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What Science Fairs Reveal About STEM Learning

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Abstract

Science fairs have long been promoted as valuable platforms for fostering authentic science learning. With current standards emphasizing active engagement in Science and Engineering Practices (SEPs), there is a growing need to examine how science fairs support students' development in these areas. This pilot study investigated the learning outcomes of 166 students (grades 6–12) who participated in a statewide science and engineering fair. Using a retrospective pretest–posttest correlational design, the study assessed students' growth in their perceived understanding of SEPs and their perceived engagement in STEM-related behaviors outside the classroom. Results from paired-samples *t*-tests indicated that both middle and high school students demonstrated significant gains in these two domains based on their self-reports. Multiple regression analyses further revealed that high school students' gains in both perceived outcomes were positively associated with self-challenge and community-based motivations and negatively associated with teacher- or parent-initiated participation. In contrast, different yet comparable patterns emerged for middle school students. Together, these findings suggest that Self-Determination Theory should more intentionally incorporate developmental nuance when applied to K–12 STEM contexts, particularly with respect to how autonomy support functions across grade levels. Implications for policy, practice, and future research are discussed.

Keywords: science fair; STEM; science and engineering practices

1. Introduction

Students are expected to demonstrate increasing proficiency in Science and Engineering Practices (SEPs), emphasizing that students should learn science by engaging in the authentic practices of scientists and engineers rather than solely memorizing content (NGSS Lead States, 2013; National Research Council, 2012). These performance expectations in SEPs, such as modeling, analyzing data, constructing explanations, and engaging in argument from evidence, reflect society's need to cultivate scientifically literate citizens (Clark et al., 2025). Alongside this disciplinary goal, science education also seeks to enhance and sustain students' interest in STEM and STEM-related behaviors, which are strongly associated with future STEM participation and identity development (Habig & Gupta, 2021; Osborne, 2014). Through actively engaged in SEPs, students' interest can be promoted and their motivation to pursue STEM-related fields may increase as well (Miller et al., 2018; Chapman et al., 2025). However, traditional classroom environments often struggle to meet these goals since the frequency of engaging students in SEPs was often once or twice a month or even less (DeLisi et al., 2021). Constraints such as limited instructional time,

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pressure to cover extensive content, and the prevalence of teacher-directed instruction rerestrict opportunities for students to engage in extended inquiry or apply SEPs in authentic contexts (Braund & Reiss, 2006). These limitations can hinder the development of robust competencies in SEPs and may inhibit students' interest and self-directed engagement in STEM beyond school (Le et al., 2023).

Within this landscape, science fairs provide an important and underutilized learning resource (Martín-García & Dies Alvarez, 2022) with authentic and student-driven learning contexts. Students' motivational alignment with science fairs can connect personally meaningful challenges with deep understanding of SEPs and promote sustained engagement behaviors (Ryan & Deci, 2020). At the same time, a variety of contextual support from the partnership ecosystem, such as parents, school science researchers, researchers, industry leaders and professionals in STEM fields, can support students during fairs and foster their motivations to deeply engage in STEM projects (Benedetti & Crouse, 2020). Prior science fair research has largely emphasized participants' interest (Grinnell et al., 2020) and career aspiration outcomes, often treating science fairs as a generic enrichment activity. Much less attention has been paid to what students learn and engagement to align science fairs with NGSS-informed visions of science learning (Institute of Competition Sciences, 2020; Le et al., 2023). Especially, very limited quantitative investigations have been conducted into students' gains in their understanding of SEP s and STEM-related behaviors and how motivation and contextual support affect these student outcomes. This study extends prior research by asking what science fairs reveal about STEM learning by examining how participation in a statewide science and engineering fair is associated with students' perceived growth in understanding of SEPs and their perceived engagement in STEM-related behaviors. Therefore, it can advance understanding of how informal STEM experiences support disciplinary ways of knowing and doing, rather than only affective or aspirational outcomes.

In addition, promoting both understanding of SEPs and interests during the secondary years is essential for preparing a scientifically literate citizenry and sustaining the STEM pipeline (National Academies of Sciences, Engineering, and Medicine, 2018). However, middle and high school students benefit differently from the features of science fairs due to evolving motivations to participate and different responses to the support from others. Middle school students' motivation is often characterized by curiosity, enjoyment, and the novelty of hands-on inquiry. They respond strongly to contextual support while they are forming foundational scientific reasoning skills and exploring emerging interests (D. H. Palmer, 2009). In contrast, high school students typically possess more advanced cognitive abilities for abstract reasoning and methodological thinking and begin making concrete decisions about STEM coursework, college pathways, and career aspirations (Tai et al., 2006). Their motivation is more strongly shaped by personal values, identity development, and long-term goals. Due to this distinction, the purpose of the current study is to investigate not only whether students' learning outcomes in their perceived understanding of SEPs and STEM-related behaviors engagement through science fair participation but also how these outcomes may differ for middle and high school students. Methodologically, this study contributes by examining predictors of change in students' perceived understanding of SEPs and STEM engagement across grade bands. It also offers practical implications for the design and implementation of science fairs as equitable, learning-focused STEM experiences across middle and high school grade bands.

2. Conceptual Framework and Literature Review

Two frameworks guide the design of the current study. In this section, we first present the conceptual framework of Science and Engineering Practices (SEPs) and a relevant

motivation theory, followed by a review of prior literature aligned with these frameworks. Research questions are proposed at the end of this section to address how this work contributes to the current understanding of the topic.

2.1. Integrating Self-Determination Theory with the Framework of SEPs in Science Fair

Research suggests that science learning must reflect the natural inquiry of children's learning (Bransford et al., 2000) and promote students' engagement in SEPs (Sinatra et al., 2015). These SEPs include: (a) asking questions and defining problems, (b) developing and using models, (c) planning and conducting investigations, (d) analyzing and interpreting data, (e) using mathematical thinking, (f) constructing explanations, (g) developing evidence-based arguments, and (h) obtaining, evaluating, and communicating information (NGSS Lead States, 2013). Learners are often engaged in many hands-on activities in science fairs, which positions them as active participants in the process of authentic scientific inquiry and problem solving in a meaningful context, promoting both conceptual understanding and procedural fluency (Mason & Singh, 2016).

While the Science and Engineering Practices (SEPs) framework emphasizes the cognitive and procedural dimensions of scientific inquiry, students' learning outcomes are also shaped by the motivational conditions that influence their effort, persistence, and depth of learning (Furtak & Kunter, 2012). Self-determination Theory (SDT) is deeply rooted in social–contextual theories that emphasize importance of motivation and contextual support (Ryan & Deci, 2000) for self-motivated behavior. First, it provides a useful lens for understanding how meaningful learning occurs when students' basic psychological needs for autonomy, competence, and relatedness are met. Autonomy refers to a sense of volition and ownership over one's actions; competence reflects feeling capable and effective in achieving desired outcomes; and relatedness involves feeling connected to and valued by others in one's learning environment. From the perspective of the SDT, gains in understanding of SEPs are expected to emerge when science fairs are uniquely positioned to support students' needs in these three areas. When students choose to participate for personally meaningful reasons, select their own research questions, design and conduct their investigations, their sense of autonomy is strengthened through ownership of the project. Competence is fostered as students successfully design investigations, collect and analyze data, and advance through school, district, and state-level competitions, providing repeated opportunities to experience effectiveness in scientific inquiry. Science fair participation also supports relatedness, as students seek out authentic novelty and challenges that are relevant to their personal life and community. Intrinsic motivations, such as challenging students themselves, being passionate about a project idea, wanting to make a positive impact on communities, could meet these needs of students and therefore positively influence students' understanding of SEPs while they participate in science fairs. In contrast, extrinsic motivations, such as class requirements, receiving awards, or teacher or parent expectations, could thwart these needs and negatively impact students' learning outcomes because they would undermine students' feeling of autonomy (Deci & Ryan, 1985). These extrinsic elements may operate as either controlling or informational support cues (Deci et al., 1999) and might decrease intrinsic motivation for participation in the fair, which may eventually influence students' learning outcomes.

