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EDITORIAL

# Advancing Inclusive, Expressive, and Transformative Pathways in STEM Education

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The December 2025 issue of the Journal of Research in STEM Education brings together four complementary studies that collectively reflect the evolving priorities of contemporary STEM education research. While situated in diverse contexts and employing varied methodological approaches, the contributions in this issue converge around a shared concern: how STEM education can be designed to be more inclusive, expressive, and transformative for learners and teachers alike. Taken together, these studies extend current discussions on creativity, communication, teacher professional learning, and equity, offering timely insights for both researchers and practitioners.

The issue opens with Zhou's conceptual contribution, 'Ah!-HaHa!-Aha!': A Tool of Creativity Development in STEM Education, which foregrounds the often-underexamined role of emotion in STEM learning and teaching. Moving beyond cognitive-only accounts of creativity, Zhou introduces a pedagogical tool that integrates curiosity ("Ah!"), joy and playfulness ("HaHa!"), and insight ("Aha!") into a coherent framework for fostering creative climates in STEM classrooms. By synthesizing inquiry-based learning, problem-based learning, playful learning, and teaching for deeper learning, the proposed model positions everyday experiences as fertile ground for creativity development. This work is particularly significant in its insistence that creativity is not an exceptional trait reserved for a few, but a situated, emotion-mediated process accessible across educational levels. As such, it sets a conceptual foundation for rethinking STEM education as a deeply human and affective enterprise.

Building on this emphasis on expression and meaning-making, Wang, Jacobsen, and Jackson offer an empirical investigation into science communication through their study A Text Analytical Study of STEM Inquiries in Grad Slam Competition. Employing text analytics and

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natural language processing, the authors examine transcripts of graduate students' three-minute research presentations to uncover patterns in STEM inquiry and communication. Their findings highlight how structured communication training, such as Grad Slam workshops, can strengthen both disciplinary understanding and confidence in public science communication—particularly within a Hispanic Serving Institution context. Methodologically, this study demonstrates the growing potential of computational approaches for analyzing rich qualitative data at scale. Substantively, it underscores communication as a core competency in STEM education, aligning with broader calls to prepare scientists and engineers who can effectively engage diverse audiences.

The third contribution, STEM Research Experiences for Teachers: A Feasibility Study of the Sustainable Energy for Empowering Rural Communities Program, by Simpson and colleagues, shifts the focus to teacher professional development and capacity building. Through a mixed-methods evaluation of a research experience program for rural teachers in the United States, the study documents how authentic engagement with sustainable energy research can enhance teachers' confidence, disciplinary knowledge, and classroom practice. Importantly, the authors situate their work within the specific challenges and strengths of rural educational contexts, emphasizing the value of place-based and context-sensitive professional learning models. The findings reinforce the argument that effective STEM reform depends not only on curricular innovation, but also on sustained investment in teachers as learners, researchers, and agents of change.

The issue concludes with Goreth and Lutz's large-scale quantitative study, Gender and Diversity Awareness among STEM-Teachers: Mono Makes the Difference, which directly addresses questions of equity and inclusion in STEM education. Drawing on survey data from over 500 teachers, the authors examine how gender, subject affiliation, and experience in mono-educational settings relate to teachers' attitudes and knowledge regarding gender and diversity. The findings reveal nuanced differences that have important implications for teacher education and professional development, particularly in relation to gender-sensitive pedagogical practices. By foregrounding teachers' beliefs and experiences, this study contributes critical empirical evidence to ongoing debates about how STEM education can challenge—rather than reproduce—structural inequalities.

Collectively, the four articles in this issue illustrate the multidimensional nature of STEM education research today. Creativity is framed not merely as cognitive problem solving, but as an emotional and social process; communication is positioned as a central outcome of STEM learning; teacher education is examined as a key lever for sustainable change; and equity is treated as an integral, rather than peripheral, concern. The methodological diversity represented—from conceptual modeling and text analytics to mixed-methods program evaluation and large-scale survey research—further reflects the field's increasing sophistication and openness to interdisciplinary approaches.

As STEM education continues to respond to global challenges such as sustainability, technological transformation, and social inequity, the studies presented in this issue offer both theoretical guidance and empirical grounding. We hope that readers will find in these contributions not only rigorous scholarship, but also inspiration for designing STEM learning environments that are inclusive, expressive, and transformative.

