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Impact of Social-Emotional Learning Strategies in K-12 Science Classrooms: A Meta-Synthesis of Contemporary Research

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Abstract

Social and emotional competencies, such as self-awareness, self-regulation, and interpersonal skills, are vital. Previous studies have highlighted their importance for education. Consequently, studies on social-emotional learning (SEL) and science education are increasing, although still limited. The small-scale view of many studies has thus far limited our understanding of the broader impact. This study explored that impact by synthesizing smaller studies through a meta-synthesis approach. A comprehensive review of literature published between 2013 and 2023 identified 33 studies meeting the inclusion criteria for a thematic meta-synthesis. The meta-synthesis evaluates findings, providing a deeper understanding of how SEL can be integrated into science curricula, its impact on student outcomes, and evolving trends in the field. Findings show that integrating SEL into K-12 science education enhances students' self-efficacy, emotional well-being, metacognitive skills, learning engagement, and learning environment. A positive classroom environment improved comprehension and outcomes, promoting a deeper understanding of scientific concepts. These findings highlight SEL's importance in fostering a supportive learning atmosphere that encourages growth and academic success in science education, showing how emotions affect learning and how learning science generates various emotions in students. The results are discussed to create a more significant impact on K-12 science education by utilizing SEL strategies.

Introduction

SEL strategies focus on developing students' self-awareness, emotional regulation, and interpersonal abilities. In general, SEL strategies foster the capacity to grasp and express emotions suitably, demonstrate empathetic responses to others, and engage in responsible decision-making (*Advancing Social and Emotional Learning - CASEL*, n.d.) (O'Conner et al., 2017). Addressing these competencies is crucial for students' academic engagement and performance, as improved social adjustment in children is linked to higher learning engagement, better school performance (Denham et al., 2012), and reduced risks of conduct problems, substance abuse, and juvenile delinquency (Moffitt et al., 2011). In science education, expecting students to rely solely on rational thinking and ignore their emotions is unrealistic. Emotions consistently influence learning outcomes, whether related to the subject matter, specific topics, or the learning environment (Broughton et al., 2013) (Goetz et al.,

2006). Emotions like test anxiety or sadness about species extinction are ever-present in STEM classrooms. Since emotions also play a critical role in decision-making (Immordino-Yang & Damasio, 2007), addressing them is essential.

There is extensive research on SEL in general K-12 education. Although the number of research studies specifically focused on the impact of SEL within K-12 science instruction is growing, the work is still limited, and much of the work is narrowly focused on a small number of students. The time is right to enhance this growing field by collectively looking at the findings from these smaller studies in a manner that allows us to understand the broader impacts of SEL strategies in K-12 science education. This study aimed to identify the broader impact of SEL approaches in K -12 science education by utilizing the findings from a growing body of research. The question guiding this study was: What is the impact of SEL approaches in K-12 science classrooms?

Theoretical Underpinning of SEL

SEL is a vital aspect of education and personal growth. It enables individuals, both young and adult, to develop healthy identities, manage emotions, build empathy, maintain positive relationships, achieve goals, and make responsible, caring decisions. It encompasses a wide range of skills related to social, emotional, and behavioral development in children. It is broadly categorized into three key components: emotional processes, social and interpersonal skills, and cognitive regulation (Jones & Bouffard, 2012). SEL involves a deliberate approach to teaching students essential skills for understanding and managing emotions, demonstrating empathy, building positive relationships, and making responsible decisions (Zins et al., 2004) (Meyers et al., 2019). Empirical evidence indicates that SEL not only fosters social and emotional growth, enhances well-being, and improves academic performance but also mitigates and prevents mental health and behavioral challenges (Durlak et al., 2011) (Sklad et al., 2012).

CASEL's framework emphasizes the importance of a systematic approach to SEL. This framework outlines five core competencies that span the cognitive, affective, and behavioral domains: self-awareness, self-management, social awareness, relationship skills, and responsible decision-making (Weissberg et al., 2015).*Self-awareness* refers to the ability to recognize one's emotions, goals, and values. It involves understanding personal strengths and limitations, fostering a positive mindset, and developing a strong sense of self-efficacy. Additionally, self-awareness includes recognizing the connections between thoughts, feelings, and behaviors. *Self-management* refers to the ability to control feelings and actions efficiently. It involves handling pressure, resisting urges, postponing immediate rewards, and showing determination to navigate obstacles and reach individual or educational objectives. *Social awareness* includes the capacity to relate to others and appreciate their viewpoints, especially those from varied cultural and societal contexts. It also entails acknowledging societal expectations and locating external networks and assistance available through home, educational, and local environments.
Relationship skills involve forming and maintaining healthy, meaningful relationships through clear communication, active listening, cooperation, and conflict resolution. This competency also includes resisting inappropriate social pressures and seeking or offering help when necessary. *Responsible decision-making* involves the capacity to make thoughtful and positive judgments about one's actions and relationships. It necessitates

evaluating moral principles, societal expectations, possible outcomes, and the welfare of both oneself and those around them. Mastery of these five competencies serves as the foundation for positive attitudinal and behavioral outcomes, both in the short and long term. Furthermore, these competencies are reinforced by implementing a systematic, schoolwide SEL approach that addresses the various contexts and relationships shaping students' lives and learning environments (Weissberg et al., 2015).

The Need or Importance of Social and Emotional Learning in Education

What is the true purpose of education? Fundamentally, what do children need from their education to navigate the challenges of daily life and achieve long-term success? While academic achievement often takes center stage, the origins of the American public school system reveal a broader intent. The nation's founders envisioned schools as institutions that would cultivate not only academic skills but also the qualities necessary for active participation in a democratic society. They aspired to produce independent, critical thinkers capable of collaboration and contribution to the greater good.

To achieve this vision, children need more than proficiency in reading, writing, and arithmetic. They must also develop the skills to set personal goals, work effectively with others, and cope with setbacks and challenges. As we will discuss further, SEL interventions offer students the opportunity to acquire these essential life skills, fostering well-rounded development. Education, therefore, should be recognized as a platform for nurturing a wide range of cognitive, personal, and social competencies. Schools have a responsibility not only to enhance students' academic abilities but also to support their overall well-being (Greenberg et al., 2017).