Second, SDT is not just about individual drive; it's a theory about how social environments support or impede human potential (Ryan & Deci, 2000). Therefore, contextual factors are embedded in SDT and represent social–contextual factors that are associated with students' engagement and learning outcomes (Ryan & Deci, 2020). Interpersonal interactions with teachers, parents, researchers, and professionals who provide encouragement, feedback, and recognition allow for immediate contextual support of students to

further help them build perceived autonomy, competence, and relatedness (Dionne et al., 2012; Ryan et al., 1994). Through this contextual support while students participate in science fairs, they persist through challenges, revise ideas, and engage in reflective scientific reasoning behaviors which are central to the development of SEP understanding. This support could also reinforce students' feelings of connection to a broader STEM community and important others. Therefore, this dual perspective of the SDT guided the current study's focus on the motivational and contextual factors, such as students' personal goals and external support, that contribute to SEP's understanding outcomes.

Furthermore, while autonomy, competence, and relatedness are fulfilled, students internalize the science fair as personally meaningful, feel increasingly competent in conducting scientific work, and identify with a supportive STEM community, students are seen as autonomous participants who are actively engaged in and responsible for the learning (Ryan & Deci, 2020). These experiences not only cultivate SEP understanding but also lay the groundwork for increased STEM-related behaviors. Repeated activation of situational interest (D. H. Palmer et al., 2016) through science fair participation can evolve into more enduring forms of interest, leading students to voluntarily engage in activities such as reading scientific information, discussing science topics, and pursuing additional STEM opportunities (Hidi & Renninger, 2006; D. Palmer et al., 2017). For these reasons, SDT also provides the theoretical basis for examining middle and high school students with different motivations and contextual support related to another learning outcome, engagement in STEM-related behaviors (see Figure 1). This framework informed our data collection strategy, including selecting intrinsic and extrinsic motivation variables and support from significant others that align with the three psychological needs of autonomy, competence, and relatedness.

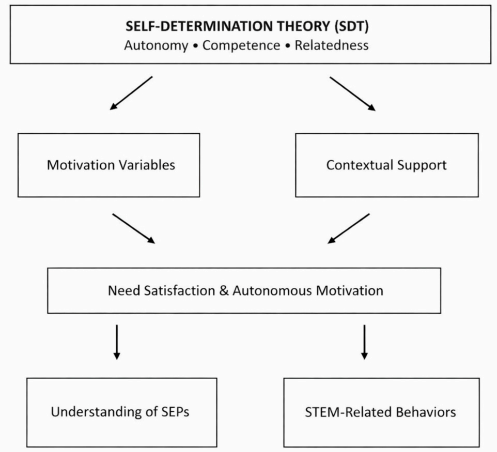


Figure 1. Conceptual Framework of SDT and Two Key Learning Outcomes.

2.2. Motivational and Contextual Factors with Students' Understanding of SEPs in Science Fairs

Only a small body of research has examined whether participation in science fairs contributes to students' understanding of SEPs (DeLisi et al., 2021; Schmidt & Kelter, 2017). These two existing studies (DeLisi et al., 2021; Schmidt & Kelter, 2017) were conducted in middle school contexts and reported mixed findings. Using qualitative focus groups with 41 middle school participants across three schools, Schmidt and Kelter (2017) found that students reported perceived growth in procedural aspects of inquiry, such as identifying variables, testing hypotheses, and analyzing data. Their thematic analysis suggested that engaging in science fair projects supported students' development of their understanding of key SEPs through hands-on investigation and iteration. But they did not discuss the roles of students' motivation in this learning outcome. DeLisi et al. (2021) conducted a larger mixed-methods study with 343 sixth-grade students participating in 21 school-level fairs. Although

average pre–post gains on assessments aligned with selected SEPs (planning investigations, analyzing data, and constructing explanations) were not statistically significant, their hierarchical linear modeling (HLM) revealed important contextual factors. Specifically, teachers' explicit scaffolding and opportunities for peer critique were positively associated with students' SEP understanding on posttests. These findings suggest that the learning environment surrounding the fair plays a critical role in supporting SEP development.

2.3. Motivational and Contextual Factors with Students' Engagement in STEM-Related Behaviors Through Science Fairs

Limited studies explored outcomes of science fairs on students' STEM interests (Grinnell et al., 2020, 2021, 2022; Schmidt & Kelter, 2017), especially engagement in STEM-related behaviors. Across studies, positive outcomes related to interest in STEM are consistently reported. In Schmidt and Kelter's (2017) middle school focus groups, most participants described increased enthusiasm and curiosity toward STEM after completing their projects. Similar patterns were found in Grinnell and colleagues' multi-year research with high school participants, who reported increased STEM interest across several survey-based investigations (2020, 2021, 2022). Contextual supporting factors were identified to associate with these positive outcomes across middle and high school students. Even though these studies did not adopt SDT to discuss the results, autonomy, particularly students' ability to choose whether to participate and to select their own project topics, was repeatedly highlighted as a key variable related to students' interest in STEM (Schmidt & Kelter, 2017; Grinnell et al., 2020). In contrast, required participation was associated with reduced motivation and increased stress (Grinnell et al., 2020).

Among contextual factors, some middle school participants reported stress and negative emotions tied to competition pressure (Schmidt & Kelter, 2017). In contrast, high school students in a national sample specifically mentioned supportive mentorship, coaching and competition incentives were important for their interest outcomes in STEM through a descriptive data analysis based on an online survey (Grinnell et al., 2021). These supports were particularly salient for students from underrepresented groups, pointing to the critical role of contextual resources. Grinnell et al. (2022) additionally documented ethnic disparities in experiences in science fairs. Asian American students in STEM fairs were shown to be over-represented among survey respondents compared to other groups of students. Asian and Hispanic students indicated a greater interest in careers in STEM compared to Black and White students. Black students reported the least help received from parents, teachers, and scientists. These patterns illustrate persistent equity issues, suggesting that variations in access to resources and contextual support may lead to differential benefits from participation in science fairs. Taken together, existing research suggests that science fairs can promote STEM interest, but the extent of these benefits depends heavily on students' feelings of autonomy and contextual conditions.

2.4. Demographic Factors with Students' STEM Learning Outcomes

Several demographic variables have been identified in prior research as influential factors shaping students' STEM learning outcomes. Parental educational level, in particular, has been shown to affect both the level and type of parental involvement. Using survey data from 127 parents of sixth-grade students across 17 schools participating in science fairs, Fields et al. (2022) found that parents with a bachelor's degree or higher were significantly more likely to provide substantive support than parents with an associate degree or lower, based on chi-square analyses. This finding is consistent with other studies indicating that high school students whose parents do not hold college degrees are less likely to receive STEM-related support at home and less likely to participate in STEM extracurricular activities compared to peers with college-educated parents (Starr et al., 2022).

In addition to parental education, students' enrollment in advanced STEM coursework—such as Advanced Placement (AP) or International Baccalaureate (IB) programs has been shown to play an important role in secondary students' STEM learning and the development of STEM pathways (Gottfried, 2015). Prior research has also demonstrated that race, ethnicity, and cultural background shape patterns of parental involvement in education (Cheung & Pomerantz, 2011), which in turn influence students' engagement and academic achievement. Accordingly, these variables were included as background controls in the current study when examining the relationships among motivational factors, contextual support, and learning outcomes for middle and high school students participating in science fairs.

In summary, despite some documented challenges, science fairs overall appear to support two important student outcomes, including development of SEP understanding and increased interest in STEM. None of the studies specifically used SDT lens to discuss students' learning outcomes. Very few studies have used rigorous quantitative models to identify how motivational and contextual factors influence students' outcomes in science fairs. Although several studies documented changes in STEM interest, none have directly examined STEM-related behaviors, which are theoretically and empirically linked to interest. Most studies examine students' understanding of SEPs in middle school contexts while most studies use high school contexts when they measure students' interest. Prior research suggests differences in how middle and high school students respond to motivational and contextual support factors; none of these studies have compared to what extent these factors are associated with two key learning outcomes. The current study aims to contribute to filling this gap through answering the following four research questions (RQ):

RQ1. To what extent do middle and high school students' perceived understanding of Science and Engineering Practices (SEPs) and engagement in STEM-related activities outside the classroom differ before and after participating in a state science and engineering fair?

RQ2. What motivational and contextual factors are significantly associated with the change in students' perceived understanding of Science and Engineering Practices (SEPs) before and after participating in a state science and engineering fair, after controlling their demographic backgrounds?

RQ3. What motivational and contextual factors are significantly associated with the change in students' perceived engagement in STEM-related activities outside the classroom before and after participating in a state science and engineering fair, after controlling their demographic backgrounds?