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RESEARCH REPORT

# 'Ah!-HaHa!-Aha!': A Tool of Creativity Development in STEM Education

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**Abstract**

*Creativity is a complex phenomenon. This paper highlights emotion mediates creativity development in various situations that happen in our everyday life. Particularly, three important emotional expressions of 'Ah!'(wonder/curiosity), 'HaHa!'(laughter/fun), and 'Aha!'(discovery/inspiration) are focused on in the theoretical discussion that helps to explore links between emotion, creativity, teaching, and learning in STEM education. The interplay between experiences of 'Ah!', 'HaHa!' and 'Aha!' forms a new tool of 'Ah!-HaHa!-Aha!' that can be used to foster a creative climate. Furthermore, a pedagogical model is proposed for developing creativity in STEM education. The model integrates with 'Ah!-HaHa!-Aha!', Inquiry and Problem-Based Learning, Playful Learning, and Teaching for Deeper Learning in one framework. It regards everyday life as the learning context and underpins a systematic perspective to facilitate creativity in STEM education. This also provides STEM teachers with various methods and strategies to develop students' creativity in their daily pedagogical practice.*

**Keywords:** *Creativity, Emotion, Pedagogy Design, STEM Education*

## Introduction

Creativity is one of key skills in the 21st century; it has been addressed as a necessary and fundamental to personal achievement and organization innovation. The importance of creativity has been recognized in STEM education. Scientific creativity can be defined as any thought or behavior in science that is both novel and useful (De Vires, 2021); it is an ability of exploring new discoveries, conducting science experiments, solving science problems, and carrying out science activities (Raj, 2016; Zhou, 2019).

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Scientific creativity also involves 'everyday creativity' that regards everyday life as a learning context, concerns everyone's learning experience and occurs in many ordinary situations (Craft, 2005; Zhou, 2020). This also means creativity is a phenomenon in which a scientist, a technician, an engineer, or a mathematician habitually responds to daily tasks in a novel and meaningful way (Conner & Silvia, 2015; Villanova & Cunha, 2020). Social-cultural theories have emphasized creativity as a contextual activity (Amabile, 1996; De Vires, 2021; Sternberg, 1999;). As Zhou (2019) addressed, creativity can be explained partly by personality characteristics but also by situational variables related to changing or enhancing affective states, which leads to options that creativity happens in the interaction between individuals and their situations. Like Amabile (1983, 1996), Mihaly Csikszentmihalyi (1988, 1996, 1999) developed the systems model of creativity, addressing how creativity is influenced by three components: the person, the domain, and the field. This model suggests that creativity is not only a property of individuals but also a property of societies, cultures, and historical periods. Meanwhile, growing from diverse perspectives (i.e., cognition, personality, creativity techniques, etc.), four interesting areas of focus have emerged: a) the Person, who is the creator; b) the creative Process, how creativity occurs; c) the Place or Press, which emphasizes environmental influencing factors; and d) the Product, what the creative outcomes look like (Zhou, 2018, 2019, 2020).

In this sense, 'climate' has been argued as one of key concepts in creativity research. As Ismail (2015) suggested, the climate evolves in the confrontation between the learners and their situational realities, and the situational factors are its determinants, for example, task challenge, freedom, time, playfulness, humor, and idea support, and openness, etc. As well as the physical places in which digital technologies have also been used to support the creative climate and creative learning environment by imaginative play, speculation, and brainstorming, etc (Zhou, 2017; 2018). In learning situations, creativity is also embedded in the process of problem-solving that shapes as many opportunities of gaining new knowledge and experience (Craft, 2005; Zhou, 2014). Both creativity and learning are emotion-related concepts (Zhou, 2017). According to Illeris (2007), 'incentive' is one of dimensions of learning covering motivation, emotion, and volition. This might be uncertainty, curiosity or unfulfilled needs that cause us to seek new knowledge and develop our sensitivity in relation to ourselves and our environment. As Zhou (2019) suggested, having fun provides potential conditions for students to be creative in certain learning processes and learning environments. In comparison with negative emotions, positive emotions play more crucial roles in developing creative thoughts, fostering creative climate, and achieving learning objectives.

The above lines drive this paper to consider emotion as one of important aspects in fostering creative climate in STEM education, discuss three emotional expressions of 'Ah!'(wonder/curiosity), 'HaHa!'(laughter/fun), and 'Aha!'(discovery/inspiration), and explore their relations with creativity. 'Ah!-HaHa!-Aha!' is addressed as a tool that teachers can use to cooperate with diverse creative pedagogies to facilitate students' creativity and foster creative climate in STEM education. This paper has its important significance of rethinking STEM education innovation across various levels from primary to higher education.