In today's world, Americans largely agree that schools must go beyond academic instruction to prepare students for success in college, careers, and communities. Over the last century, children's life circumstances have changed significantly (Weissberg et al., 2003). Families now face heightened social and economic pressures, and schools and communities have become increasingly diverse, both culturally and linguistically. Moreover, children are growing up in a complex, fast-paced world shaped by pervasive media influences and constant access to information and social networks through technology.

These societal shifts, coupled with the transition from a manufacturing-based economy to an information-driven one, underscore the need for new priorities in education. Students must learn to manage stress, build positive relationships, and collaborate in group settings, skills commonly referred to as 21st-century competencies. These abilities are not only vital for thriving in adulthood but also form the foundation for personal and career achievement in a constantly evolving and highly interconnected global environment (Council et al., 2012).

Furthermore, evidence suggests that SEL can reduce issues like depression and anxiety (Durlak et al., 2011), while stronger emotional and social abilities during early years are linked to improved psychological well-being and other beneficial outcomes later in life. According to Durlak et al. (2011), comprehensive, school-wide SEL initiatives showed a moderate impact (0.57) on enhancing youth's interpersonal and emotional capabilities. The primary objectives of SEL include addressing mental health challenges, fostering emotional and social

proficiency, and boosting educational performance (Humphrey, 2013). SEL encompasses the methods by which individuals gain and successfully utilize the awareness, perspectives, and abilities to regulate their feelings, express compassion toward others, set and accomplish constructive objectives, build and sustain healthy connections, and exercise thoughtful judgment.

Since the 1990s, SEL has gained prominence as a key focus in American education, with over 200 classroom-based SEL programs now being implemented in schools nationwide (Hoffman, 2009). In 2001, the National Conference of State Legislators approved a motion endorsing the instruction of emotional and interpersonal abilities in classrooms. By 2004, Illinois pioneered the creation of detailed benchmarks for SEL targeting kindergarten through 12th-grade learners, with numerous other states exploring similar frameworks. While integrating SEL has not yet gained prominence within educator training initiatives across the United States, there is increasing enthusiasm for incorporating it into both teacher development programs and ongoing professional training (Hoffman, 2009).

SEL strategies such as fostering mindfulness, acceptance, and maintaining full awareness can help students manage academic stress and overcome negative thoughts that arise when dealing with unfamiliar content or challenging tasks (Vestad & Tharaldsen, 2022). SEL can impact students' learning of scientific concepts by building a better emotional connection with the content. Proficiency in SEL enables individuals to identify and regulate learners' feelings, build constructive connections, create meaningful objectives, address individual and community needs, and make thoughtful and principled choices (Elias, 1997) (Payton et al., 2000). Educational institutions achieve the greatest success in their objectives when they combine initiatives to advance students' intellectual, interpersonal, and emotional development (Elias, 1997). Qualitative studies focused on a few students have supported this at a localized level.

Methodology

A meta-synthesis approach was used to synthesize the qualitative data from published research on the impact of SEL on K-12 science learning. Meta-synthesis is a systematic approach to research integration in which existing qualitative studies are used as data sources. The process involves scratching below the surface (Thorne, 2016) of original studies to create new knowledge. These syntheses can incorporate studies from diverse contexts and participants, enabling a broader understanding. Research data from these multiple studies are analyzed to build more meticulous and significant assertions. This meta-analysis strategy was selected for its ability to open "up spaces for new insights and understandings to arise, rather than one in which totalizing notions are prioritized above richness and thickness of description" (Walsh & Downe, 2005). It is appropriate for developing an overarching understanding from the collective interpretation of primary studies (Barnett-Page & Thomas, 2009). As a qualitative synthesis, it goes beyond the findings of individual studies to transform the collective results into a more comprehensive understanding that exceeds the implications of the individual parts alone (Noblit & Hare, 1988). Qualitative syntheses are increasingly acknowledged as valuable tools for exploring participants' meanings, experiences, and perspectives comprehensively and nuancedly due to their qualitative approach. They have proven to be especially beneficial in identifying research gaps, informing the design of primary studies, and offering

evidence to support intervention development, implementation, and evaluation (Tong et al., 2012). The meta-synthesis procedure established by Harris Cooper (2015) was precisely followed. This procedure includes seven steps for research synthesis, i.e., formulating the problem, searching the literature, gathering information from studies, evaluating the quality of studies, analyzing and integrating the outcomes of studies, interpreting the evidence, and presenting the results (Cooper, 2015).

Empirical Studies/Data Base

As a meta-synthesis of existing research, the data for this study were the results of contemporary empirical studies on the impacts of SEL on K-12 students' science learning. A comprehensive search for peer-reviewed empirical articles using a qualitative approach was conducted, with the qualitative component being dominant in describing emotions impacting the students' learning in science. The search focused on research published in or after 2013 with clearly stated a) research questions, b) study context, c) sampling method, d) method of analysis, e) clearly described findings and f) sufficient evidence to support claims. The search was narrowed to the following nine science education journals: 1) *International Journal of Environmental and Science Education*; 2) *International Journal of Science and Mathematics Education*; 3) *Journal of Science Education and Technology*; 4) *Journal of Science Teacher Education*; 5) *Journal of Research in Science Teaching*; 6) *Research in Science Education*; 7) *Science Education*; 8) *Science Education International*; and 9) *Cultural Studies of Science Education*. One hundred twenty-one articles containing the necessary characteristics were identified and published in these journals from 2013 to 2023. This resulted in 33 articles being subjected to complete analysis to locate the potential impact of SEL on K-12 students' learning in science, as shown in Table 1.