Based on SDT and literature review, we proposed following hypotheses related to three research questions:

Hypothesis 1. *School students' perceived understanding of SEPs and engagement in STEM-related activities outside the classroom will significantly increase after participating in a state science and engineering fair.*

Hypothesis 2. *Intrinsic motivation and contextual factors that support students' feelings of autonomy, competence, and relatedness will have significantly positive relationships with gains in students' perceived understanding of SEPs. Extrinsic motivation and contextual factors that thwart students' feelings of autonomy, competence, and relatedness will have significantly negative relationships with gains in students' perceived understanding of SEPs.*

Hypothesis 3. *Intrinsic motivation and contextual factors that support students' feelings of autonomy, competence, and relatedness will have significantly positive relationships with gains in students' perceived engagement in STEM-related activities outside the classroom. Extrinsic motivation and contextual factors that thwart students' feelings of autonomy, competence, and relat-*

edness will have significantly positive relationships with gains in students' perceived engagement in STEM-related activities outside the classroom.

3. Method

This exploratory study employed a retrospective pretest–posttest design and multiple regression analyses with a quantitative focus to examine the educational outcomes of students participating in a State Science and Engineering Fair. Rather than relying on simple correlational approaches, regression models were used to identify predictors of change in students' perceived understanding of Science and Engineering Practices (SEPs) and engagement in STEM-related behaviors.

The retrospective pretest–posttest method (also referred to as post-then-pre or now-then design) assesses participants' perceived changes in knowledge, skills, attitudes, or behaviors after a learning experience (Little et al., 2020). Instead of collecting data at two distinct time points, participants retrospectively evaluate their prior and current levels of understanding at the conclusion of the program. This design helps mitigate response-shift bias, an internal recalibration of self-assessment that occurs as participants' conceptual understanding evolves throughout the experience (Bhanji et al., 2012).

3.1. State Science and Engineering Fair (SSEF)

The State Science and Engineering Fair (SSEF) is a premier statewide STEM competition for students in grades six to twelve established in 1957 by a state legislature in the southeastern U.S. It aligns with the state's vision of developing a scientifically literate and innovation-driven workforce. It is sponsored by the State Department of Education, administered by a non-profit organization in the state and coordinated in partnership with a large state metropolitan university. SSEF identifies and promotes young scientific talents through research-based inquiry and competition. Each year, the fair convenes around 900 student finalists from across the state for a three-day event that recognizes excellence in scientific research and innovation. Student research projects are classified into 13 categories, reflecting a broad range of scientific and engineering disciplines, such as animal sciences, behavioral and social sciences, and engineering. The SSEF uses a multi-tiered judging system comprising volunteer judges from the state's universities, research institutions, industries, and professional organizations. Each project is reviewed by three to five judges, ensuring interdisciplinary evaluation and fairness based on scientific ideas and methodology, engineering design and creativity, thoroughness and skill in scientific research, and communication. The SSEF aims to (1) introduce students to authentic scientific research, (2) strengthen students' science and engineering practices (SEPs), (3) provide teachers a professional platform for exchanging ideas and best practices, and (4) promote public engagement and interest in STEM education across the state. In the current study, we focus on examining development of students' perceived understanding of SEPs and STEM-related behaviors.

3.2. Participants

The participants in this study were state-level finalists in the 2025 State Science and Engineering Fair (SSEF), which served as the culminating event for a network of 37 affiliated regional science fairs representing all 67 school districts across the state. Students in grades six through twelve advanced through school or local competitions and then succeeded at the regional level to qualify as finalists. 750 students were selected as finalists (325 middle school and 425 high school students) in the SSEF.

All finalists were invited to participate in an online survey distributed via Qualtrics two weeks after the fair. The survey link was sent by the state science fair coordinator to

those finalists for whom email addresses were available. Of the 750 finalists, 166 complete surveys were included in the data analysis. These participants represented a diverse cross-section of the state's student population, providing valuable insights into the outcomes associated with engagement in high-level STEM competitions. Approximately 56.40% of students came from suburban school districts, 24.76% from urban districts, and 18.84% from rural districts.

3.3. Instrument Design

Data were collected through a comprehensive student survey designed to capture a broad range of variables related to science fair participation and its educational impact. The survey consisted primarily of quantitative items administered to both middle and high school students. The variables were organized into four categories: (a) demographic variables, (b) partnership support, (c) motivation variables (see Table 1), and (d) learning outcomes (see Tables 2 and 3).

- **Demographic variables** included grade level, race, and parent or guardian education level, providing background information about the diversity of participants and potential influences on science fair experiences.
- **Motivation variables** were captured through multiple-response items, allowing students to indicate reasons for participation such as class requirements, desire for challenge, pursuit of recognition or awards, enhancement of college or career prospects, passion for a project idea, desire to make a positive impact, and encouragement from teachers or parents. These responses provided insights into intrinsic and extrinsic motivational orientations (see Table 1).
- **Contextual Support** was measured using multiple-choice items asking students to identify sources of assistance, including parents and science research teachers.
- **Learning outcomes** were based on what students reported both pre-fair (retrospective) and post-fair perceptions regarding two core constructs: students' perceived understanding of Science and Engineering Practices (SEPs) (See Table 2) and students' perceived engagement in STEM-related behaviors after school (see Table 3)

Researchers developed SEPs instrument based on eight NGSS-aligned practices (NGSS Lead States, 2013), such as asking questions and defining problems, constructing explanations, and developing evidence-based arguments (See Table 2). Students rated their understanding of these practices on a 4-point scale ranging from 0 ("no understanding") to 3 ("very well understood"). This measurement showed good reliability (Hair et al., 2019) for pre-test (Cronbach $\alpha = 0.87$) and good reliability for post-test in this study (Cronbach $\alpha = 0.81$).

Behavioral engagement in STEM-related activities was measured using an adapted version of the Survey of Science-Related Activities developed by D. Palmer et al. (2017). The original instrument demonstrated strong psychometric properties, including high internal consistency (Cronbach's $\alpha = 0.89$ pre-test; 0.87 immediate post-test; 0.87 delayed post-test) and test–retest reliability ($r = 0.61$, $p < 0.01$). Construct validity was supported through factor analysis and triangulation with an interest inventory and interviews, confirming that the items represent everyday science-related behaviors. For the current study, the instrument was modified to reflect STEM contexts and included 11 items such as "I take an interest in STEM news," "I read articles about STEM discoveries," and "I talk about STEM with friends." Participants rated how often they engaged in each activity on a 4-point scale: 0 = Never or almost never, 1 = A few times a year, 2 = A few times a month, and 3 = Once a week or more. Reliability was assessed using Cronbach's alpha for pre- and post-SSEF responses. The results showed high reliability for pretest (Cronbach's $\alpha = 0.91$) and good reliability posttest (Cronbach's $\alpha = 0.81$) measuring students' engagement in STEM-related activities outside of the classroom.

Table 1. Coding Variables.

Variable	Coding Description
Demographic Variables	
Grade Level	Lower grades (6th–8th) = 1; Upper grades (9th–12th) = 2
Race (dummy coding)	Asian = 1; White = 2
Parent/Guardian Education	Some Colleges or associate degree = 1; college degree = 2 Master's = 3; Doctorate = 4
Course Type	Standard = 0; Advance (AP/IB/AICE) = 1
Motivation Variables	
Intrinsic Motivation	
Passion Project	0 = Did not select; 1 = Selected
Positive Impact	0 = Did not select; 1 = Selected
Challenge Myself	0 = Did not select; 1 = Selected
Extrinsic Motivation	
Class Project Requirement	0 = Did not select; 1 = Selected (reference = Did not select)
Win Prize Recognition	0 = Did not select; 1 = Selected
College/Job Application	0 = Did not select; 1 = Selected
Teacher/Parent Encouragement	0 = Did not select; 1 = Selected
Other	0 = Did not select; 1 = Selected
Contextual Factors	
Parents	0 = Did not select; 1 = Selected
Science Research Teachers	0 = Did not select; 1 = Selected

Note. All predictor variables were coded to facilitate regression analysis. Parent education was treated as an ordinal variable with four levels: High School (1), College (2), Master's (3), and Doctorate (4). Race was dummy coded with Asian (1) and White (2), using "Other" as the reference category (0). All other predictors—including contextual factors such as parents, science research teachers, and the remaining reference categories, were coded as dichotomous variables. The same approach was used for other course requirements and motivational factors (e.g., 'positive impact'), which were treated as dichotomous.

Table 2. Students' Perceived Understanding of SEPs Before and After Participating in SSEF.