## Linking Creativity with Emotion and Learning

### *STEM as Creative Work*

Creativity has been defined as the generation of novel, appropriate ideas in any realm of human activity in science, arts, education, business, even in everyday life (Amabile, 1996). In general, creativity can be divided into three types: creating something new, combining things together, and improving or changing things (Al-Ababneh, 2020; Mikdashi,1999). Creativity includes two characteristics: one is the notion of novelty which means a phenomenon in everyday life and therefore anyone can be creative as an essential aspect in tackling any challenges and solving any problems (Zhou, 2016); and one is the notion of usefulness which refer to material, product, or practical methods of assessing the usefulness of novel ideas (Zhou, 2019; Shalley, Zhou & Oldham, 2004).

STEM involves creative field of work that interplays disciplinary and interdisciplinary learning. For example, scientists develop their creative ideas to find and solve scientific problems (Draper et al., 2021). As Zhou and Larsen (2025) suggested, in mathematics education, problem solving is a crucial part in teaching and learning activities; it is a means to sharpen reasoning that is careful, logical, critical, analytical, and creative. To solve a mathematical problem requires creativity; problems are sources as well as goals for developing creativity. Previous studies have discussed the concept of scientific creativity (Daud et al., 2011; De Vires, 2021; Simonton, 2008). These studies have been compatible with the general notion of creativity, the nature of science and engineering, the complexity in STEM professional practice, and the realistic issues in contexts of STEM education (Draper et al., 2021).

According to the previous studies (Zhou, 2019; 2020), creativity in STEM contexts can be identified either with 'historical creativity' (i.e., when something, like a new idea, a new theory, a new discovery, is historically new) and/or with 'personal creativity' (when something is new in a personal sense regardless of whether that something is not new to others) (Zhou et al., 2017). This involves both extraordinary 'big creativity' in 'revolutionary science' (Kuhn, 1970) and everyday 'little creativity' in 'normal science' (Craft, 2005; Simonton, 2004).

The recent efforts have paid much attention to 'everyday creativity' or 'little creativity' (Zhou, 2020). As Hadzigeorgiou and his colleagues (2012) suggested, it is true that everyday scientific work like problem finding and solving, hypothesis formation, and modelling, requires creative, imaginative, and logical thinking; in other words, everyday scientific work is the context of creativity development. As Richards (2010) mentioned, the construct of everyday creativity is defined in terms of human originality at work and leisure across the diverse activities of everyday life. Zhou and Frisdahl (2024) describe that everyday creativity drives us to explore our

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individual identity, foster competence, and enhance ingenuity. This contributes to positive development, as we are motivated by possibility thinking. We become accustomed to asking 'what if?' to explore diverse solutions. This mindset further promotes the generation of new knowledge and self-insight, enabling us to solve daily problems, chart our future course, achieve more, shift paradigms, and adapt flexibly to ever-changing environments. Moreover, creativity is the result of a complex interplay between the person and his/her context (Amabile, 1996). This complexity coupled with the way and the context under which scientific ideas burst forth (Gardner, 1997), sometimes makes scientific creativity an emergent ability or unpredictable event (Sawyer, 2012). As Zhou (2019) addressed, creativity happens in between routine and non-routine problem-solving contexts. It is influenced by different factors including intellectual abilities, prior knowledge, domain-specific knowledge, personality trait, motivation, emotion, environment, and culture.

*Creative Climate and Learning*

Creative climate has been discussed much as a means to evaluate and promote scientific creativity (Peter-Szarka, 2012; Daud et al., 2012). 'Climate' has been used to describe the recurring patterns of behavior, attitudes, and feelings that characterize life in certain learning or working environments (Al-Beraldi & Rickards, 2003). Climate may arise from interactions between two approaches: one is the cognitive schema approach that highlights individuals' constructive representations or through attempts to uncover individuals' sense making of their proximal work environment (Anderson & West, 1998); and one is the shared perceptions approach that highlights in learning situations, the individuals' shared perception on their joint experiences or the manner of working together with others (Mathisen et al., 2004; Zhou, 2017). So, creative climate influences and is influenced by the interaction between the person and the situation in which creativity takes place; it provides conditions of creative learning. As Zhou (2017) argued, creativity cannot be taught, only the conditions created to encourage it. Similarly, Kaufman (2014) addressed when it comes to nurturing creativity in the classroom, classroom context matters. The learning environment is one of the most important factors - determining, in large part, whether creative potential will be supported (or suppressed).

Creative climate reflects subjective experience of learning. This highlights that creative learning is a process of involving emotions, the development of the self, identity, and humanist social relations (Jeffrey & Craft, 2006; Conner & Silvia, 2015). This also views individuals as agencies for making decisions (sometimes only implicitly if not unconsciously) that are guided by and have consequences for emotions. Rationality and emotions are thus so intricately connected at all levels of the biological, the cognitive, and the behavioral (Cornett, 1986; Averill, 2005; Zhou, 2020). As Jeffrey and Craft (2004) suggested, creative learning involves the experience of dynamic atmosphere, climates of anticipation and expectation, the generation of emotional expression, and development of understandings, skills, processes, appreciation and thinking. For

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STEM teachers, it is important to remember that all students have creative potential, understand how students experience the learning environment, and recognize how students express their creativity in different ways. As Kaufman (2014) suggested, the key question is not so much about whether creativity has a place in the classroom, but rather when and how creativity can be best supported and encouraged.

