Changes in Knowledge Structures Among Middle School Students Participating in Technology Infused Space Science Engagement Activities

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Abstract: The significance of attitudes in shaping middle school students' STEM career aspirations and STEM dispositions is vital in preparing students for a future in a STEM profession. The purpose of this study was to identify middle school students' interests in a STEM career path with exposure to technology infused activities related to space science. Topics relating to the Parker Solar Probe mission to the sun, moon orbits, eclipses, space weather, solar storms, and solar wind were taught through various technologies to pique students' interest in space science in hopes of ultimately creating interest in a STEM field. Twenty-three middle school students participated in these technology-infused activities. The analysis of data in the pre-/post- survey revealed a highly significant gain overall (p = .007; ES = .70, moderately large; t = 3.06; 18 df) in content knowledge of space science. Further analyses through Epistemic Network Analysis revealed peculiar growth in both boys and girls content knowledge structure and interest to pursue a profession in STEM.

Keywords: STEM, science, space science, middle school

Introduction

A series of studies supported by the US National Aeronautics and Space Administration (NASA) over half a decade (Cline et al., 2020; Knezek & Christensen, 2020a; Knezek, Christensen & Ng 2020) have indicated that technology-infused space science learning engagement activities can promote long-lasting gains in content knowledge and interest in space science in middle school students. In this paper, newly-developed data visualization and analysis techniques are applied to data from a study conducted in 2022, to emphasize distinctions in the types of knowledge networks that appear to evolve for girls versus for boys among middle school students who participate in the same space science learning engagement activities.

Study Rationale

To stay competitive in rapidly increasing global economies that rely on information and innovation-driven enterprises, it is essential to augment student success and pique interest in STEM-related careers. STEM professions employ individuals who develop concepts and applications that are commercialized and lead to the genesis of new jobs. Classroom learning settings may be an avenue to create highly engaging and effective hands-on and inquiry-based STEM learning to support the development of new abilities that highlight higher levels of thought, creativity, design, and innovation in a technologically rich and linked world (National Academy of Engineering, 2005; Partnership for 21st Century Skills, 2004). Therefore, technologies, via hands-on investigation, can influence the understanding of middle schoolers' abstract materials and scientific concepts into concrete real-world applications. Previous research has revealed that students in middle school who have optimistic views about science are more likely to pursue a STEM profession (Tai et al., 2006). Furthermore, Smith and Karr-Kidwell (2000) have highlighted similar findings. The principal target of integrated STEM education is to be able to have "a holistic approach that links the disciplines so the learning becomes connected, focused, meaningful, and relevant to learners" (p.22). The infusion of new technology continues to be a catalyst for the educational sector. In order to enhance learning, technology can be infused as a pedagogical tool to support students' knowledge acquisition and high-order thinking (Trevisan, 2019). According to research findings, the use of technology in teaching and learning is advantageous in terms of boosting their engagement in learning (Sadik, 2008; Schilling, 2009) and also, enhances learning motivation (House, 2009; Hsu, 2008). Additional research studies (Liu et al., 2011; Small, 2011) have found a positive correlation between motivation and scientific learning when cutting-edge technology is adapted.

In a previous large scale STEM study involving energy monitoring activities for middle school students (Knezek et al., 2013; Knezek & Christensen, 2020a), leaders of the current research team found positive impacts and that the effect was especially positive for girls. Specifically, "… substantial (ES > .3) and significant (p < .05) positive differences in mean score gains were found for both male and female students regarding STEM content knowledge. Female STEM content knowledge began at approximately the same level as boys, but the gain was 8.38% greater for females than gains for males" (Knezek & Christensen, 2020b, p. 160). In the current study, the research team sought to examine whether similar positive impacts resulted from NASA-focused, technology-infused STEM engagement activities conducted during 2022, and to describe more richly the types of gender differences that might emerge.

Research Questions

The research questions posed in this study were:

1. To what extent will technology-infused activities enhance middle school participants' understanding of space science?
2. Are there dissimilarities between boys and girls and their understanding of space science?

Methods

Participants

Teacher training for enrichment activities derived from NASA content and focusing on using innovative technologies in space science, were conducted at a university in which a NASA grant was held. Activities that were introduced included exploring different spacecraft using augmented reality, experiencing the solar system using virtual reality, and exploring the Parker Solar Probe's mission to touch the sun using drones. Two of the participants, an 8th grade science teacher and a librarian who sponsored an enrichment class for middle school students (referred to as The Geek Squad program), went back to their school and taught the activities to eighth-grade students over a one-month period of time. The librarian gathered pre-post data from her students regarding their experiences with the activities.