Table 1. Studies Included in the Meta-Synthesis

Publication
Tomas, L., Rigano, D., & Ritchie, S. M. (2016). Students' regulation of their emotions in a science classroom. *Journal of Research in Science Teaching*, *53*(2), 234–260. https://doi.org/10.1002/tea.21304
Burks, G., Clancy, K. B. H., Hunter, C. D., & Amos, J. R. (2019). Impact of Ethics and Social Awareness Curriculum on the Engineering Identity Formation of High School Girls. *Education Sciences*, *9*(4), Article 4. https://doi.org/10.3390/educsci9040250
Vestad, L., & Tharaldsen, K. B. (2022). Building Social and Emotional Competencies for Coping with Academic Stress among Students in Lower Secondary School. *Scandinavian Journal of Educational Research*, *66*(5), 907–921. https://doi.org/10.1080/00313831.2021.1939145
Dyson, B., Howley, D., & Shen, Y. (2019). Teachers' perspectives of social and emotional learning in Aotearoa New Zealand primary schools. *Journal of Research in Innovative Teaching & Learning*, *12*(1), 68–84. https://doi.org/10.1108/JRIT-02-2019-0024
Bellocchi, A., & Ritchie, S. M. (2015). "I Was Proud of Myself That I Didn't Give Up and I Did It": Experiences of Pride and Triumph in Learning Science. *Science Education*, *99*(4), 638–668. https://doi.org/10.1002/sce.21159
ÇetiN, A., Gül, M., & Doğanay, A. (2021). How Students Feel at School: Experiences and Reasons. *International Journal of Psychology and Educational Studies*, *8*(2), 232–245.

Publication
https://doi.org/10.52380/ijpes.2021.8.2.388
Lanouette, K. (2022). Emotion, place, and practice: Exploring the interplay in children's engagement in ecologists' sampling practices. *Science Education*, *106*(3), 610–644. https://doi.org/10.1002/sce.21702
Sathasivam, R. V., & Rahim, S. S. A. (2021). I do it Better: How Social and Emotional Learning Environment Enhances Assessment for Learning Strategies in Science Classrooms. *Journal of International and Comparative Education (JICE)*, 117–131. https://doi.org/10.14425/jice.2021.10.2.0913
Almqvist, J., & Quennerstedt, M. (2015). Is There (Any)Body in Science Education? *Interchange*, *46*(4), 439–453. https://doi.org/10.1007/s10780-015-9264-4
Andrée, M., & Lager-Nyqvist, L. (2013). Spontaneous Play and Imagination in Everyday Science Classroom Practice. *Research in Science Education*, *43*(5), 1735–1750. https://doi.org/10.1007/s11165-012-9333-y
Hagenah, S. (2021). Laughing and Learning Together: Intersections of Socioemotional Activity with Science Talk. *Science Education International*, *32*(1), 14–22. https://doi.org/10.33828/sei.v32.i1.2
King, D., Ritchie, S., Sandhu, M., & Henderson, S. (2015). Emotionally Intense Science Activities. *International Journal of Science Education*, *37*(12), 1886–1914. https://doi.org/10.1080/09500693.2015.1055850
Ritchie, S. M., Hudson, P., Bellocchi, A., Henderson, S., King, D., & Tobin, K. (2016). Evolution of self-reporting methods for identifying discrete emotions in science classrooms. *Cultural Studies of Science Education*, *11*(3), 577–593. https://doi.org/10.1007/s11422-014-9607-y
Davis, J. P., & Bellocchi, A. (2018). Objectivity, subjectivity, and emotion in school science inquiry. *Journal of Research in Science Teaching*, *55*(10), 1419–1447. https://doi.org/10.1002/tea.21461
Calabrese Barton, A., Kang, H., Tan, E., O'Neill, T. B., Bautista-Guerra, J., & Brecklin, C. (2013). Crafting a Future in Science: Tracing Middle School Girls' Identity Work Over Time and Space. *American Educational Research Journal*, *50*(1), 37–75. https://doi.org/10.3102/0002831212458142
Melton, J. W., Ali Saiful, J., & Pat Shein, P. (2022). Interdisciplinary STEM program on authentic aerosol science research and students' systems thinking approach in problem-solving. *International Journal of Science Education*, *44*(9), 1419–1439. https://doi.org/10.1080/09500693.2022.2080886
Tramowsky, N., Messig, D., & Groß, J. (2022). Students' conceptions about animal ethics: The benefit of moral metaphors for fostering decision-making competence. *International Journal of Science Education*, *44*(3), 355–378. https://doi.org/10.1080/09500693.2022.2028924
Sullivan, F. R., & Wilson, N. C. (2015). Playful Talk: Negotiating Opportunities to Learn in Collaborative Groups. *Journal of the Learning Sciences*, *24*(1), 5–52. https://doi.org/10.1080/10508406.2013.839945
Calabrese Barton, A., & Tan, E. (2019). Designing for Rightful Presence in STEM: The Role of Making Present Practices. *Journal of the Learning Sciences*, *28*(4–5), 616–658. https://doi.org/10.1080/10508406.2019.1591411
McCurdy, R. P., Nickels, M. L., & Bush, S. B. (2020). Problem-Based Design Thinking Tasks: Engaging Student Empathy in STEM. *The Electronic Journal for Research in Science & Mathematics Education*, *24*(2), Article 2.