*Emotion-Mediated Creativity*

Emotion is one of the elements in fostering creative climate. It is well known that emotion plays crucial roles in mediating our social life (Zhou, 2017). Most emotions are organized by a combination of biological and social factors. As Newton (2013) suggested, emotions are mental states arising from personal evaluations of the world with prompt a readiness to act in support of well-being. Emotional expressions provide information to observers, which may influence their behaviors (Van Kleef et al., 2010). Emotions such as anger, happiness, and love are sharable and public, which are sued for interpersonal communication such as expressing how one feels about an object, person, or event (Lubart & Getz, 1997). Emotions sometimes confer flexibility in action by enabling people to reorder priorities as situations change and to set long-term goals especially when choices involve incomplete data or incommensurate alternatives (Zhou, 2017).

Emotions influence creativity in general (Averill, 2005). Previous studies on mood and creativity show that emotional states such as feeling happy, enthusiastic, and elated, are likely to foster creative ideas (Conner & Silvia, 2015). These states are positive and activated that help to foster approach toward a desired goal rather than avoidance of an undesired goal. As Turner and Stets (2005) emphasized, emotions influence decisions, both consciously and unconsciously. Emotions are the gyroscope of human behavior, keeping it on track in diverse situations so that individuals can experience positive and avoid negative experiences. However, some negative emotions can have both positive and negative effects on creative performance (Van et al., 2010). Particularly, sadness and anxiety have been studied more often than others; the effects of anger have received scant empirical attention. Shortly, findings pertaining to negative emotions have been less conclusive than positive emotions (Zhou, 2017). Accordingly, research on emotion and creativity has much focused on intra-personal effects in examining how individuals' emotional states influence creative climate and innovation process (Zhou, 2019). As Lubart and Getz (1997) suggested, emotion can serve as a motivating force. For example, in a collaborative performance context, individuals may infer from another's expressions of anger that performance is unsatisfactory, which may increase motivation and effort (Huy, 2005; Zhou, 2018; 2019).

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### ‘Ah!’, ‘HaHa!’, ‘Aha!’ and ‘Ah!-HaHa!-Aha!’

*‘Ah!’, ‘HaHa!’ and ‘Aha!’*

‘Ah!’ arises from curiosity and wonder. It usually accompanies deliberate musings about something, a puzzling over or pondering sparked with extraordinary curiosity (Parse, 2002). According to L’Ecuyer (2014), wonder drives learning motivation, as it is an inner desire to learn that awaits reality in order to be awakened. Curiosity is also an intrinsically motivated exploration with an information-seeking goal (Bzahydai & Westermann, 2020). As Glăveanu (2019) suggested, the experience of wondering defines a particular kind of relation between person and world, this opens the space of the possible in thought and action. The experience of wondering includes three interconnected, cyclical processes: a) awareness (of the possible), b) excitement (about the possible), and c) exploration (of the possible). These processes can be described in terms of what ‘triggers’ wonder, of the ‘hunches’ specific for wondering, and the ‘search’ for new ideas and perspectives. Accordingly, an expansive state of wonder (the kind most similar to awe) affects creative thinking through modification of pre-existing mental frames and openness to alternative perspectives (Chirico et al., 2018).

‘HaHa!’ expresses our laughter. When fun is found, ‘HaHa!’ happens simultaneously that usually fosters a kind of positive mood. ‘HaHa!’ indicates the context of glimpsing an unexpected moment with exhilaration (Zhou, 2017). There is buoyancy that accompanies with the surprise in ‘HaHa!’ that bubbles forth in the joyful and pleasant experiences (Parse, 2002). According to Zhou (2017), individuals in an ‘up’ mood tend to be more creative problem-solvers. As Cornett (1986) addressed, laughter helps students to relax and release themselves from stressful situations such as test taking. Laughter opens our energy channel and places us directly in the present moment, where memories of the past no longer burden us, and speculations about the future seem irrelevant (Steven, 2004). When ‘HaHa!’ happens, it usually releases oneself and informs other people that all is going well and the environment is unproblematic; thereby it prompts looser, less systematic, and less effortful information processing; it fosters an attitude or outlook that encourages divergent thinking for new possibilities (George & Zhou, 2007).