Before				Understanding of Science and Engineering Practices	After			
0	1	2	3	Asking Questions and Defining Problems	0	1	2	3
0	1	2	3	Developing and Using Models	0	1	2	3
0	1	2	3	Planning and Carrying Out Investigations	0	1	2	3
0	1	2	3	Analyzing and Interpreting Data	0	1	2	3
0	1	2	3	Using Mathematics and Computational Thinking	0	1	2	3
0	1	2	3	Constructing Explanations and Designing Solutions	0	1	2	3
0	1	2	3	Engaging in Argument from Evidence	0	1	2	3
0	1	2	3	Obtaining, Evaluating, and Communicating Information	0	1	2	3

Note. 0: I do not know how to do it at all. 1: I somewhat know how to do it; 2: I know how to do it; 3: I even know how to evaluate other's practice.

Table 3. Students' Perceived Engagement in STEM-Related Activities Before and After Participating in SSEF.

Before				How Often Do You Do This STEM-Related Activity	After			
0	1	2	3	I take an interest in STEM news.	0	1	2	3
0	1	2	3	I read articles about STEM discoveries.	0	1	2	3
0	1	2	3	I like to understand STEM ideas.	0	1	2	3
0	1	2	3	I talk about STEM with friends.	0	1	2	3
0	1	2	3	I discuss things I learn about STEM with my family.	0	1	2	3
0	1	2	3	I watch STEM shows on television.	0	1	2	3
0	1	2	3	I look up information about STEM on the web.	0	1	2	3
0	1	2	3	I would like to study more STEM-related topics in the future.	0	1	2	3
0	1	2	3	I like to find out about STEM-related issues.	0	1	2	3
0	1	2	3	I like to think about STEM-related problems.	0	1	2	3
0	1	2	3	I would be interested in learning more STEM than my school program requires.	0	1	2	3

Note. 0: never or almost never; 1: a few times a year; 2: A few times a month; 3: Once a week or more.

3.4. Data Analysis

Data were analyzed using a combination of descriptive and inferential statistical techniques to examine changes in students' perceptions of their understanding of SEPs and engagement in STEM-related behaviors, as well as to explore predictors of these changes. Descriptive statistics were first calculated to summarize demographic characteristics and variable distributions. To answer research question 1, paired-samples *t*-tests were then conducted to evaluate students' perceived growth in SEP understanding and STEM engagement before and after participation in the state fair.

To answer research questions 2 and 3, four multiple regression analyses were performed separately for two students' perceived learning outcomes with middle school and high school participants. Predictor variables included motivational orientations and sources of partnership support, and control variables were demographic variables. Because we focused on understanding how the predictor variables were associated with students' perceived changes in their understanding of SEPs and engagement in STEM-related behaviors before and after participating in the science fair, we used the students' perceived change between post-test and pre-test scores as the two dependent variables. Changes were calculated as post-test scores minus pre-test scores (see a full regression equation example in Appendix A). All analyses were conducted using IBM SPSS Statistics (version 29). Assumptions of normality, linearity, and homoscedasticity were checked prior to analysis. Statistical significance was determined at $p < 0.05$.

4. Results

4.1. Descriptive Results

Among the 166 respondents, the largest group identified as White ($n = 68$), followed by Asian or Asian American ($n = 60$), Hispanic or Latino/a/x ($n = 14$), more than one race ($n = 8$), Black or African American ($n = 6$), Middle Eastern or North African ($n = 4$), Others ($n = 1$), and Prefer not to say ($n = 5$). Most students were in 8th grade ($n = 47$), followed by 12th grade ($n = 26$), 11th grade ($n = 26$), 10th grade ($n = 24$), 9th grade ($n = 19$), 7th grade ($n = 13$), and 6th grade ($n = 11$). Table 3 presents the distribution of students' grade levels by race (See Table 4).

Table 4. Distribution of students' grade levels by Race.

Grade Level	Asian or Asian American	Middle Eastern or North African	Black or African American	More than One Race	Hispanic or Latino/a/x	White	Other	Prefer Not to Say	Total
6th	1	1	1	0	1	7	0	0	11
7th	7	0	0	0	3	3	0	0	13
8th	21	0	0	3	4	17	1	1	47
9th	9	1	2	0	2	4	0	1	19
10th	11	1	0	0	0	11	0	1	24
11th	7	1	0	0	3	15	0	0	26
12th	4	0	3	5	1	11	0	2	26
Total	60	4	6	8	14	68	1	5	166

Across the 166 respondents, most parents held a master's degree ($n = 62$), followed by a college degree ($n = 40$), doctoral degree ($n = 39$), some college or associate degree ($n = 16$), high school graduate or GED ($n = 7$), and did not finish high school ($n = 2$). Grade-level distributions were relatively balanced, with the largest number of students reporting their parents' education level in 8th grade ($n = 47$) and the fewest in 6th grade ($n = 11$). Table 4 shows the distribution of students' grade levels by their parents' or guardians' highest education level (See Table 5).

Table 5. Parent Education Level by Student Grade.

Grade Level	Didn't Finish HS	HS Gradate	Som College/Associate	College Graduate	Master's/ Postgrad	Doctoral Degree	Total
6th	0	0	0	3	5	3	11
7th	1	0	0	2	8	2	13
8th	0	3	5	9	20	10	47
9th	0	1	5	5	5	3	19
10th	0	0	2	7	7	8	24
11th	0	1	3	7	10	5	26
12th	1	2	1	7	7	8	26
Total	2	7	16	40	62	39	166

Across the 166 respondents, most students were enrolled in Honors (n = 70) or AP/IB/AICE (n = 68) courses, followed by Standard (n = 10), Pre-AP/Pre-IB/AICE (n = 8), Other (n = 7), and Dual Enrollment (n = 3). Enrollment patterns varied by grade level: lower grades (6th–8th) were primarily in Standard or Honors classes, while upper grades (9th–12th) showed a higher concentration in AP/IB/AICE courses. For example, 11th graders were mostly in AP/IB/AICE courses (n = 24), and 12th graders also predominantly took AP/IB/AICE courses (n = 22). Table 6 presents students' grade levels by the types of science classes they were mostly enrolled in during the current school year (See Table 6).

Table 6. Academic Program Enrollment by Grade Level.

Grade Level	Standard	Honors	AP/IB/AICE	Dual Enrollment	Other	Pre-AP/ Pre-IB/AICE	Total
6th	3	6	0	1	1	0	11
7th	2	10	0	0	1	0	13
8th	4	37	1	0	1	4	47
9th	0	9	6	0	3	1	19
10th	1	4	15	1	1	2	24
11th	0	1	24	0	0	1	26
12th	0	3	22	1	0	0	26
Total	10	70	68	3	7	8	166

4.2. RQ1. To What Extent Do Middle and High School Students' Perceived Understanding of Science and Engineering Practices (SEPs) and Engagement in STEM-Related Activities Outside the Classroom Differ Before and After Participating in a State Science and Engineering Fair?

A paired-sample t-test was conducted to compare high school and middle school students perceived understanding of Science and Engineering Practices (SEPs) before and after participating in the state science and engineering fair. The results for high school students showed a significant increase in their perceived understanding of SEPs from pre-test to post-test. The mean difference was 0.807 (SD = 0.560, 95% CI [0.693, 0.921]), indicating substantial improvement following participation in the fair. This change was statistically significant, t (94) = 14.036, $p < 0.001$ (see Table 7). The effect size was large, with Cohen's d = 1.440.

Table 7. Paired-Sample T-test Results for High School Students' Perceived Understanding of SEPs.

Measure Difference	Mean	SD	SE	95% CI Lower	95% CI Upper	*t*	*df*	*p* (Two-Tailed)
Post—Pre	0.807	0.560	0.057	0.693	0.921	14.036	94	<0.001 ***

Note. *** $p < 0.001$.

The results of the paired-sample *t*-test with middle school students showed that the increase from pre- to post-score in their perceived understanding of SEPs was 0.84 (*SD* = 0.51, 95% CI [0.72, 0.96]), which was statistically significant, *t* (70) = 13.86, $p < 0.001$. The effect size was Cohen's d = 1.645. These indicate that students perceived notably higher levels of understanding after participation in the SSEF (See Table 8).

Table 8. Paired-Sample T-test for Middle School Students' Perceived Understanding of SEPs.

Measure Difference	Mean	SD	SE	95% CI Lower	95% CI Upper	*t*	*df*	*p* (Two-Tailed)
Post—Pre	0.843	0.512	0.061	0.722	0.964	13.86	70	<0.001 ***

Note. *** $p < 0.001$.