Publication
Varelas, M., Kotler, R. T., Natividad, H. D., Phillips, N. C., Tsachor, R. P., Woodard, R., Gutierrez, M., Melchor, M. A., & Rosario, M. (2022). “Science theatre makes you good at science”: Affordances of embodied performances in urban elementary science classrooms. *Journal of Research in Science Teaching*, *59*(4), 493–528. https://doi.org/10.1002/tea.21735
Tobin, K., Ritchie, S. M., Oakley, J. L., Mergard, V., & Hudson, P. (2013). Relationships between emotional climate and the fluency of classroom interactions. *Learning Environments Research*, *16*(1), 71–89. https://doi.org/10.1007/s10984-013-9125-y
King, D., Ritchie, S. M., Sandhu, M., Henderson, S., & Boland, B. (2017). Temporality of Emotion: Antecedent and Successive Variants of Frustration When Learning Chemistry. *Science Education*, *101*(4), 639–672. https://doi.org/10.1002/sce.21277
Jaber, L. Z., & Hammer, D. (2016b). Learning to Feel Like a Scientist. *Science Education*, *100*(2), 189–220. https://doi.org/10.1002/sce.21202
Han, M., & Gutierez, S. B. (2021). Passive elementary student’s constructed epistemic emotions and patterns of participation during small group scientific modeling. *Science Education*, *105*(5), 908–937. https://doi.org/10.1002/sce.21665
Jaber, L. Z., & Hammer, D. (2016a). Engaging in Science: A Feeling for the Discipline. *Journal of the Learning Sciences*, *25*(2), 156–202. https://doi.org/10.1080/10508406.2015.1088441
Jung, Y. J., Zimmerman, H. T., & Land, S. M. (2019). Emerging and developing situational interest during children’s tablet-mediated biology learning activities at a nature center. *Science Education*, *103*(4), 900–922. https://doi.org/10.1002/sce.21514
Dohn, N. B. (2013). Upper Secondary Students’ Situational Interest: A case study of the role of a zoo visit in a biology class. *International Journal of Science Education*, *35*(16), 2732–2751. https://doi.org/10.1080/09500693.2011.628712
Ayotte-Beaudet, J.-P., Chastenay, P., Beaudry, M.-C., L’Heureux, K., Giamellaro, M., Smith, J., Desjarlais, E., & Paquette, A. (2023). Exploring the impacts of contextualised outdoor science education on learning: The case of primary school students learning about ecosystem relationships. *Journal of Biological Education*, *57*(2), 277–294. https://doi.org/10.1080/00219266.2021.1909634
Garner, P. W., Gabitova, N., Gupta, A., & Wood, T. (2018). Innovations in science education: Infusing social emotional principles into early STEM learning. *Cultural Studies of Science Education*, *13*(4), 889–903. https://doi.org/10.1007/s11422-017-9826-0
Bellocchi, A. (2022). Science students’ social bonds and knowledge construction. *Journal of Research in Science Teaching*, *59*(5), 746–778. https://doi.org/10.1002/tea.21743
Jaber, L. Z. (2021). The role of epistemic empathy in teachers’ learning and responsiveness to students’ experiences in science. *National Association for Research in Science Teaching*. https://par.nsf.gov/servlets/purl/10257330
Ingram, E., Reddick, K., Honaker, J. M., & Pearson, G. A. (2021). Making Space for Social and Emotional Learning in Science Education. *Frontiers in Education*, *6*. https://doi.org/10.3389/feduc.2021.712720

Data Analysis

The analysis adhered to Noblit and Hare's (1988) procedures. In the first stage, the goals and objectives of the individual studies were examined to determine how closely primary constructs, techniques, and themes in the published findings corresponded. Next, the impact of the SEL instructional strategies on students' science learning was identified, and this information was used to develop codes. For content analysis, MAXQDA 2022 software was used. Many codes were used during the first stage of coding. Sample codes included emotional regulation, active listening, sense of achievement, mindful acceptance, etc. Following that, categories, similar/different codes, were assigned to the received codes. Finally, themes were identified, and reliability processes were in place. The themes included positive emotions, negative emotions, awareness, environment, and active participation/growth mindset. Once complete, the codes and themes were sent to a researcher who had worked on SEL in science education for the peer-reviewing procedure. It helped to determine how closely sentences and codes coincide. The researchers analyzed each paper several times based on the research questions and took the necessary measures during the analysis. So, prolonged exposure to the research data prevented the development of personal biases. The last stage, "reciprocal translation" by Noblit and Hare (1988), was added to integrate the investigations and find additional elements. The findings and their dimensions will be explained in the synthesis's final stage.

Findings

As noted, the guiding question for this study was: What is the impact of SEL approaches in K-12 science classrooms? The findings are presented here as themes that emerged in the analysis. These themes are 1) developing self-efficacy and positive emotions, 2) overcoming negative emotions, 3) enhancing metacognition and awareness, 4) creating a learning environment, and 5) fostering engagement for better learning. In the sections below, these themes are described, and supporting data is provided.

Developing Self-Efficacy and Positive Emotions

Most articles reported student self-efficacy and enjoyment while learning science in the classroom. While coding papers, it was found that positive emotions such as pride, interest, empathy, achievement, sense of belonging, praise, and happiness students felt during the classroom enhanced their learning and self-efficacy toward science. A preliminary finding that we can draw from our analysis is that increases in students' self-efficacy and ultimate enjoyment in learning science result when teachers praise their students during science instruction, such as when the teachers comment on students' ability to perform complex tasks quickly and enthusiastically. Students noted a sense of pride because of teachers' appreciation (Bellocchi & Ritchie, 2015). The student's interest and sense of pride are evident from their diaries and the support they receive from their teachers. Evidence of this was found in the student comments in emotional diary entries associated with specific science lessons. For example, students feel happiness and show more interest in the lesson when they are appreciated by the teachers (Tomas et al., 2016). This newfound confidence led to them feeling more confident in answering questions, which led to an even greater enjoyment; with the enjoyment, students felt a sense of pride when they understood the science concepts. As one student in Bellocchi and Ritchie's (2015) study noted:

> "I like it when no one has their hand up [to answer a question], and you are the only one with your hand up, then you get it right, and you are like the only one who knows. (Student diary response, emphasis added)." (p. 648)

So, grasping the lessons and concepts in the science class led to a positive transformation in their enjoyment of learning science. Students felt proud when discussing science topics with friends, family, or their community, drawing on experiences from the science club and applying knowledge gained in the science club. Classroom data revealed that the students found greater enjoyment and connection with science when engaged in activity-based learning rather than absorbing information without participation (Jaber & Hammer, 2016).