‘Aha!’ indicates a discovery or an inspiration. The ‘Aha!’ experience in history is well-known as Archimedes’ ‘Eureka!’. According to Topolinski and Reber (2010), we should consider four attributes: a) ‘Aha!’ occurs suddenly, without any conscious awareness, b) the solution to the problem can be processed quickly and fluently once it has been found, c) ‘Aha!’ yields positive affect before the assessment of the solution, and d) the problem solver experiencing the ‘Aha!’ moment is convinced that the solution is true. These four attributes are not separate but can be combined. ‘Aha!’ indicates the discovery is a sudden insight and shows the unpredictability of creativity. It is a hint of an emergent process transforming implicit ideas to an explicit discovery (Zhou, 2017). As Shen and his colleagues (2016) addressed, ‘Aha!’ springs forth in the wake of calm-turbulent drifting with an availability to see the new possibilities. Additionally, happiness

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is the most typical psychological feature in the feeling of ease that is the closest cognitive characteristic of 'Aha!' experience (Zhou, 2017).

*Addressing 'Ah!-HaHa!-Aha!' as a Tool*

Following the above, 'Ah!', 'HaHa!', and 'Aha!' are all emotional expressions leading to 'coming to know' that indicate the situations where are friendly with creativity development. In STEM education, when teachers learn these expressions from students, they may adjust their ongoing teaching strategies that help students to gain creative learning experience. Previous studies also addressed the experiences 'Aha!', 'HaHa!' and 'Aha!' may interplay with each other that grows potential of creativity. 'Aha!' brings curiosity-driven knowledge acquisition, information seeking, question asking, and active exploration (Bazhydai & Wstermann, 2020). This fosters possibilities of 'Aha!', which further underpins the feeling of fun that brings moments of 'HaHa!'; while 'HaHa!' expresses positive mood that may bring possibilities of 'Ah!' or 'Aha!' (Zhou, 2017). These interplays facilitate students to engage their learning process backwards and forwards in the process of seeking answers to questions, which also gives birth to creative ideas (Zhou, 2019). As Thagard and Stewart (2010) addressed, creative thought combines different emotional components; creative mind can employ a full range of sensory modalities derived from sight, hearing, touch, smell, taste, and motor control.

In this sense, 'Ah!-HaHa!-Aha!', as a new compound indicating interplays between emotional expressions of 'Ah!', 'HaHa!' and 'Aha!', and between emotional components of wonder/curiosity, laughter/fun, and discovery/inspiration, is addressed as a tool to facilitate creativity in STEM education. As a tool, 'Ah!-HaHa!-Aha!' highlights the mediating roles of emotion in creativity development and fostering creative learning environments. As Beghetto (2013) addressed, science teachers should be able to 'read the environment', know when (and when not) to be creative, and timely take corresponding measures. Creative climate requires, supports, and interacts with an atmosphere where there is full of mutual respect between teachers and students, and where incorporates open dialog and collaborative activities. As Sawyer (2003) addressed, creativity is a kind of 'collaborative emergence', which means novelty is a collective process involving the dialogues between individuals in a way of constructing the unexpected meaning. 'Ah!', 'HaHa!', and 'Aha!' are vital parts of language in daily dialogues; they help to shape the turning points in exploring trajectory of creativity both individually and collectively; they show the creators are enjoyable in the process of sparking new ideas and working with others together (Zhou, 2017).

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**Creative Pedagogies by, for and through 'Ah!-HaHa!-Aha!'**

*Triggering 'Ah!', 'HaHa!' and 'Aha!'*

Regarding pedagogy design, a holistic approach becomes a necessity to foster creative climate. 'Ah!-HaHa!-Aha!' requires to be cooperative with appropriate designs of pedagogies that may provide conditions to trigger the interplays between experiences of wonder/curiosity, laughter/fun, and discovery/inspiration. This means the selected pedagogies should construct an open environment where encourages students' active learning and social-emotional learning experience. Based on these ideas, a new pedagogy model of 'Ah!-HaHa!-Aha!' is proposed (Figure 1).