This study took place in a school district located in a north-central region of Texas, in the southern part of the United States. Twenty-three eighth graders with ages ranging from 13 to 15 years old participated in the study. Usable data were obtained from 19 of the 23. Ten girls and nine boys were identified for analysis of findings from this study. At their school, these students participated in a program known as the Geek Squad, headed by the librarian.

Technology infusion activities were targeted toward middle school participants in the science classroom. This was a one-month intervention with NASA-focused activities including augmented reality, virtual reality, brief informational videos, as well as computational thinking activities for drones. Students at remote locations were also able to participate in this intervention via related online activities developed by the project team. Immersive VR space science exploration and quests were incorporated on site at the school via NASA VIVE segments converted for Oculus Quest 2 portable deliveries. There was also an option for approximately half the participants to visit university facilities where participants were able to engage with other technologies including 2D and 3D design and printing, as well as extensive space explorations in the NASA VIVE environment, allowing projection of what the learner is experiencing inside the simulation to a large screen for all participants.

Data Collection

A pre-test and post-questionnaires were administered to the middle school participants. The pre and post-questionnaire consisted of sixteen content knowledge items (see Table 1) (multiple-choice, binary coding: correct, incorrect), as well as a career plan question.

Table 1

Sixteen Content Knowledge Questions

Theme of Question	Item Number
Eclipse	3, 4, 5, 6, 7, 8, 9
Sun (location, temperature, umbra)	1, 11, 15
Moon Phases	2
Parker Solar Probe	10
Space Weather (solar winds, solar storms)	12, 13, 14
Earth's Magnetic Field	16

Data were analyzed in two ways: through SPSS and ENA. SPSS was used to assess significant differences between pretest and posttest scores on the 16 content knowledge items, both on the pooled sample and for each gender separately (paired sample t-test, $p<.05$). Epistemic Network Analysis was used to further explore the data investigating the knowledge structure of the pupils at pre-and post-test, both on a pooled and gender specific basis.

Our ENA model included the 16 survey items for content knowledge, modeled together simultaneously as a collection. ENA models the connections between codes (i.e., items) by quantifying the co-occurrence of codes within events or episodes (e.g. pre-test/post-test), producing a weighted network of co-occurrences, along with associated visualizations for each unit of analysis in the data. We defined the units of analysis as all of the data associated with a single value of Pre/post-test aligned within individuals. For example, one unit consisted of all the lines associated with *Pupil 1* at *pre-test.*

The ENA model normalized the networks for all units of analysis before they were subjected to a dimensional reduction, which accounts for the fact that different units of analysis may have different counts of coded entries in the data. For the dimensional reduction, we used a singular value decomposition, which produces orthogonal dimensions that maximize the variance explained by each dimension. (Shaffer et al., 2016).

Results

Findings

Middle schoolers' understanding of space science over a month of technology-infused activities

A total of 23 middle school students (8th grade) participated in the technology-enhanced, engaged learning activities at their school. Nineteen (19) of the students provided complete pre and post data on all measures used in this study. Among the study participants, 13 entered the activities indicating interest in a STEM career, while 11 confirmed this choice at the end of the experience (only one pupil changed their mind, in favor of a STEM career, by the end of the activities).

The first research question (i.e. how will technology-infused activities enhance middle school participants' understanding of space science?) was investigated through the analysis of the answers to the 16 content knowledge items. Pupils' correct answers significantly improved over a month of technology-infused, space science engagement activities as indicated by a paired sample t-test (t = 3.06, 18 df, p = .007) performed in SPSS. The difference among the correct answers in the pre-test (mean= 10.16, st.d. = 3.34) and in the post-test (mean= 12.74, st.d.=2.02) had also a moderately large effect size (Cohen's d = .70). Analysis revealed a highly significant (*p* = .007) and moderately large gain overall (ES = .70) (Cohen, 1988), as shown in Table 2. The average knowledge gain was three additional questions answered correctly (of 16 total), after the month of technology-infused, space science engagement activities, with improvement of the group as a whole advancing from approximately 10 correct to 13 correct (Table 2).