Incorporating SEL into science education strengthens students' empathy and deepens their connection with the concepts taught. During analysis, it was found that intervention of SEL activities in the classroom significantly shifted students' sentiments, emotions, and perceptions toward arthropods, leading to a more positive and engaged attitude after the intervention. For this study, a curriculum was built for grades 4-12 matched with next-generation science standards (NGSS) and then aligned with SEL principles/objectives given by CASEL (Zins & Elias, 2007).In exploring how emotional engagement in science can influence students' attitudes, during analysis, I found that two studies reveal important findings about the role of teacher enthusiasm and student perceptions in fostering positive emotions and self-efficacy. In Ingram et al.'s study (2021), data show a significant shift in students' emotional responses to science after an educational intervention. Initially, many students held negative views toward tarantulas, with the highest number of negative responses recorded before the curriculum was introduced. However, following the intervention, there was a marked increase in positive sentiment. This transformation was not limited to their feelings toward tarantulas alone but also extended to their perceptions of arthropod behaviors, which became more favorable after the lesson. These findings highlight the critical role that interventions, influenced by passionate and engaging teaching, can play in changing students' emotional responses to scientific topics.

This concept is further explored in Jaber and Hammer's study (2016), where a conversation with a student named Sandra demonstrates the powerful connection some students feel toward science. When asked if she ever felt uncomfortable sharing her thoughts during science lessons, Sandra confidently denied it, describing her relationship with science in a deeply personal way. She stated, "It's like when you like somebody, it's like you and somebody and else. I'm that somebody and science is the other person that I'm hooked into." (p.182). This analogy reveals Sandra's emotional and intellectual connection to science, comparing it to a close relationship. It suggests that for some students, science can become a subject they feel intrinsically connected to, fostering both confidence and enthusiasm in the learning process.

Together, these findings indicate that both teacher passion and student engagement play key roles in shaping how students feel about science. Ingram et al. (2021) highlight that positive teacher behaviors and attitudes can help shift students' emotions and perceptions, while Jaber and Hammer (2016) show that students who feel a personal connection to science experience greater comfort and self-assurance in their learning. These studies collectively suggest that fostering an emotionally supportive and engaging environment is crucial in encouraging students'

interest and self-efficacy and enhancing positive emotions and attitudes toward science.

In conclusion, integrating SEL into science education significantly enhances students' self-efficacy, interest, and enjoyment. Positive emotions such as pride, empathy, and a sense of achievement fostered by teacher praise and supportive interactions help students feel more confident and connected to science. Studies show that SEL interventions can shift student perceptions from negative to positive. Ultimately, when students develop an emotional connection to science, it deepens their engagement, participation, and overall learning experience.

Overcoming Negative Emotions

Students' emotional responses to science education deeply influence their attitudes and learning progress. From the analysis of data collected in the study conducted by Han and Gutierez (2021), it was found that when students enter the classroom with negative emotions, such as anxiety and fear about science topics, it often leads to a decline in their confidence and active participation. For example, one student shared that feelings of anxiety stemmed from uncertainty about whether their understanding was correct or not. This lack of assurance caused hesitation, ultimately affecting their engagement in classroom activities and discussions. The findings suggest that such negative emotions can become a barrier to effective learning if not addressed. Building a supportive classroom environment where students are encouraged to ask questions and make mistakes without fear of judgment is crucial. Strategies such as reassuring students of the value of their contributions can significantly reduce these negative emotions, enabling them to engage more confidently with science learning.

The meta-synthesis also revealed that students often don't view science as an inquiry-based learning process, where the focus isn't on having the "right" or "wrong" answer but on understanding why something went wrong and exploring the reasons behind it. This limited perspective contributes to a lack of interest. When students don't fully grasp the nature and importance of science, negative emotions like frustration and confusion emerge, further diminishing their interest and engagement with scientific concepts. For example, a student in the study conducted by King et al. (2017) shared her feelings regarding one of the lessons:

> "Author One: What emotions do you feel?
> Sonya: Oh, I am so frustrated! I am so confused to this. I really do not like chemistry. ((hand up to her face and she pushes her hand away; see Figure 3)) Like, I can't picture it. So ((Shaking her head a lot as a negative signal))
> Author One: So, you are having trouble" (p. 658).

Excessive stress, especially around exams, negatively impacts students' classroom performance and learning ability. Overthinking about future academic outcomes generates even more negative emotions. Additionally, when students struggle to understand science concepts in the classroom, they often feel annoyed, angry, and frustrated not only with the subject but also with their teachers, and sometimes even with themselves, feeling guilty for not grasping the material. In the emotion journals, a group of ten learners reported feeling irritated, while another ten expressed experiencing exasperation while studying ions and the formation of ionic bonds. During an exercise

focused on ionic charges later in the session, students vocalized their dissatisfaction with remarks such as “I don’t like this, sir” and “this is so annoying . . . .this is my emotions right now . . . annoyed” and “You’ve got to be killing me.” (King et al., 2017 p. 652). I also observed that boredom or a lack of joy is common among students who don't feel enthusiastic or energized by science content. This makes it challenging for them to participate actively in class activities and lessons. Therefore, it’s essential to find engaging and interesting ways to evoke positive emotions in students, helping them overcome negative feelings and enhance their overall learning experience, especially in science. So SEL is the one way to connect students emotionally with the topics, which further fosters engagement and improves students’ learning and understanding of the topics. As data from (Han & Gutierez, 2021) the study showed, in the science classroom, students showed more interest and engagement in the class topics with that teacher who has social-emotional competencies (SEC) skills. When the teacher acknowledges the students’ small efforts and encourages them with positive and uplifting words, then students feel more comfortable and become more open to learning.

In conclusion, students' negative emotional responses, such as anxiety, fear, frustration, and boredom, significantly impact their engagement and learning outcomes in science education. Feelings of uncertainty, confusion, and stress often arise when students struggle to understand scientific concepts, leading to a loss of confidence and interest in the subject. The emotional disconnect between students and science affects their perception of the content and can create negative associations with their teachers and themselves. Therefore, addressing these emotional barriers through engaging, inquiry-based approaches is crucial to fostering positive emotions, enhancing student participation, and improving overall learning in science.