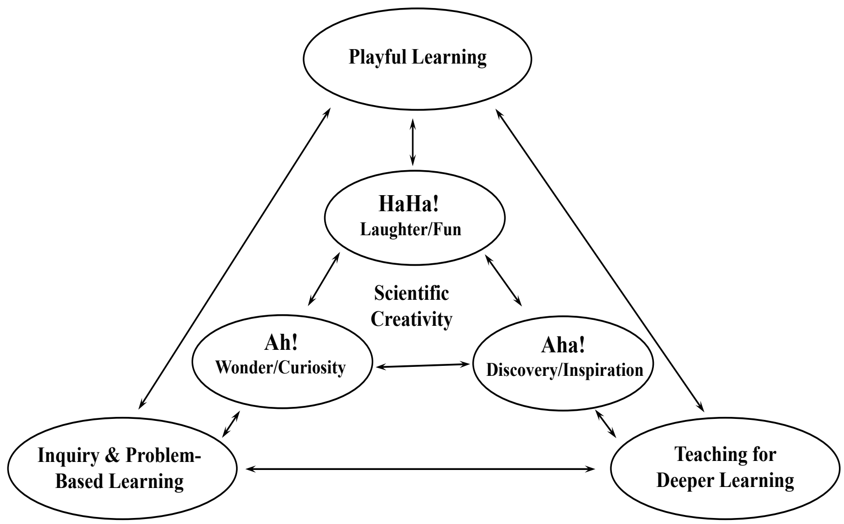


*Figure 1*. A Pedagogy Model of 'Ah!-HaHa!-Aha!' for Creativity

In the model, it shows the interplays between 'Ah!' (wonder/curiosity), 'HaHa!' (laughter/fun), and 'Aha!' (discovery/inspiration) grow potential of developing creativity in learning situations. Pedagogy methods of 'Inquiry and Problem-Based Learning', 'Playful Learning', and 'Teaching for Deeper Learning' are integrated into one framework with roles of fostering creative climate. In comparison with any other two pedagogy methods, Inquiry and Problem-Based Learning provides students more opportunities of 'Ah!' (wonder/curiosity); Playful Learning engages students with more experience of 'HaHa!' (laughter/fun); and Teaching for Deeper Learning motivates students more to learn through 'Aha!'(discovery/inspiration).

The formulation of 'Ah!-HaHa!-Aha!' extends the author's previous studies in STEM education. In Zhou (2017), a theoretical discussion examines how 'HaHa!' interacts with 'Aha!' and how the 'HaHa!-Aha!' interplay supports a playful approach to fostering a creative learning environment. Playfulness is highlighted as a key facilitator of creative learning and explores various pedagogical strategies to encourage the 'HaHa!-Aha!' interplay, such as incorporating games, pretend play, digital tools, and collaborative interactions (Zhou, 2017). In a subsequent study (Zhou, 2019), the roles of 'HaHa!-Aha!' in cultivating creative group learning environments are further investigated. This research focuses on using Problem-Based Learning to support the creative learning processes of technology design students and examines how the integration of humor into group learning environments can influence creativity. Building on these studies and linking 'HaHa!-Aha!' to the concept of 'Ah!' (wonder/curiosity), the 'Ah!-HaHa!-Aha!' tool is formulated in this article. This framework enriches the findings of previous research (Zhou, 2017; 2019) while emphasizing an active and reflective learning cycle that integrates curiosity, fun, and discovery into pedagogies in STEM education.

The proposed pedagogy model regards everyday life as the learning context in STEM education. This means we try to consider how to bridge informal and formal learning environment, how to extend STEM learning to outside the classrooms, and how to mobilize the full resources - e.g. the new discovery of knowledge in daily life, literacy practices, experiential learning- of STEM students within specific situations (Edwards, 2009). STEM teachers should consider how to best involve students' entire sensorial body in the process of learning and how to best use both individual and social factors that play supportive roles in development and expression of creativity (Zhou, 2020).

*Inquiry and Problem-Based Learning*

Inquiry-Based Learning (IBL) and Problem-Based Learning (PBL) engage us to start new learning experience from wonder or curiosity, moments of 'Ah!'. Even though there are differences between them (Ayse& Sertac, 2011), both pedagogies hold on principle of 'student-centered learning' and encourage students to learn knowledge through triggering and engaging student curiosity (Purichia, 2015). IBL and PBL help students to develop their 'hard knowledge' and 'soft skills' and facilitate them to understand how scientists study the natural world (Anderson, 2002; Zhou, 2020). As Coombs and Elden (2008) suggested, these pedagogies overcome the gap between theory and practice and between general knowledge and skills and abilities to apply it appropriately to unscripted but authentic problematic situations typical of work in the professions. Thus, we can call them social inquiry pedagogy. 'Social' means that learning is an interpersonal, constructivist process. 'Inquiry' connotes active, student-driven learning. In this sense, we combine IBL and PBL as Inquiry and Problem-Based Learning.