Table 2

Middle Schoolers Pre and Post Means for Content Knowledge

	Mean	N	Std. Deviation	t-test
CorrectPre	10.16	19	3.34	.007
CorrectPst	12.74	19	2.02	

To further analyze the results, Epistemic Network Analysis (ENA) was utilized to draw a more in-depth picture of what the patterns of the gains in content knowledge would further reveal. Trends in gains in content knowledge can be visualized through the Epistemic Network Analysis (ENA) as per Figure 1.

Figure 1

Epistemic Networks of Middle schoolers Before (Red) and After (Blue) a Month of Technology-Infused, Space Science Engagement Activities

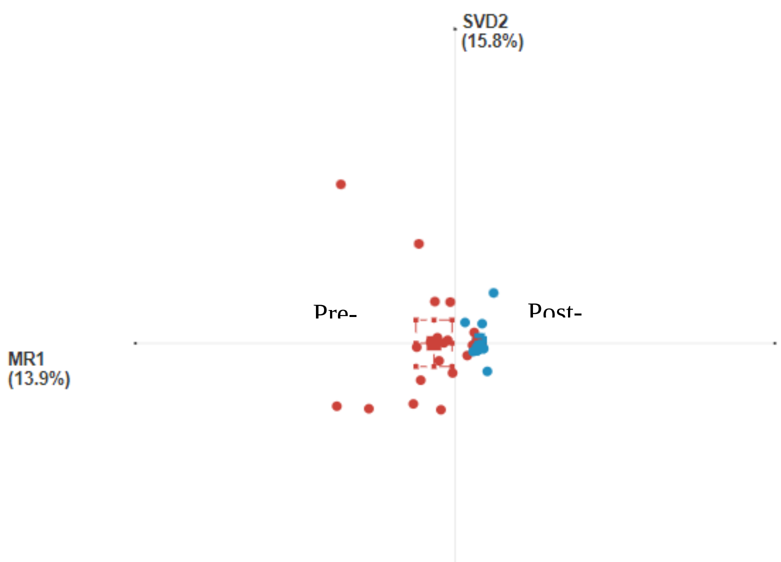


Figure 1 shows the epistemic networks of the pupils when entering the activities (in red) and again after a month of technology-infused, space science engagement activities (in blue). The dots represent the various pupils, whose epistemic networks are scattered and highly individualistic, in the pre-test group. On the contrary, the blue dots, i.e. pupils in the post-test group, are much closer together, sharing a more homogeneous/communal epistemic network for the space science content at stake.

A Mann-Whitney nonparametric test in ENA showed that pupils' answers on their pre-test (Mdn. = -0.33, N=22) differed statistically significantly at the alpha=0.05 level from their answers in the post-test (Mdn.=0.55, N=19 U=383.00, *p*=0.00, r=-0.83). Hence, ENA visualization (see Figure 1) corroborates the t-test analysis performed in SPSS.

Gender-related differences in understanding of space science over a month of technology-infused activities

Considering the pooled-sample differences between pre-and post-test, further analyses were performed to investigate whether gender was a relevant variable in the configuration of knowledge structures for space science. As shown in Table 3 and graphically displayed in Figure 1, the boys were much higher than the girls at pretest time, but the girls were equal to boys by post. The gains in total correct were significant ($p<.05$) for girls (t= 4.19, 9 df, *p* = .002; ES = 1.33) but not for boys (*p* = .353 NS, 8 df; but ES = .33 educationally meaningful still).