The average score of high school students' reported engagement in STEM-related activities outside the classroom increased 0.44 (*SD* = 0.48, 95% CI [0.34, 0.53]) after participating in the state science and engineering fair. This difference was statistically significant, *t* (94) = 8.95, $p < 0.001$ (See Table 9). The effect size was large, with Cohen's d = 1.645. The results suggest that high school students demonstrated a significant increase in self-reported engagement in STEM-related activities after participating in the SSEF.

Table 9. Paired-Sample T-Test for High School Students Perceived Engagement in Stem-Related Activities.

Measure Difference	Mean	SD	SE	95% CI Lower	95% CI Upper	*t*	*df*	*p* (Two-Tailed)
Post—Pre	0.437	0.476	0.049	0.340	0.534	8.951	94	<0.001 ***

Note. *** $p < 0.001$.

Middle school students' results indicated that the post-score increase was 0.60 (*SD* = 0.56, 95% CI [0.47, 0.74]), which was statistically significant, *t* (69) = 9.01, $p < 0.001$. The effect size was Cohen's d = 0.918. These results demonstrated that middle students reported greater engagement in STEM-related activities outside of classroom after participation in the SSEF (See Table 10). In summary, all the results from the pre-post *t*-tests with middle and high school students' outcomes supported Hypothesis 1.

Table 10. Paired-Sample T-Test for Middle School Students' Perceived Engagement in STEM-related Activities.

Measure Difference	Mean	SD	SE	95% CI Lower	95% CI Upper	*t*	*df*	*p* (Two-Tailed)
Post—Pre	0.604	0.561	0.067	0.470	0.737	9.005	69	<0.001 ***

Note. *** $p < 0.001$.

4.3. RQ2. What Motivational and Contextual Factors Are Significantly Associated with the Change in Students' Perceived Understanding of Science and Engineering Practices (SEPs) Before and After Participating in a State Science and Engineering Fair, After Controlling Their Demographic Backgrounds?

The multiple linear regression analysis assessed the relationships between the predictors and change in students' perceptions of their understanding of SEPs following participation in the SSEF. Prior to the multiple linear regression analysis, a reliability test was conducted among the individual predictors, only one variable was statistically significance. Students who indicated they participated in the SSEF because they wanted to make a positive impact by addressing challenges in both their personal life and community

demonstrated a significant positive relationship with change in students' perceptions of their understanding of SEPs (B = 0.314, SE = 0.130, p = 0.018). Among demographic variables, two of parents' education levels were also significant and positive predictors, with students who reported their parents' education level as college degree (B = 0.682, SE = 0.279, p = 0.017, 95% CI [0.202, 1.162]) and as master degree (B = 0.579, SE = 0.285, p = 0.046, 95% CI [0.089, 1.069]) showing increased students' perceived understanding of SEPs. No other predictors or demographic variables were statistically significant. The overall regression model was statistically significant, F (17, 77) = 1.83, p = 0.039, indicating that the predictors collectively accounted for a significant proportion of variance in changes in understanding of SEPs. The model explained approximately 29% of the variance (See Table 11).

Table 11. Multiple Regression Predicting Change in High School Students' Perceived Understanding of SEPs.

Predictor	B	SE B	β	*t*	*p*	95% CI Lower	95% CI Upper
Constant	0.352	0.355	—	0.991	0.325	−0.258	0.962
Demographic Variables							
Race Asian	0.069	0.156	−0.062	−0.445	0.658	−0.337	0.198
Race White	0.223	0.158	−0.188	−1.410	0.163	−0.494	0.049
Parent Edu: Master	0.579	0.285	0.479	2.031	0.046 *	0.089	1.069
Parent Edu: Doctorate	0.341	0.284	0.266	1.202	0.233	−0.146	0.829
Course Type	0.013	0.133	−0.011	−0.097	0.923	−0.241	0.216
Motivation Variables							
Class Project Requirement	0.018	0.135	0.014	0.133	0.895	−0.215	0.251
Challenge Myself	0.140	0.124	0.119	1.129	0.263	−0.073	0.352
Win Prize/Recognition	0.124	0.140	−0.111	−0.884	0.379	−0.365	0.117
College/Job Apps	0.153	0.144	−0.131	−1.058	0.293	−0.401	0.095
Passion Project	0.016	0.135	−0.013	−0.115	0.909	−0.248	0.217
Positive Impact	0.314	0.130	0.282	2.416	0.018 *	0.091	0.538
Teacher/Parent Encouragement	0.091	0.137	−0.072	−0.661	0.511	−0.326	0.145
Contextual Factors							
Support: Parent	0.045	0.137	0.036	0.326	0.745	−0.190	0.280
Support: Research Science Teacher	0.062	0.144	0.049	0.431	0.667	−0.186	0.310

Note. * $p < 0.05$.

Another multiple linear regression was conducted to examine the associations between predictors, demographic variables, and the change in middle school students' perceived understanding of SEPs. The model indicated that two motivation predictors were significant. Notably, students who reported participating in the SSEF to win a prize or earn recognition demonstrated a significant negative association with change in their SEP understanding (B = −0.329, SE = 0.141, p = 0.024, 95% CI [−0.612, −0.046]). Conversely, students indicating that they participated to "make a positive impact in addressing challenges in their personal life and community" was a significant positive predictor (B = 0.313, SE = 0.142, p = 0.032, 95% CI [0.028, 0.598]). The overall model was not statistically significant, F (17, 53) = 1.452, p = 0.151, with an R^2 = 0.318 and adjusted R^2 = 0.099, indicating that the predictors explained approximately 32% of the variance in the outcome. Other predictors or demographic variables were not significant (See Table 12).

Table 12. Multiple Regression Predicting Change in Middle school Students' Perceived Understanding of SEPs.

Predictor	B	SE B	β	*t*	*p*	95% CI Lower	95% CI Upper
Constant	1.300	0.417	—	3.116	0.003	0.463	2.137
Demographic Variables							
Ethnicity Asian	0.168	0.192	−0.163	−0.878	0.384	−0.553	0.216
Ethnicity White	0.195	0.178	−0.186	−1.097	0.277	−0.552	0.162
College Education Degree = 2	0.577	0.290	−0.451	−1.989	0.059	−1.159	0.005
Master Education = 3	0.352	0.267	−0.345	−1.319	0.193	−0.888	0.183
Doctoral education = 4	0.464	0.286	−0.372	−1.625	0.110	−1.037	0.109
Course Type	0.082	0.147	−0.070	−0.557	0.580	−0.376	0.213
Motivation Variables							
Class Project	0.030	0.156	−0.028	−0.195	0.846	−0.344	0.283
Challenge Myself	0.083	0.135	0.082	0.616	0.540	−0.187	0.354
Win Prize/Recognition	0.329	0.141	−0.318	−2.332	0.024 *	−0.612	−0.046
Teacher/Parent Encouragement	0.187	0.135	0.177	1.382	0.173	−0.084	0.457
College/Job Apps	0.053	0.148	−0.050	−0.356	0.723	−0.349	0.244
Passion Project	0.192	0.146	−0.180	−1.311	0.196	−0.486	0.102
Other Reasons	0.080	0.321	0.032	0.248	0.805	−0.564	0.724
Positive Impact	0.313	0.142	0.307	2.203	0.032	0.028	0.598
Contextual Factors							
Parental Support = 1	0.221	0.164	0.217	1.351	0.183	−0.107	0.549
Research Science Teacher Support = 2	0.316	0.197	0.260	1.604	0.115	−0.079	0.712

Note. * $p < 0.05$.

4.4. RQ3. What Motivational and Contextual Factors Are Significantly Associated with the Change in Students' Perceived Engagement in STEM-Related Activities Outside the Classroom Before and After Participating in a State Science and Engineering Fair, After Controlling Their Demographic Backgrounds?

A multiple linear regression was conducted to examine the associations between predictors, demographic variables, and changes in high school students' perceived engagement in STEM-related activities outside of the classroom. High school students who reported participating in the SSEF because they wanted to challenge themselves and try something new demonstrated a significant positive relationship with increased SEP engagement ($B = 0.282$, $SE = 0.108$, $p = 0.011$, 95% CI [0.096, 0.468]). Conversely, those who participated to win a prize or earn recognition showed a significant negative relationship ($B = -0.259$, $SE = 0.123$, $p = 0.038$, 95% CI [−0.470, −0.048]). Additionally, students who reported being encouraged by a teacher or parent to participate in the fair was also negatively associated with increased students' perceived engagement in STEM-related activities outside of the classroom ($B = -0.283$, $SE = 0.120$, $p = 0.021$, 95% CI [−0.489, −0.077]). The overall regression model predicting change in perceived STEM-related engagement was not statistically significant, F (17, 52) = 0.828, $p = 0.655$, $R^2 = 0.213$, adjusted $R^2 = -0.044$, indicating that the predictors accounted for approximately 21%. All other predictors or demographic variables were not statistically significant ($p > 0.10$) (See Table 13).