Enhancing Metacognition and Awareness

Metacognition is thinking about one’s thinking, which is very close to awareness. Still, in awareness, students are also aware of their surroundings, which helps them to learn and understand not only themselves but also the world, and they find interconnectedness. Findings related to the impact of SEL strategies on students’ metacognition and understanding were found throughout the data set. Specifically, students’ understanding of how various emotions and thinking patterns influence their learning processes. Most students or informants found that when asked to practice mindfulness, acceptance, and paying complete attention or awareness, it helped them cope with academic stress or negative thoughts that surfaced when encountering new material or facing challenging tasks. For example, one student in a study conducted by Vestad and Tharaldsen (2022) mentioned:

> “I find it useful to take deep breaths and to use the breathing exercise when I am stressed before presentations in school.”
> “To accept and let go helps a lot when I have thoughts that I find unhelpful and don’t like having about schoolwork” (p. 913).

With mindfulness, students accept the present moment without any internal resistance. Understanding the importance of the present moment enhances students' engagement, allowing them to focus entirely on classroom topics and refine their ideas during discussions. During the analysis, I found that when students became more

aware of their own thinking and emotional patterns, they recognized emotional regulation as a very challenging competence for coping with stress in their academic life. Attention plays a vital role in students' learning; when teachers actively listen to their students, it demonstrates SEL competencies. This practice helps students feel valued and creates a relaxed classroom environment, enhancing their learning experience.

The data from Han & Gutierez., 2021 indicated that students taught how to focus were better equipped to overcome distractions and foster an attentive classroom environment through active participation. Additionally, when students recognized that a lack of awareness about their topic knowledge contributed to their anxiety regarding concepts, they became more motivated to concentrate. Students expressed that accepting their emotional states has proved beneficial for regulating their emotions and managing academic stress.

I found in the study by Tomas et al. (2016) that when students grasp concepts and enjoy their work, their awareness of their ideas and emotions increases, leading to an increased ability to understand and respect the perspectives of others. In group activities, self-reflection on their emotional states enables students to accept their peers' decisions, enhancing overall productivity. Students feel valued and are more interested in learning when teachers demonstrate active listening skills. My analysis identified key themes such as emotional regulation, awareness, active listening, mindful acceptance, and learning through experiences, which reveal how self-awareness and understanding impact student interactions and interest in science. Furthermore, when students connect science topics to real-world challenges, they find authenticity in their studies, leading to increased participation and systematic, creative problem-solving. This approach fosters an understanding of the relationship between science and society, highlighting the interconnectedness of people and their environment. For example, when students involved in the study conducted (Melton et al., 2022) were discussing some real challenges such as climate change, air quality, and air pollution problems, some students shared their thoughts in the semi-structured interview:

> "I have researched this, and around seven million people die from air pollution, according to the World Health Organization. I think it is a huge problem because the particles of aerosol can cause both short-term and long-term effects (S8-interview-problem, information needs). The student's ability to connect additional information to the problem helps characterize the situation, giving relevance to the student's task." (p. 1432)

Metaphors serve as a powerful tool for enhancing students' environmental awareness and understanding of animal species, fostering empathy and moral values by encouraging them to adopt the perspective of animals. While coding, I found a shift in students' attitudes and observed that they felt the interconnectedness between humans and the animal kingdom. This shows that including metaphors in science classrooms can enhance students' learning, understanding, and empathy with other species living on this earth. A student in Tramowsky et al.'s (2022) study shared an experience when he got a chance to learn and understand better the animal field metaphor:

> "The animal feels bad because I WOULD ALSO FEEL BAD if I had to be locked up in such a SMALL SPACE with many others. That is NOT FAIR to animals because we would not treat ourselves like that (Nora, Ln. 98–111)" (p. 370).

In conclusion, integrating SEL strategies, mindfulness, and metacognitive practices significantly enhances students' awareness, emotional regulation, and engagement in science education. Understanding and accepting their emotions, students can better manage academic stress and develop a deeper connection to their learning. Active attention, mindfulness, and real-world applications of science topics help students overcome distractions, build systematic thinking, and foster creativity. Furthermore, metaphors and discussions on real-world challenges, such as climate change and air pollution, deepen students' empathy and awareness of the interconnectedness between science, society, and the environment. These approaches promote cognitive growth and emotional and social development, leading to more meaningful and engaged learning experiences.

Creating a Learning Environment

Findings revealed how emotional climate, learning space, and friendly environment within a science classroom significantly influence student engagement and learning outcomes. An inclusive and friendly atmosphere during group activities fosters open discussions and dynamic exchanges of ideas. While the analysis was being conducted, interesting points were found, which were further converted into codes, such as how the environment influences the feelings or emotions of the students. Other codes were friendly environment, creating student space, the importance of student-student interactions, family environment/parents' behavior, the entanglement of emotions, place, and practice. The findings revealed that when students get a friendly environment in science, they can feel more comfortable and confident, which further enhances the exchange of ideas and arguments during group discussions. For example, In the study by Han & Gutierez (2021), one student, Susan, reflected on how her interactions with peers influenced her behavior during a lesson. In the early stages of the lesson, Susan appeared much more at ease compared to previous sessions. When asked about this change, she explained that the supportive atmosphere created by her classmates, Jenny and Sylvia, played a key role in helping her feel comfortable. She shared that their encouragement and acceptance made it much easier for her to express her thoughts. Susan felt that unlike in earlier lessons when she was unsure of her opinions, this time, she could share freely without worrying about being judged. She appreciated that even when she joked, her peers laughed along without criticism, which made her feel more confident and willing to participate in the lesson. This shift in her comfort level was attributed to the positive and non-judgmental environment fostered by her classmates, illustrating the importance of peer support in creating a conducive learning atmosphere.