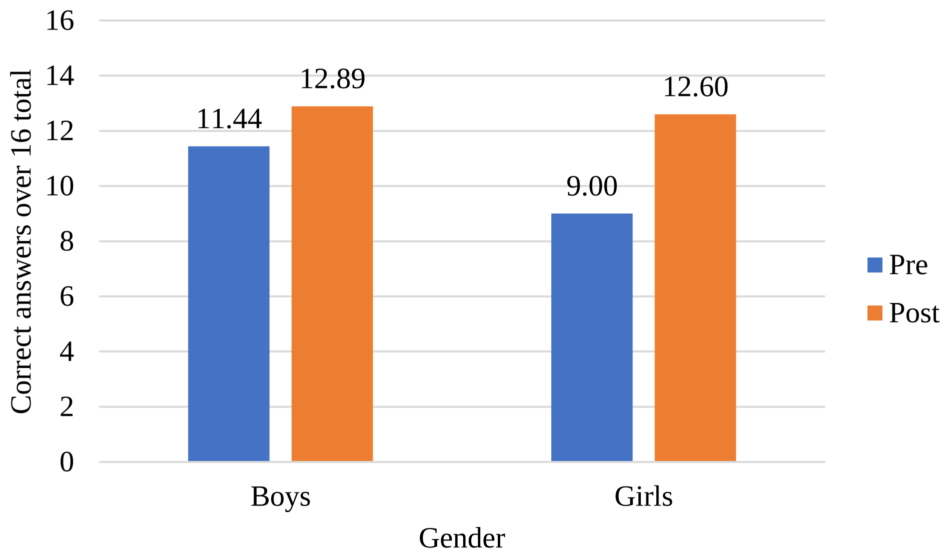
Table 3

Boys and Girls in Middle School Pre and Post Means for Content Knowledge

Gender	N	Mean correct pre (st.d.)	Mean correct post (st.d.)	t-test
Boys	9	11.44 (4.00)	12.89 (2.26)	NS
Girls	10	9.00 (2.21)	12.60 (1.90)	.002

Figure 2

Space Science Questions Answered Correctly by Gender, Pre and Post



Boys started with a mean of correct answers equal to 11.44 of 16 (st.d. = 4.00), while girls had a lower starting point (mean at pre-test= 9.00, st.d.=2.21). Nevertheless, after a month of technology-infused, space science engagement activities, girls' correct answers increased significantly, with a mean at post-test of 12.60 (st.d.=1.90). Such knowledge gain was both statistically significant (paired *t-test*, t= 4.19, 9 df, p = .002) and largely meaningful (ES= 1.33). This was not the case with boys, whose mean at the post-test was 12.89 (st.d. 2.26), not statistically significantly different from their pre-test scores, although still educationally meaningful (*ES*=.33) according to established research guidelines (Bialo & Sivin-Kachala, 1996).

ENA's network visualization capabilities were used to investigate the nature and implications of these knowledge gains, for both boys and girls. The resulting epistemic networks are graphs where nodes correspond to the items, and edges reflect the relative frequency of co-occurrence, or connection, between two codes (see Figures 3 and 4). The positions of the network graph nodes are fixed, and those positions are determined by an optimization routine that minimizes the difference between the plotted points and their corresponding network centroids. Because of this co-registration of network graphs and projected space, the positions of the network graph nodes—and the connections they define—can be used to interpret the dimensions of the projected space and explain the positions of plotted points in the space.

Figure 3 displays the boys' epistemic networks based on the 16 space science items at pre-test (in blue) and post-test (in orange).

Figure 3

Boys' Epistemic Networks based on 16 Space Science Questions, Pre (top) and Post (bottom - n=9)