For middle school students, the overall multiple regression model was not statistically significant. overall model was not statistically significant, F (17, 52) = 0.828, $p = 0.655$, with $R^2 = 0.213$ and adjusted $R^2 = -0.044$, indicating that the predictors explained approximately 21% of the variance. (See Table 14).

Table 13. Multiple Regression Predicting Change in High School Students' Perceived Engagement in STEM-Related Activities Outside of The Classroom.

Predictor	B	B	SE B	β	*t*	*p*	95% CI Lower	95% CI Upper
Constant	0.002	0.311	0.311	—	0.005	0.996	−0.532	0.535
Demographic Variables								
Ethnicity: Asian	0.108	0.136	0.136	0.113	0.795	0.429	−0.126	0.343
Ethnicity: White	0.071	0.138	0.138	−0.070	−0.510	0.612	−0.308	0.167
Parent Edu: College	0.313	0.245	0.245	0.295	1.281	0.204	−0.107	0.734
Parent Edu: Master	0.256	0.250	0.250	0.250	1.027	0.308	−0.172	0.685
Parent Edu: Doctorate	0.225	0.249	0.249	0.206	0.904	0.369	−0.202	0.651
Course Type	0.036	0.117	0.117	0.035	0.308	0.759	−0.236	0.164
Motivation Factors								
Class Project Requirement	0.046	0.119	0.119	0.041	0.388	0.699	−0.158	0.250
Challenge Myself	0.282	0.108	0.108	0.284	2.605	0.011 *	0.096	0.468
Win Prize/Recognition	0.259	0.123	0.123	0.273	2.112	0.038 *	−0.470	−0.048
College/Job Apps	0.170	0.126	0.126	0.171	1.342	0.184	−0.047	0.387
Passion Project	0.025	0.118	0.118	0.025	0.212	0.832	−0.228	0.178
Positive Impact	0.060	0.114	0.114	0.063	0.526	0.600	−0.136	0.256
Teacher/Parent Encouragement	0.283	0.120	0.120	0.266	2.358	0.021 *	−0.489	−0.077
Other Reason	0.012	0.517	0.517	0.003	0.024	0.981	−0.875	0.899
Contextual Factors								
Support: Research Science Teacher	0.189	0.126	0.126	0.173	1.493	0.140	−0.028	0.406
Support: Parent	0.159	0.120	0.120	0.150	1.327	0.188	−0.047	0.365

Note. * $p < 0.05$.

Table 14. Multiple Regression Predicting Change in Middle School Students' Perceived Engagement in STEM-Related Activities Outside of the Classroom.

Predictor	B	SE B	β	*t*	*p*	95% CI Lower	95% CI Upper
Constant	0.295	0.513	—	0.574	0.568	−0.735	1.325
Demographic Variables							
Ethnicity: Asian	0.049	0.236	−0.043	−0.206	0.838	−0.522	0.425
Ethnicity: White	0.121	0.219	−0.106	−0.554	0.582	−0.561	0.318
Parent Edu: College	0.101	0.357	−0.072	−0.284	0.778	−0.818	0.615
Parent Edu: Master	0.121	0.329	0.109	0.370	0.713	−0.538	0.781
Parent Edu: Doctorate	0.058	0.351	0.043	0.166	0.869	−0.647	0.763
Course Type	0.183	0.181	0.142	1.010	0.317	−0.180	0.545
Motivation Factors							
Class Project Requirement	0.171	0.192	0.144	0.891	0.377	−0.214	0.557
Challenge Myself	0.096	0.166	0.086	0.579	0.565	−0.237	0.429
Win Prize/Recognition	0.227	0.174	−0.201	−1.310	0.196	−0.576	0.121
College/Job Apps	0.163	0.182	−0.141	−0.898	0.374	−0.528	0.202
Passion Project	0.076	0.180	−0.065	−0.420	0.676	−0.437	0.286
Positive Impact	0.024	0.175	0.022	0.139	0.890	−0.327	0.375
Teacher/Parent Encouragement	0.140	0.166	0.121	0.844	0.402	−0.193	0.474
Other Reason	0.125	0.395	−0.045	−0.317	0.753	−0.918	0.668
Contextual Factors							
Support: Teacher	0.129	0.201	0.116	0.641	0.524	−0.275	0.533
Support: Parent	0.221	0.243	0.166	0.912	0.366	−0.266	0.708

In summary, Hypotheses 2 and 3 were partially supported. High school students' perceived gains in both learning outcomes were positively associated with two intrinsic motivation variables, self-challenge, and community-based motivations and negatively associated with an extrinsic motivation factor, teacher- or parent-initiated participation. In contrast, different comparable patterns emerged for middle and high school students (see Table 15). However, none of contextual factors that were included in the regression models were significantly associated with the two self-reported learning outcomes.

Table 15. Summarizing All Significant Variables for High School and Middle School Students' Perceived Learning Outcomes.

Grade Level	Dependent Variable	Predictor	Direction of Association	*p* Value
High School	ΔSEP Understanding	Parent education (college degree)	Positive	0.017
High School	ΔSEP Understanding	Parent education (master's degree)	Positive	0.046
High School	ΔSEP Understanding	"I want make a positive impact by addressing challenges in both my personal life and my community"	Positive	0.018
Middle School	ΔSEP Understanding	"Win a prize or earn recognition"	Negative	0.024
Middle School	ΔSEP Understanding	"I want make a positive impact by addressing challenges in both my personal life and my community"	Positive	0.032
High School	ΔSTEM-related	"I wanted to challenge myself and try something new"	Positive	0.011
High School	ΔSTEM-related Behaviors	"Win a prize or earn recognition"	Negative	0.038
High School	ΔSTEM-related Behaviors	"My teacher or parents encouraged me to participate"	Negative	0.021

5. Limitations

This quantitative exploratory study employs purposive sampling and offers valuable insights into how motivational factors and student background characteristics are associated with students' understanding of Science and Engineering Practices (SEPs) and engagement in STEM-related activities through participation in science fairs. However, several significant limitations should be considered before discussing these results.

First, this study focused on a state-level science fair finalists in grades six through twelve. A particularly significant limitation involves incomplete survey responses. This may reduce sample size and have introduced nonresponses bias, as students who did not complete the survey may differ systematically from those who did. Additionally, the resulting sample was disproportionately White and Asian, included more high school students than middle school students, and most respondents were enrolled in advanced coursework. These patterns reflect the structure of advanced science fairs, which often favor students with greater access to resources and advanced classes (Grinnell et al., 2022). As a result, the findings may not be generalizable to the broader student population. Instead, the results should be interpreted within the context of students who voluntarily participate in science and engineering fairs.

Second, the study relied on a retrospective self-report design. While this approach was chosen to reduce response-shift bias (Little et al., 2020), it introduces potential recall bias because participants estimated prior knowledge after the intervention rather than reporting it at the actual pretest. Additionally, self-report measures are inherently vulnerable to social desirability bias, which could lead participants to overstate positive outcomes.

Third, another limitation of this study concerns the measurement of students' understanding of the NGSS Science and Engineering Practices (SEPs). The survey relied on students' self-reported perceptions of their understanding of each SEP rather than direct assessments of their performance. In addition, the practices were presented by their titles (e.g., "developing and using models," "analyzing and interpreting data"), which may have been interpreted differently by students depending on their prior experience and grade level. As a result, the findings should be interpreted as reflecting students' perceived understanding of the SEPs rather than measures of SEP competence.

Fourth, the cross-sectional design limits causal inference. While associations between motivational factors and outcomes are evident, it cannot determine whether certain motivations cause higher SEP learning or whether students already high in intrinsic motivation simply engage more deeply.

6. Discussion

Despite the limitations acknowledged earlier, this exploratory study advances the field by providing empirical evidence of two key learning outcomes, students' perceived understanding of SEPs and their perceived engagement in STEM-related behaviors, within the context of a state-level science and engineering fair across both middle and high school settings. It also provides initial insights into how SDT-aligned motivational and contextual factors are associated with these outcomes across middle and high school contexts.

