, there were no differences for the growth in scores between genders or class attended (see Tables 7 and 8). These results may be explained by the relatively high self-concepts of the participants prior to beginning the camp (M = 6.39; M = 6.27; see Table 5). These participants were confident in their abilities in academic domains in general, as well as in science specifically. They were identified by their teachers as being superior science students, a perception demonstrated to be shared by the participants. This effect could have been enhanced by the participants' knowledge of being selected to participate in this program.

Researchers such as Marsh (1987) have theorized that when high-ability students are grouped together, there is a drop in academic self-concept due to social comparisons between students. However, this was not demonstrated in this study. This may have been due to the small sample size; however, the effect sizes also demonstrate a negligible effect (see Table 5). Another explanation may be due to the nature of the constructivist-based approach, which emphasized cooperation and group work rather than competition. Thus, the academic self-concept of the students may have been enhanced or maintained through working with other competent peers, rather than lowered as in a competition.

Scientific Knowledge

The participants showed significant growth in both knowledge of aquatic biology and biomedical content areas (see Table 5) and this growth did not vary across gender (see Table 6). However, the aquatic biology group did demonstrate greater growth than the biomedical group (see Table 8). This data shows that the constructivist-based summer camp increased students' knowledge of science, and that the aquatic biology students showed greater growth. There are several explanations for the difference in achievement levels between the groups. One explanation is that the aquatic biology curriculum was more directed towards the gaining of scientific knowledge. Alternatively, it could be that the questions selected for aquatic biology were more aligned with the curriculum that was taught. Finally, the aquatic biology students may have been more capable of learning and growth than the biomedical group, due to differences in ability, motivation, or other factors not measured in this study.

Overall, the participants showed significant growth in knowledge about science. However, since the test questions were identical from pre- to post-tests, the increase in scores may be due to memory of the tests, as only one week passed between the test administrations.

Identical tests were chosen to ensure that the pre- and post-tests had the same level of difficulty. The non-instructional test items (i.e., biomedical questions for the aquatic biology group and aquatic biology questions for the biomedical group) can serve as a control for the test-item memory. For the aquatic biology group, the difference between the growth in the instructional and non-instructional items was a mean of 1.25 questions, which is not statistically significant ($t = 1.38$), with an effect size of 0.66 (*CI* = [-.35, 1.66]). In the biomedical group, the growth in non-instructional items was actually greater than in the instructional items ($M = 0.43$), which was also not statistically significant ($t = 0.37$) and with an effect size of 0.18 (*CI* = [-.87, 1.23]). Thus, it is inconclusive if the memory effect was the cause of the increases in achievement, or if the types of knowledge assessed were inconsistent with the instructional practices.

Finally, there may be some debate as to the validity of using a selected-choice exam to measure the learning that occurred in a constructivist-based program. As the program focused on hands-on, authentic investigations that engaged participants in explorations of research questions based upon student interests, quantitative measures based upon standardized state assessments may not capture the extent of the learning that occurred in the camp. Although there is no evidence that the participants hit a ceiling on the test, as no participant answered every question correctly, these assessments may not be able to measure the specific concepts learned, or the conceptualization and schema of the new learning, in a constructivist framework. Thus, the focus on the analysis of the concept maps and other measures may provide more valid interpretations.

Science Understanding

The analysis of the concept maps provided greater insights into the understandings and schema of the participants around the nature of scientific understanding. After their participation in the camp, the participants had a greater frequency of ideas about scientific research and greater scores on their understanding of the nature of science (see Table 6). There were no differences in this growth by gender or class attended (see Tables 7 and 8). The growth in frequency of terms and ideas included in the concept maps is further validated by the qualitative finding of the inclusion of more detail and more technical language (see Table 6). Thus, participants at the end of the camp were able to generate more ideas and elaborate in more detail and with more specificity than they were prior to the camp. However, the frequency of words on the maps is insufficient in measuring how these ideas are interconnected and organized for the students.

To measure and quantify this deeper organization, the researchers used a rubric based on the research of Novak (see Table 2). However, this analysis did not indicate statistically significant differences in scores. This lack of statistical significance could be due to the large variability between subjects. The scores ranged from 8 to 77 on the pre-intervention maps and from 12 to 94 on the post-intervention maps. This, in combination with a relatively low sample size ($n = 15$) could lead to a lack of ability to detect differences. The qualitative analysis of the maps indicated that overall, the participants increased in the complexity of their understandings, including more open and closed groupings, rather than only closed groupings, in the post-intervention maps. Future research might work to develop rubrics that restrict the variability of scores, which may improve the ability to detect statistically significant differences.