Moreover, students feel joy working with each other when they find open space for their work without any pressure. Students' emotions change with the environment, directly affecting their behavior and engagement toward science learning. In a study (Ayotte-Beaudet et al., 2023), students shared how their curiosity and engagement were heightened during outdoor science activities. One student explained that working indoors, particularly with exercises in a notebook, often led to a loss of focus and distraction. However, when they transitioned outdoors, the change in environment made it much easier to stay focused and engaged with the task at hand. Another student echoed this sentiment, noting that while indoor activities prompted fewer questions, being outside sparked more curiosity and led them to ask more questions. The student emphasized that being able to observe the natural world directly, rather than just reading about it, made the experience more interesting and meaningful. These reflections highlight how outdoor learning environments can foster greater engagement,

curiosity, and critical thinking in science education.

Students' discussions of their experiences with lectures and seatwork sound more monotonous; with that, they also want to experience the world, touch, smell, and look. During the interview, students mentioned that before going outside and experiencing the insects and animals' way of life, they were just entangled with their emotions, but with direct experience alongside the knowledge they got from class, their emotions, such as fear, turned into curiosity, joy, and empathy. With class lectures alone, students did not experience any emotions or engagement in the class. In addition, students enjoyed interacting with their teachers; they learned something new with laughter or in a more fun way. Their hesitation dissolves, and they become more open to asking questions and exchanging ideas. Students' emotions changed with the environment; for example, students loved to spend time in the garden and enjoyed break periods. Students love to practice activities at a place where they feel an emotional connection or sense of happiness. Another factor influencing students' emotions in the classroom is its classroom size. When students cannot interact with their teacher or communicate with peers due to overcrowding, their emotional experience is negatively affected. A conducive learning environment is essential for fostering positive emotions and engagement among students. However, challenges such as overcrowded classrooms can significantly hinder this process. During the analysis, I found good insights from the paper (ÇetiN et al., 2021), highlighting that large class sizes make it difficult for teachers to establish meaningful communication with individual students. Teachers noted that reducing the number of students per class to below 30 would create opportunities for more personalized interactions, enabling them to address students' emotional and academic needs better.

Beyond classroom dynamics, the influence of the family environment plays a pivotal role in shaping students' emotions and behaviors. Teachers have observed how parental pressure or family conflicts often contribute to emotional distress among students, negatively affecting their participation and focus in class. For instance, one teacher recounted witnessing a child in tears upon seeing their parent near the classroom, a moment that revealed deeper issues at home. Conversations with students during such moments frequently uncovered unhappiness stemming from family problems, underscoring the strong connection between home life and school experiences. These findings highlight the importance of not only addressing structural challenges, such as overcrowding but also fostering collaboration between schools and families to ensure a nurturing and emotionally supportive learning environment. By doing so, educators can better support students' emotional well-being, paving the way for more effective learning and personal growth.

Teacher behavior plays an essential role in influencing students' emotions, participation, and overall success in the classroom. Educators lacking skills in SEL or SEC often struggle to engage students effectively, resulting in diminished outcomes compared to teachers who successfully incorporate these elements into their practice. For instance, in a study by (Sathasivam & Rahim, 2021) a teacher named Tharini demonstrated how fostering a supportive and interactive classroom environment could enhance student engagement. In one lesson, she encouraged her students to collaborate in groups to create a short story illustrating their understanding of heat. Each group then presented their ideas to the class. One pair shared a playful and creative example that brought humor to the discussion. The students compared the heat generated by hugging a wrestler from World Wrestling Entertainment (WWE) versus hugging a classmate named Sugen, humorously concluding that the wrestler would

generate more heat due to his size. Their peers laughed at the analogy, and Tharini smiled, reinforcing their creativity by remarking that they could even try this as an experiment. This interaction highlighted a sense of trust and comfort within the classroom, as students felt secure enough to include their friend's name in their example and express their ideas without fear of judgment. By maintaining a safe, inclusive, and lighthearted atmosphere, Tharini fostered both emotional connection and meaningful engagement in learning.

Introducing science concepts through interactive and creative methods, such as acting, plays, or drama, has proven to be an effective way to engage students and deepen their understanding of scientific ideas. These approaches make learning more dynamic and enjoyable, allowing students to connect with the subject matter on both intellectual and emotional levels. In a study conducted by Varelas et al. (2022), fourth-grade science students expressed how much they valued this approach. One student shared that participating in group activities involving acting helped them understand concepts better while fostering teamwork and collaboration. Another student noted how embodying the roles of animals during these activities made the experience feel authentic, almost as if they were genuinely living the roles they were portraying. By physically engaging with the subject matter and using their imagination, students were able to internalize science concepts in ways that brought them joy, pride, and a sense of accomplishment. This method of learning not only reinforced scientific ideas but also created a vibrant and emotionally fulfilling classroom environment where students felt more connected to the material and to one another.

In summary, it was found that the emotional climate and teacher behavior within a science class influence student engagement and learning outcomes in science education. A friendly and inclusive atmosphere during group activities encourages dynamic discussions, while sensory experiences, such as outdoor learning and hands-on experiments, deepen emotional connections to scientific concepts. Smaller class sizes promote better interaction, and effective teacher behavior incorporating SEL skills significantly enhances student participation. Supportive teachers, counselors, and family environments are crucial in nurturing students' interest in science. SEL, collaborative efforts, and creative approaches contribute to emotional stability, trust-building, and improved academic performance. Understanding these dynamics is essential for creating a holistic and enriching science education experience.

Fostering Engagement for Better Learning

Engaging students in hands-on activities, active participation, outdoor experiences, and discussions of real-world problems using a systematic inquiry approach is essential for fostering a growth mindset, increasing interest, evoking positive emotions, and deepening their connection to science education. Evidence shows that students are more enthusiastic and retain information better when they actively participate in discussions and activities rather than relying solely on passive reading. Findings from the study conducted by Jaber and Hamer (2016), revealed that students feel more engaged and motivated when lessons incorporate discussions that naturally integrate questions rather than relying solely on reading from textbooks. One student shared how discussions helped them stay involved, as reading directly from a book made it easier to disengage or skip over questions. While the students enjoyed reading in general, they found textbook-based learning less appealing, particularly

when it felt disconnected from active participation in the classroom.