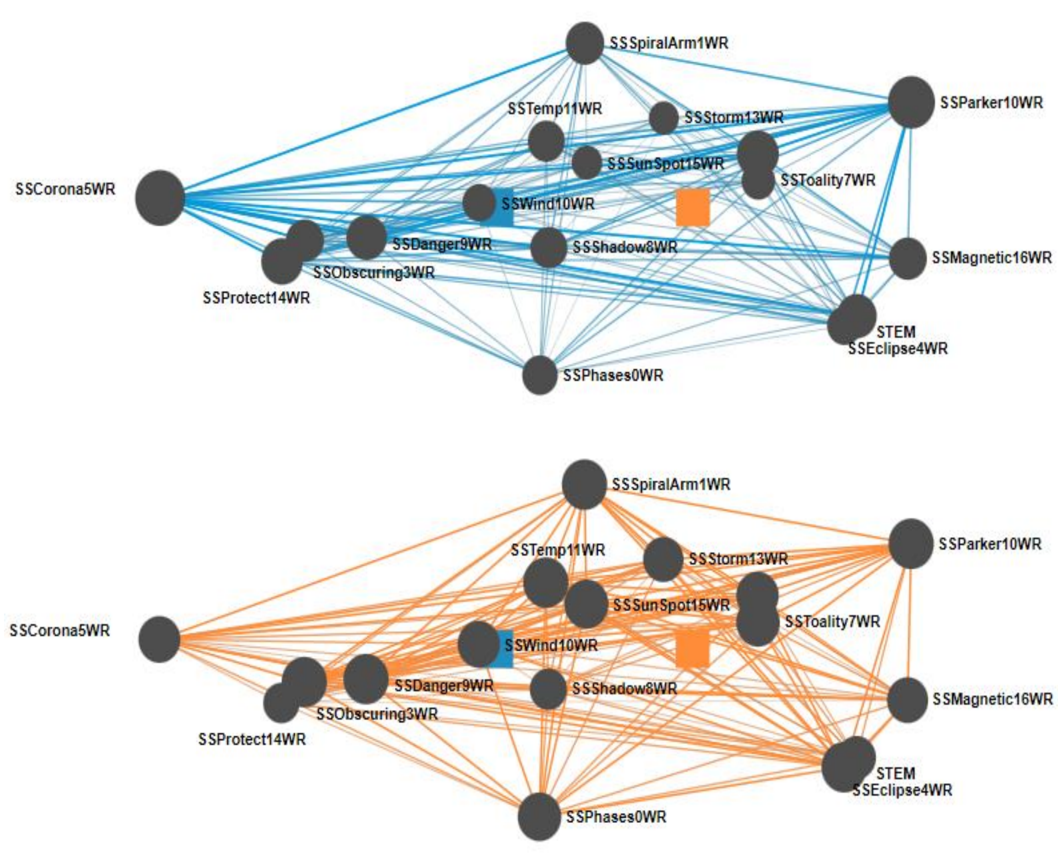


Figure 3 confirms that boys increased in their understanding of the content, as the nodes' size (i.e. frequency of correct answers) increase from the blue group (pre) to the orange group (post). Moreover, the links among nodes become clearer in time, enabling pupils to draw their answers from a multiplicity of interconnected sources. The core of the conversation, i.e. the squares in Figure 3, also shift from pre- to post- survey administrations. In the blue group (pre) the centroid is close to a focus on general, common sense knowledge (e.g. item nine that reads "It is dangerous to look directly at the sun during the eclipse because it may cause eye damage"). The centroid of the post-test conversation is closer to specific scientific items, like item 7, on the average duration of the "totality" phase in a total solar eclipse. Such shift in the core of the conversation/understanding for boys is testified also by a Mann-Whitney test, significant at $p<.05$ for the differences between pre (Mdn=-1.06, N=10) and post (Mdn=2.21, N=9 U=3.00, p=0.00, r=0.93). While these findings overall corroborate the meaningful educational shift in content understanding already assessed through the t-test in SPSS, boys' epistemic networks add more information. Figure 3 shows that boys' knowledge structure is quite linear (see central nodes forming sort of a line from left to right), and their core understanding moves along such lines without further modifications.

Figure 4 displays the girls' epistemic networks based on the 16 space science items at pre-test (in pink) and post-test (in green).

Figure 4

Girls' Epistemic Networks based on 16 Space Science Questions, Pre (top) and Post (bottom - n=10)