Finally, the concept maps were analyzed based on the participants' understanding of the nature of science, using the VNOS framework (see Table 3). These analyses demonstrated that through the constructivist-based science camp, participants grew in their understanding of the nature of science. Specifically, there were no observations of sophisticated understanding of any domain in the pre-intervention concept maps, but in the post-intervention concept maps, four participants demonstrated sophisticated understanding of *Tentativeness* and two demonstrated sophisticated understanding of the *Empirical Basis of Science*. It may be that more participants possessed sophisticated understandings in other areas, but did not record these on the concept maps. As the maps were open-ended and did not prompt participants to discuss the domains, the maps may not measure the fullness of their understandings. In addition, many of the concept maps were ambiguous, and could have been clarified with additional explanations from the participants. It may be that the interpretations of the researchers could have been improved if the participants had additional opportunities to explain their thoughts.

Limitations

This article reports findings from a pilot study that gathered preliminary data to explore the effectiveness of a constructivist-based science camp. As such, there are many limitations of the study. The small sample size limited the ability to detect differences. It is possible that given a larger sample size, the results would be different. In addition, the camp had only one location and all of the participants were from one region of the country, so the results cannot be generalized to other, more diverse, populations. Future research should expand the sample size and investigate the effectiveness in other contexts.

There were also several limitations in the instruments used to measure the effectiveness of the camp. The Science Content Test was limited in the ability to measure deeper conceptual knowledge that was targeted by the constructivist approach, and since the same test was given to both pre- and post-intervention, a week apart, the increase in scores may have been due to memory rather than specific learning. This was somewhat mitigated by the administration of both subject areas (aquatic biology and biomedicine) to both groups, to allow the other subject area to serve as a control.

The concept maps captured conceptual knowledge more aligned with the constructivist approach, but the open-ended nature may have meant that some students did not record all of their understandings, particularly in regard to the nature of science. Future research should continue develop valid measures of conceptual understandings.

Finally, the study did not include a control group, and thus, growth cannot be attributed solely to participation in the camp. However, it is unlikely that significant growth in science knowledge or scientific understanding would occur over the course of one week in the summer absent the intervention.

The reliability of the measures, including the measures of science knowledge and academic self-concept, are limited in reliability of scores given the small sample size of the study. In addition, they are limited in the validity of interpretation as they are unlikely to measure the growth of sophisticated understandings of science content that is developed through constructivist-based teaching practices.

Implications

These results begin to demonstrate the effectiveness of a constructivist-based summer science program for gifted secondary students, particularly for increases in science knowledge and conceptual understanding. As constructivist-based approaches, including active and inquiry learning, collaborative work, and teacher as facilitator, are not inherently focused on standards-based assessments, this research begins to show that these approaches have the potential to improve student achievement on these tests. This research begins to demonstrate the effectiveness of constructivist-based pedagogy in the era of accountability in education, provides support for the use of learner-centered instruction, and adds to the literature investigating constructivism in modern learning environments. This study is of particular interest to researchers involved in constructivist theory as it provides additional evidence of the effectiveness of educational approaches based on the theory.

In addition, this research speaks to educators focused on secondary science instruction, beginning to provide evidence that constructivist-based techniques can provide effective means for increasing student achievement and understanding. As science is focused on the investigation of the natural world, constructivist-based pedagogy can provide successful methods of instruction, developing both increased knowledge and conceptual understanding.

Finally, this research also begins to provide support for constructivist-based approaches for gifted learners. As gifted learners have a need to be challenged, can make connections between disparate concepts, and have accelerated background knowledge, constructivist-based instructional strategies are particularly suited for this population.

Conclusion

This research provides the foundation for providing support for Constructivist-based approaches to science instruction for gifted secondary students. Specifically, this research demonstrated that scientific knowledge and scientific understanding increased with a week-long, intensive science intervention for academically talented students. Future research should expand upon this study to make it more generalizable, as well as focus on the use of concept maps to document growth in student conceptual understanding.

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