STEM teachers should design students' learning activities through open problems or inquires in which 'Ah!', wonder or curiosity arise. For example, in primary mathematics education, teachers may use open-ended math questions. Since open-ended questions have more than one correct answer or solution, they are typically presented as problems in real-world situations. For example, a question like, 'How many different shapes can you use to draw a ship? As Zhou and Larsen (2025) suggested, focusing on 'everyday creativity' in mathematics or STEM education means that every student can respond creatively to daily learning tasks in a novel and meaningful way. According to Zhou (2016), problems usually indicate a wondering which takes the concrete form of a question. A problem triggers the context for inquiry, engagement, curiosity, and a quest to address a real-word concern. These psychological events, in turn, set in motion certain mental processes and behavioral changes such as the development of creative ideas. Abd-El-Khalick et al. (2004) distinguish between inquiry as: means-inquiry in science, a way of teaching to help students understand science content, inquiry as ends, or inquiry about science involving students learning about epistemic aspects of science practice and development of knowledge, as well as inquiry skills such as generating research questions. As Zhou (2020) emphasized, when the inquiry process skills (i.e., observing, classifying, measuring, communicating, predicting, inferring, and experimenting) relate to the science content, the students gain opportunities to discover meaningful concepts and understandings.

In practice, Inquiry and Problem-Based Learning advocates experience-based education. Diverse models of PBL have been developed, range from limited implementations that present a question or case, to broad implementations where students define and research their own problems in collaboration with a teacher or practicing professional (Simons & Ertmer, 2005; Zhou, 2020). In general, there are at least five dimensions to be considered to design PBL: a) engaging students in an ill-structured problem, b) introducing students to the problem before they have acquired content-relevant knowledge, c) allowing students to work collaboratively, d) supporting students throughout the problem- solving process, and e) promoting student reflection following the presentation of their solutions to the problem. These dimensions can serve as effective ways to bridge formal and informal learning environments. For example, in teaching the Pythagorean Theorem, a project titled 'Pythagorean Theorem in Daily Life' can be assigned to students. Under this theme, students might begin by observing various phenomena in daily life, such as road transportation, mechanics, aviation, and electronics. Based on their observations, they can formulate group research questions and collaborate on a detailed project exploring how the Pythagorean Theorem is applied in practical contexts.

Moreover, Socio-Scientific Inquiry-Based Learning (SSIBL) has been paid much attention to bring together three supporting and mutually interactive pillars (Amos et al., 2020): a) Learning through Socio-Scientific Issues that addresses climate change, pandemics, digitalization, and sustainable development, etc. to engage students in educational activities, resulting in an environment which is characteristically more enjoyable and accessible to students; b) Citizenship Education shapes a form of science that relates in reflexive ways to concerns, interests and activities of citizens as they go about their everyday business, which broadens students' world views, promotes their critical thinking, and contributes to their capacity to navigate an increasingly culturally diverse world; and c) Inquiry-Based Science Education reflects a focus on the creativity and possibilities of learning through inquiry in science education.

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*Playful Learning*

Playful learning usually gives birth to experience of 'HaHa!'. Playful learning supports learning through play. As Singer (2013) suggested, play has the following characteristics: a) play has value in itself and play gives pleasure; b) play binds through rhythms, rules and structure; c) play gives freedom to change experience; d) play is bounded by fluid boundaries, through rules in time and space; and e) play is one of the wellsprings of culture. Shortly, play involves players' engagement in a voluntary leisure activity and/or choosing non-serious behaviors just for fun, enjoyment, satisfaction, involvement, and pleasure (Chang et al., 2013). Thus, play encourages learners' cognitive, affective, motivational and skill dimensions of creative processes; it fosters a psychological and social-relational climate that is conductive to creativity (Zhou, 2017).

A playful learning environment is characterized by playfulness. As Change (2013) described, playfulness can be interpreted in terms of abilities such as emotional expression and the use of intrinsic motivation as well as in terms of characteristics and behaviors such as naturalness, a sense of freedom, happiness, being childlike, playing or being funny. It allows safe experimentation and, like jokes, institutionalizes disorder with order, expression of taboo issues within a legitimate form, and surfacing of the repressed without extreme discomfort (Huy, 1999). This increases learners' willingness to develop interpersonal relationships through synergistic endeavors. So, playful learning is well suited to scientific investigation, Inquiry and Problem-Based Learning in classrooms, because it allows students to develop self-awareness as well as control over environmental objects, their movements, and their bodies (Zhou, 2017). Additionally, playfulness also drives students to attain traits such as flexible thinking, persistence, commitment, and a love of and fascination with learning (Boyer, 1997).