6.1. Two Learning Outcomes Through a State-Level Science and Engineering Fair

To answer research question 1, both middle and high school participants demonstrated significant gains in their perceived understanding of SEPs and their engagement in STEM-related behaviors outside the classroom. These results provide empirical support for conceptual assumptions that science fairs can function as meaningful learning resources that enhance students' cognitive and affective outcomes (Martín-García & Dies Alvarez, 2022) as students learn science through authentic scientific inquiry (Bransford et al., 2000). These results are also consistent with prior research showing that authentic inquiry experiences inherent in science fairs can deepen students' understanding of the inquiry process and specific SEPs through authentic hand-on experiences (Schmidt & Kelter, 2017) and can also promote the transfer of situational interest (Hidi & Renninger, 2006; D. Palmer et al., 2017) toward sustained engagement in STEM-related activities beyond the classroom. Collectively, the results extend previous work that has focused primarily on general STEM interest (e.g., Grinnell et al., 2020, 2021, 2022) by demonstrating gains in specific, behaviorally grounded indicators of STEM engagement as well as cognitive understanding of SEPs. Moreover, these outcomes reinforce the NGSS vision that engaging students in SEPs is essential for helping them understand how scientific and engineering knowledge is developed and for fostering long-term interest in STEM careers (NGSS Lead States, 2013). This vision could be supported through an informal science education context, such as science fairs, in addition to formal science classrooms.

6.2. Factors Influencing Students' Perceived Understanding of Science and Engineering Practices (SEPs)

As for research question 2, meaningful insights also emerged from examining how different motivational and contextual factors were associated with students' perceived growth in their understanding of SEPs. A particularly noteworthy result was the significant positive relationship between an intrinsic motivational variable, "I wanted to make a positive impact by addressing challenges in my life or community", and students' growth in their perceived understanding of SEP among both middle and high school contexts. This pattern not only partially supports our Hypothesis 2 but also strongly aligns with

Self-Determination Theory (SDT), as working on a community-oriented project and successfully addressing a meaningful problem through the science fair can satisfy all three psychological needs, including autonomy (choosing and directing their project focus), competence (feeling effective in solving a real challenge), and relatedness (contributing to one's community). When these needs are supported, students are more likely to exhibit autonomous motivation, which in turn fosters deeper engagement with inquiry processes and stronger gains in SEP understanding. This finding extends the work of Schmidt and Kelter (2017), who identified improvements in inquiry skills through qualitative analysis but did not explicitly examine the motivational factors underlying SEP learning. By identifying a community-aligned motivational factor, this study provides quantitative evidence that students' motivations can support their cognitive development specifically in students' perceived understanding of SEPs while they are engaged in scientific inquiry within science fair contexts.

In addition, the distinct extrinsic motivation variable "I wanted to win a prize or earn recognition" was negatively associated with middle school students' perceived growth in their understanding of SEPs, which partially supports Hypothesis 2. Although SDT assumes that extrinsic rewards can function as either controlling or informational forms of support (Deci et al., 1999), performance-contingent rewards, those tied directly to evaluations of performance, often carry a controlling meaning. Such rewards can undermine students' perceived competence and shift their focus from learning to external evaluation, thereby inhibiting behaviors that lead to positive learning outcomes (Ryan & Deci, 2020). This result echoes the qualitative findings based on previous study's interview data (Schmidt & Kelter, 2017), where some middle school participants reported stress and negative emotions due to the competition pressure experiences of science fair.

When examining students' background control variables, the results revealed divergent patterns of parental influence on learning outcomes across grade levels. From an SDT perspective, this pattern may reflect differences in access to competence-enhancing resources at home, such as academic guidance, structured problem-solving strategies, and exposure to scientific reasoning practices. These forms of support may strengthen students' perceived competence and relatedness, thereby fostering deeper engagement in scientific inquiry and supporting SEP-specific cognitive development. The result is consistent with prior research highlighting the influence of parental education on students' STEM learning experiences (Fields et al., 2022). Interestingly, having parents with doctoral-level degrees was not significantly associated with students' perceived growth in their understanding of SEPs. This pattern suggests that parents' high education level might not automatically translate into positive science and engineering learning outcomes. Effective parental support needs to align with three needs in SDT, especially autonomy for high school students. Excessive parental involvement or over-guidance may inadvertently undermine students' perceived autonomy, thereby limiting opportunities for authentic inquiry learning (Bradshaw et al., 2025). In the context of science fair participation, this may require parents to strike a balance between providing appropriate structure and guidance while preserving students' ownership and autonomy over their inquiry processes. In contrast, no significant relationship was observed between parental education level and middle school students' perceived SEPs growth. One possible explanation is that students from higher-education households may have entered the science fair with relatively higher baseline in their perceived understanding of SEPs, leaving less room for measurable growth over time.

Finally, although growing literature on K-12 STEM fairs shows that contextual factors such as parents, teachers and peers also play a crucial role in shaping students' science fair experiences (DeLisi et al., 2021), our regression analyses did not identify significant associa-

tions between these support factors and students' perceived gains in SEP understanding among both middle and high school participants. The component of Hypothesis 2 concerning the influence of contextual factors on students' gain in their understanding of SEPs is not supported in this study. Although the SDT framework emphasizes the importance of contextual support for students' experiences of autonomy, competence, and relatedness, this relationship was not observed empirically. This may be because the available measures were not sufficiently sensitive to capture the levels, types, or quality of support students received from key social agents (e.g., parents, teachers, or other partnerships) during their science fair projects. This possible interpretation is also consistent with prior research (DeLisi et al., 2021), in which teachers' scaffolding varies substantially across school contexts, and only certain forms of support (e.g., explicit inquiry scaffolding or peers' structured critique) directly influence SEP learning.

6.3. Factors Influencing Students' Perceived Engagement in STEM-Related Behaviors Outside the Classroom

For research question 3, across middle and high school participants, distinct motivational patterns emerged in predicting students' perceived increases in out-of-school STEM-related behaviors. For high school students, the intrinsic motivational factor "I wanted to challenge myself and try something new" emerged as the only positive predictor of students' perceived growth in STEM-related behaviors, whereas "My teacher or parent encouraging me to participate" was associated with lower gains. This pattern partially supports our Hypothesis 3 for high school students since contextual support factors' influence on perceived engagement in STEM-related activities outside the classroom is not supported in this study. Interpreted through SDT, these results suggest that autonomously regulated and self-endorsed motivation reflecting students' intrinsic motivation and desire for competence development may be particularly important for sustaining behavioral engagement in science fair contexts at the high school level. This interpretation aligns with prior research indicating that autonomy and self-directed choice play a critical role in enhancing high school students' engagement in science fairs (Grinnell et al., 2020). In contrast, encouragement from teachers or parents may function as a more externally regulated form of motivation when it is perceived as pressure rather than support, potentially undermining students' sense of autonomy and dampening their perceived relevance and ownership. This result is also reflected in prior research documenting adverse influence of externally mandated participation (Grinnell et al., 2022) and perceived tension and pressure from parents (Kim & Simpson, 2024).

However, neither of these motivational factors significantly predicted middle school students' perceived changes in STEM-related behaviors in this study. This null finding may be partly attributable to sampling limitations, including the smaller middle school subsample, which did not support a well-fitting regression model. Beyond methodological considerations, the absence of these relationships may also reflect developmental differences in motivational processes between middle school and high school students (Archer et al., 2013). SDT posits that motivational regulation develops alongside cognitive maturation (Ryan & Deci, 2000). As students grow older, they are increasingly able to assimilate values and behaviors into their sense of self, resulting in a gradual shift from externally regulated motivation toward more internalized and autonomous forms. This developmental progression suggests that younger adolescents may rely more on external structure and situational cues, whereas older students are more likely to engage in learning activities for self-endorsed reasons. As a result, motivational factors associated with perceived changes in STEM-related behaviors among high school students may not yet operate in the same way for middle school students. Similarly, situational interest research suggests that middle school students' engagement is often driven by context-specific features such as novelty,

social interaction, and instructional structure rather than enduring individual motivation (Hidi & Renninger, 2006; Renninger & Hidi, 2011). In this case, situational interest developed through science fair might function as an entry point for middle school students by generating positive feelings and engagement in the moment. However, it might not be sufficient for more developed and enduring interest without continuing development in knowledge and motivations. Absence of strong relationships between certain motivational factors and longer-term outcomes (e.g., repeated engagement or STEM-related behaviors) may indicate that students, especially at earlier developmental stages, had not yet internalized the value of participation or built sufficient domain knowledge to support deeper interest development (Hidi & Renninger, 2006).