Students believed that discussions encouraged them to develop their thinking rather than rely solely on the author's ideas. These discussions provide opportunities for sharing ideas, supporting one another, and forming friendships. Through this analysis, it was found that demonstrations and experiments in science classes significantly enhance students' learning and help them retain concepts in their long-term memory. For example, students in the study conducted (King et al., 2015) mentioned in their emotional diaries that they felt wonder, and they also commented on some interesting and exciting sentences such as 'What we are learning,' 'How it worked, ' and' What happened to the egg'?

> "three weeks after the lesson and then five months after the lesson, Ashley recalled this experiment and the 'egg in the bottle' demonstration as memorable science lessons. When asked why he remembered these lessons, he said 'because they were the most fun ones just seeing the result what happened to them'." (p. 1903)

Students commented on the egg experiment conducted outside the classroom to demonstrate scientific concepts. I found that sensory perceptions play a crucial role in engaging students with science education; they enjoy being active outdoors and experiencing hands-on learning, which evokes positive emotions and interest. Students find the process enjoyable when these sensory experiences are combined with empathetic learning, such as acting out science concepts. For instance, they can relate to different animals and insects by mimicking their body parts through their actions, making science both fun and relatable. In addition to that, they enjoy and show interest when they understand concepts through some model or artifacts. I found in the study conducted by Han & Gutierez (2021) that one student mentioned in her diary:

> "it was fun and interesting to construct the model of the human respiratory system. Her enjoyment was evident during the small group discussion when she was able to share her ideas without elicitations from her classmates." (p. 930)

When students see real-world challenges and get an opportunity in the class top to inquire and think more systematically to solve this kind of issue, these real-world challenges not only give them interest motivation but also students feel an empathetic connection with the environment, which further helps them in their growth mindset, decision making, and understanding. When students find the relationship between their studies and society, they recognize the practical implications of their science knowledge. Students try to find innovative possible solutions and imaginations to resolve real-world problems, which helps them to develop systematic thinking and a growth mindset to solve complex problems. In addition, students learn how their brains can function better to find solutions or overcome challenges, they get more confidence, they feel more receptive to learning new skills, and their attitude changes toward learning. In the study conducted by Vestad and Tharaldsen (2022), students shared insights into their understanding of the brain's capacity for growth and its impact on their learning. One student expressed how their perspective shifted after learning that the brain functions like a muscle that strengthens through practice. Initially, they had believed that talents were fixed and innate, but this new

understanding helped them realize that skills could be developed through hard work and consistent effort. Another student highlighted the significance of adopting a growth mindset, emphasizing its role in addressing mistakes during the learning process. They pointed out that a growth mindset encourages focusing not only on learning from errors but also on building resilience in overcoming them. While some students initially found the concept of the brain as a muscle challenging to grasp, they ultimately recognized its value. One student noted that although it was difficult to understand at first, they eventually saw how useful this knowledge was for their learning journey, describing it as a practical and empowering realization. These reflections demonstrate how the integration of growth mindset principles can transform students' attitudes toward learning and foster a deeper sense of engagement and motivation.

In summary, students thrive in science education when engaged in hands-on activities, outdoor experiences, and discussions. Success in challenging tasks boosts confidence, while connections to real-world applications foster a growth mindset. Utilizing diverse methods, authentic materials, and mindfulness practices enhances interest and positive emotions, creating a dynamic and engaging science learning environment. Students feel interested in learning science lessons with positive emotions, and these positive emotions can easily be excessed in the environment where students can find active participation in the lesson and learn by doing and exploring.

Discussion and Conclusion

The findings from this study underscore the significant impact of SEL approaches on K-12 science education. Through an analysis of various themes, including students' self-efficacy, the effect of negative emotions, metacognition, awareness and understanding of the learning environment, and learning engagement, it becomes evident that integrating SEL practices into the science curriculum enhances students' learning experiences and outcomes. The emotional climate within the science classroom plays a pivotal role in shaping students' attitudes toward science and their overall learning experiences. Positive emotions such as pride, enjoyment, and interest are fostered through activities that engage students actively, such as hands-on experiments and outdoor learning experiences. Conversely, negative emotions arise when students struggle to comprehend concepts or feel discouraged by external pressures. Teachers' support and encouragement foster positive emotional engagement and mitigate negative emotions.

Metacognitive skills, including mindfulness and emotional self-awareness, enable students to regulate their emotions and cope with academic stress effectively. Students can develop strategies to manage stress and maintain focus during challenging tasks by understanding how their emotions influence their learning processes. Teachers are crucial in creating a supportive environment where students feel comfortable expressing their feelings and seeking help when needed. A positive and inclusive learning environment is essential for fostering emotional engagement and learning outcomes in science education. Friendly relationships among peers, supportive teachers, and collaborative learning opportunities create a conducive atmosphere where students feel valued and motivated to participate actively. Outdoor activities and experiential learning enhance students' emotional positivity and interest in science.

Engaging students in hands-on activities, discussions, and real-world applications of science concepts fosters curiosity, creativity, and a growth mindset. Success in challenging tasks boosts students' confidence and intrinsic motivation, leading to deeper learning and understanding. Diverse teaching methods, authentic materials, and mindfulness practices contribute to creating dynamic and engaging science learning experiences.

In conclusion, this study highlights the importance of integrating SEL approaches into K-12 science education. By fostering positive emotional engagement, supporting metacognitive skills development, creating a conducive learning environment, enhancing awareness and understanding, and promoting active learning engagement, educators can improve students' overall learning experiences and outcomes in science. Recognizing the interconnectedness between emotions, cognition, and learning, educators can design effective instructional strategies that cater to students' diverse emotional and learning needs. These are very subtle and vital aspects of how emotions influence learning and how different learning approaches can generate various emotions. Ultimately, nurturing students' emotional well-being and fostering a positive learning environment are essential for cultivating lifelong learners equipped with the skills and mindset necessary for success in science education and beyond.

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