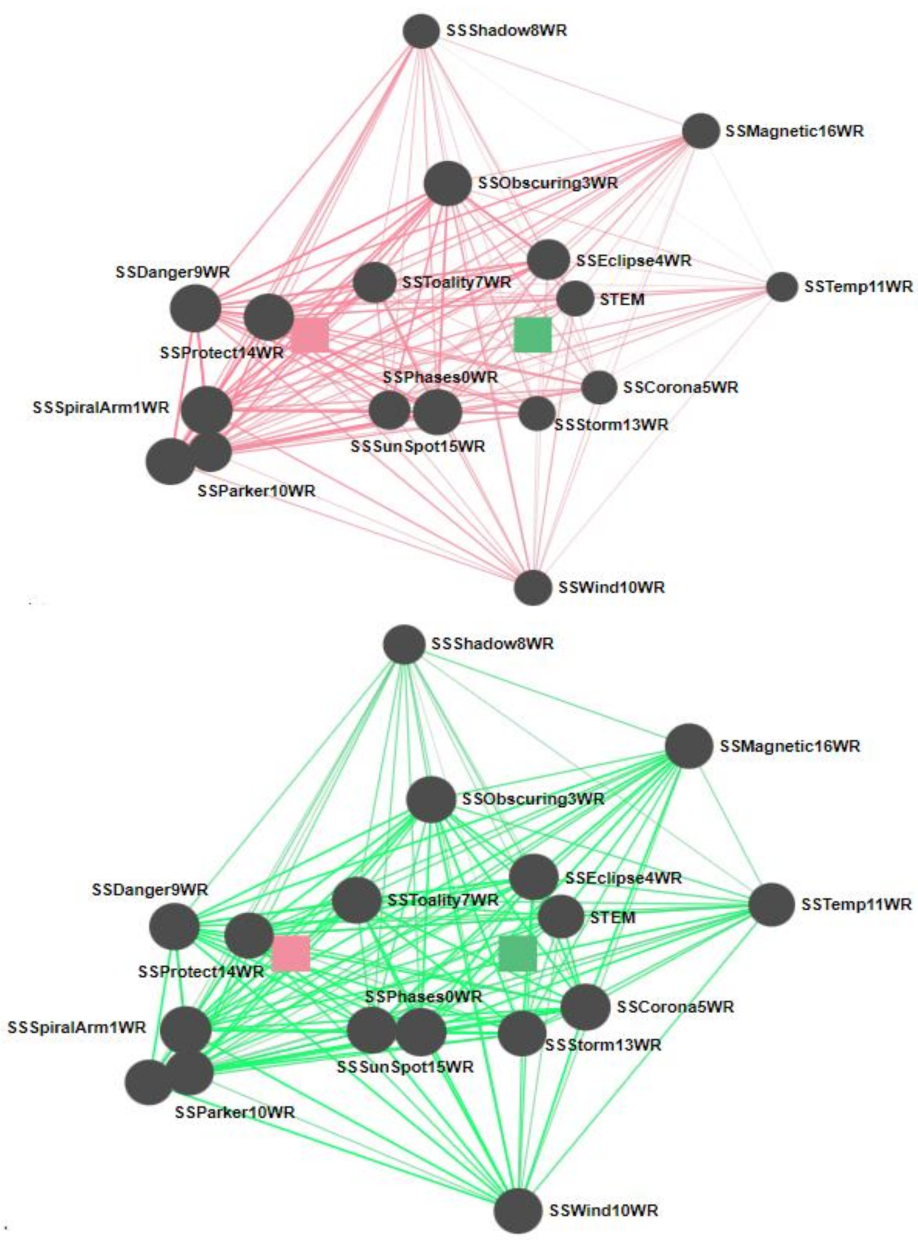


Figure 4 confirms that girls improved their understanding of the content, as the nodes' size (i.e. frequency of correct answers) increased from the pink group (pre) to the green group (post). Moreover, the links among nodes become clearer in time, enabling pupils to draw their answers from a multiplicity of interconnected sources. The core of the conversation, i.e. the squares in Figure 4, also shift from pre- to post-survey administrations. In the pink group (pre) the centroid is close to a focus on general, common sense knowledge (e.g. item nine again, and 14, which reads "Predicting space weather allows scientists to protect everyone"). The centroid of the post-test conversation is closer to specific scientific items, like item 4, on the conditions necessary for a solar eclipse to occur. Notably, the post-test centroid is extremely close to the interest in a STEM career, which became in time more relevant in shaping the content knowledge for girls. Such shift in the core of the conversation/understanding for girls is supported also by a Mann-Whitney test, significant at $p<.05$ for the differences between pre (Mdn.=1.40, N=10) and post (Mdn.=1.40, N=10). Once again, these findings overall corroborate the large and meaningful educational shift in content understanding already assessed through the t-test in SPSS. Moreover, girls' epistemic networks show how the core of their understanding moved from a position where a few different sources held worth in shaping the knowledge structure, to a position where several sources of information (i.e. nodes) are equally surrounding the centroid. This post-test configuration for girls is similar to ones common for experts, for whom knowledge is known to be a complex network (Oshima & Shaffer, 2021).

Discussion and Conclusions

These findings support a positive assessment of the technology-infused activities implemented, in enhancing middle school students' understanding of space science, both on a general level (t-tests) and on a knowledge structure (ENA) level. Boys and girls seem to have both grown in their content knowledge and, more marginally, in their interests in a career in STEM. Nevertheless, girls are the ones who improved more significantly and meaningfully in their understandings, showing a clear modification of their knowledge structure towards a more expert configuration (Oshima & Shaffer, 2021). Future research should include studies with larger data sets to further confirm and support these findings.

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