All the regression models of high school and middle school students only explained a modest variance of the two outcomes. These reflect the complexity of student learning within the context of science fairs, where numerous unmeasured factors beyond the fair's features may influence outcomes. The study included important contextual support factors in the regression models based on theoretical framework and literature review but does not fully capture quality and type of support, such as specific forms of interactions between students with teachers, parents, and other partnerships. As a result, the analysis cannot fully determine if students' needs of autonomy, competence, and relatedness were met based on the SDT.

7. Implications

Overall, this exploratory study reveals that science fairs can function as meaningful learning contexts that support students' STEM learning through the development of SEPs and engagement in STEM-related behaviors, while also highlighting important developmental differences in how motivation and contextual factors relate to learning across grade levels. By articulating implications for theory, policy, practice, and future research, the study helps position science fairs as more student-centered, developmentally responsive, and equitable experiences in informal secondary-level STEM education.

7.1. Theoretical Contributions

Findings from this study advance theoretical understanding of motivation and inquiry learning in the context of science fairs by extending Self-Determination Theory (SDT) within authentic informal K–12 STEM learning environments. The positive association between purpose-driven intrinsic motivation (e.g., "I wanted to make a positive impact by addressing challenges in my life or community") and gains in students' perceived understanding of SEPs reinforces SDT by illustrating how community-oriented, authentic inquiry projects can simultaneously support students' needs for autonomy, competence, and relatedness. In doing so, this study clarifies how specific intrinsic motivational orientations, beyond general interest, contribute to deeper engagement in disciplinary practices during science fair participation.

Importantly, the distinct motivational patterns observed between middle and high school students, particularly in relation to STEM-related behaviors, highlight meaningful developmental variation in how autonomy and external pressures shape learning outcomes. These findings suggest that intrinsic motivation may function differently across grade levels, with older students demonstrating greater internalization of purpose-driven motives that translate into sustained STEM-related behaviors. As such, this study suggests that SDT applications in K–12 STEM contexts would benefit from more explicit attention to developmental nuance, particularly regarding how motivational regulation evolves and supports long-term engagement.

7.2. Implications for Research

Findings from this study point to several directions for future research. To build on the current results, future studies may benefit from incorporating multiple sources of evidence, such as performance-based assessments, rubric-guided observations, interviews, or portfolio analyses to complement self-reported measures of SEP learning and STEM-related behaviors. Longitudinal designs could further examine whether observed gains in students' perceived SEP understanding and behaviors engagement persist over time, while experimental or quasi-experimental approaches may help clarify the nature of the relationships identified in this study. In addition, because students may interpret the SEPs differently depending on their prior experiences and grade levels, future research may improve the assessment of SEPs by developing instruments that include behavior-based or descriptive items aligned with each practice, rather than relying solely on the eight practice titles. Qualitative approaches, such as interviews, observations, and student reflections, could also provide deeper insights into how students understand and apply practices such as developing and using models or constructing explanations during their projects.

Although contextual support factors are conceptually embedded within SDT, the present study did not find empirical support for hypotheses related to these factors, likely due to limitations in the scope of survey measures. This gap points to an important direction for future research, which is examining more specific and developmentally sensitive features of contextual support, such as teachers' scaffolding, mentorship from partnerships, and feedback (DeLisi et al., 2021; Schmidt & Kelter, 2017). Through multilevel modeling, future studies can help better understand how these supports interact with motivation to influence students' cognitive and affective learning outcomes in science fairs and other informal inquiry-based STEM settings.

In addition, qualitative approaches involving students and parents may provide insight into how parents with different educational levels involve students' decision making (e.g., participating in the science fair) and how they interact with students' motivations during science fair participation. Finally, comparative studies across districts, states, or national science fairs could help determine the extent to which the patterns observed here generalize across settings and identify program design features associated with stronger support for SEP learning and sustained STEM-related engagement.

7.3. Policy Implications

Demographic patterns in this study indicate an overrepresentation of Asian, White, and advanced-course students, reflecting persistent equity concerns documented in the science fair literature (Grinnell et al., 2021, 2022). Participation in advanced-level fairs often depends on access to mentorship, research resources, family support, and school-based infrastructure resources that are unevenly distributed across racial and socioeconomic groups. As a result, state-level science fairs may disproportionately benefit students who are already advantaged within the STEM pipeline. To address these inequities, policymakers should consider investing in school-level science fair support programs and targeted teacher professional learning for schools serving historically marginalized communities. In addition, incentivizing outreach partnerships among schools, districts, universities, and community organizations could expand access to consistent mentorship, research facilities, and inquiry resources, particularly for students whose families lack STEM-related expertise. Finally, the development of equity-focused science fair participation guidelines, such as resource-sharing models and inclusive design features, could help broaden participation and promote more equitable learning opportunities. Policies oriented towards equitable access can help ensure that science fairs function as powerful learning resources for all students, rather than reinforcing existing structural advantages.

7.4. Implications for Practice

Results of this study suggest several considerations for educators and science fair organizers interested in supporting student learning through science fairs. For educators, the findings underscore the importance of designing classroom-embedded science fair experiences that emphasize purpose-driven inquiry and developmental appropriateness. Consistent with the positive associations between community-oriented motivation and gains in SEP understanding for both middle and high school students, teachers can support deeper engagement by encouraging students to pursue projects connected to real-world or community-relevant problems.

Because students' motivational orientations were associated with STEM-related learning outcomes in different ways for middle and high school students, the findings suggest the need for developmentally responsive instructional supports during science fair inquiry. For high school students, providing meaningful opportunities to challenge themselves through innovative and self-directed projects appears particularly important for fostering STEM-related behavioral engagement. Teachers can support this engagement by offering greater autonomy throughout the inquiry process, including allowing students to develop their own research questions, select methods, and determine project direction. At the same time, teachers can maintain an autonomy-supportive role by offering guidance, feedback, and resources without undermining students' sense of ownership or independence. In contrast, middle school students may benefit more from structured instructional scaffolds during science fair participation. For these students, teachers may need to provide clearer procedural guidance, modeling of scientific practices, and regular checkpoints to support students' developing competence. As students gain experience, these supports can gradually fade to promote self-regulation and the internalization of motivation, thereby supporting the transfer of situational interest during science fairs into more sustained STEM-related behaviors over time.

For science fair organizers, these findings highlight the importance of intentionally designing fair structures, mentoring systems, and recognition practices to support students' learning. The results of this study indicate that performance-contingent and award-oriented motivations were not associated with positive learning outcomes and, in some cases, were linked to less favorable patterns of engagement. This suggests that organizers may benefit from de-emphasizing competitive ranking and final awards in favor of mastery-oriented forms of recognition, such as providing feedback on students' development of SEPs, emphasizing process-based judging criteria that focus on SEPs, and incorporating structured opportunities for students to reflect on their learning. Designing science fairs that focus on learning, growth, and authentic inquiry rather than competition alone may better align with students' motivational needs based on SDT and more effectively support both meaningful SEP learning and sustained STEM-related engagement across grade levels.

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Appendix A

$$\Delta SEP = \beta_0 + \beta_1(\text{Parented: College}) + \beta_2(\text{ParentEdu:Master}) + \beta_3(\text{ParentEdu:Doctorate}) + \beta_4(\text{CourseType}) + \beta_5(\text{Race:Asian}) + \beta_6(\text{Race:White}) + \beta_7(\text{ClassProjectRequirement}) + \beta_8(\text{ChallengeMyself}) + \beta_9(\text{WinPrize}) + \beta_{10}(\text{CollegeJobApps}) + \beta_{11}(\text{PassionProject}) + \beta_{12}(\text{PositiveImpact}) + \beta_{13}(\text{TeacherParentEncouragement}) + \beta_{14}(\text{OtherReason}) + \beta_{15}(\text{Support: ScienceResearchTeacher}) + \beta_{16}(\text{Support:Parent}) + \varepsilon \quad \text{(A1)}$$

- ΔSEP = Change in students' SEP understanding (post-test minus pre-test scores).
- β_0 = Intercept; β_1–β_{16} = Regression coefficients for each predictor; ε = error term.

Note. Regression coefficients indicate the predicted change in understanding of SEPs to the reference category for each variable, holding all other variables constant.

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