In practice, it is coherent with Inquiry and Problem-Based Learning, student-centered learning is the core principle to construct a playful learning environment. Diverse strategies are full of potential to bring as many opportunities as 'HaHa!'. As Zhou (2017) suggested, these strategies include game-based learning and gamification (Ejsing-Duuun & Karoff, 2015), pretend play (Russ, 2003), use of digital technologies (Loveless, 2002), and appropriate use of humor (Garner, 2006), etc. All the strategies allow 'openness', 'freedom' and 'enjoyment' to design learning activities. For example, when students learn the Pythagorean Theorem, teachers may design various games. They can encourage students to become 'Pythagorean Explorers' by engaging in hands-on learning activities. Teachers might also present real-world scenarios that require calculating distances, combining spatial reasoning with geometry skills. Students could play a game where they calculate the distance between two points on a coordinate grid. Through playful learning, this leverages elements such as challenge, competition, exploration, and achievement, which are naturally stimulating for students. As Furman (1998) suggested, when students are in a free and carefree environment, they can be urged to attend activities to explore questions by their intrinsic motivation. Cognitive studies also show that students will be more

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creative when internally motivated, when they feel some ownership of or control over the learning process, and when they look beyond one correct answer (Zhou, 2016).

*Teaching for Deeper Learning*

Deeper learning goes along with 'Aha!', inspiration and discovery. According to Pellegrino and Hilton (2012), deeper learning can be understood as learning for transfer, which means a process through which science students become capable of taking what they learn in one situation and applying it to new situations. Through deeper learning, STEM students recognize when a new problem or situation is related to what they have previously learned, and they can apply their knowledge and skills to solve them. This also is associated with students' intrinsic motivation and their interests in the content of the tasks, a focus on understanding the meaning of the learning material, an attempt to relate parts to each other, new ideas to previous knowledge, and concepts to everyday experiences (Chin & Brown, 2000).

STEM teachers should be able to capture students' 'Aha!' experience that can be used in evidence-based facilitation and summative assessment of learning tasks (Harris et al., 2019). When students engage in meaningful learning, they are purposeful and constantly monitor and reflect on the process of learning to evaluate the results of their own learning efforts (Chin & Brown, 2000). Teaching for deeper learning requires improved assessments with new types of tasks and situations that call upon students to demonstrate well-integrated learning (Harris et al., 2019). 'Aha!' shows evidence that students engage in learning towards correct directions. Teachers may use appropriate strategies to encourage higher level of constructive activity and foster deeper learning among students (Zhou, 2020). For example, 'dialogic teaching' or 'question-based instruction' can be applied when 'Aha!' is noticed (Oyama & Yagihashi, 2020; Philipson & Wegerif, 2020), like asking students to 'explain' or 'share ideas' in classrooms (Zhou, 2017). Students should be encouraged to answer questions such as 'what', 'how', and 'why', and to reflect on their learning experiences through practice. For example, when students engage in the game of 'Pythagorean Explorers', teachers should provide opportunities for immediate feedback and rewards, promoting a sense of accomplishment and reinforcing perseverance in tackling complex problems. As Wittrock (1994) suggested, understanding in science can be facilitated by learners generating analogies, metaphors, problems, models, and related devices that build meaningful relations between new information and previous experience; self-explanations of the new understanding (i.e., those spontaneously generated) are associated with greater problem-solving success and gains in deeper understanding. Students should also be told about what counts as an explanation and the attributes of a good explanation, which helps move to a deeper level of explanation (Chin & Brown, 2000).

Teaching for Deeper Learning can be cooperative with Inquiry and Problem-Based Learning and Playful Learning in one framework. As Rath and Brown (1996) addressed, science inquiry orients students to engage in deeper learning in different ways emotionally, conceptually,

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and socially; those modes of engagement are embodied by different actions such as exploration, pet care, performance, and fantasy (Chin & Brown, 2000). According to Roo (2020), beyond motivating students' engagement, playful learning pedagogies such as humor and joy can encourage critical thinking and communicative competence, which further support deeper learning. Additionally, different technologies can also be used in service of deeper learning and provide various tools of supporting learners as makers and creators, online and hybrid education environments, immersive media, games, and simulations (Dede, 2014).

## Conclusions

Creativity often emerges when learning is relevant to students, granting them significant ownership and control over the materials, techniques, and processes involved in engaging with knowledge or skill-based activities. Creativity can be expressed through scientific knowledge in various forms. Emotional expressions like 'Ah!' (wonder/curiosity), 'HaHa!' (laughter/fun), and 'Aha!' (discovery/inspiration) stem from the creative problem-solving process. These expressions are typically unconscious, surprising, and unexpected, requiring science teachers to apply appropriate pedagogies to nurture a creative climate. The 'Ah!-HaHa!-Aha!' tool is closely intertwined with pedagogies such as Problem- and Inquiry-Based Learning, Playful Learning, and Teaching for Deeper Learning. These approaches foster creativity by encouraging divergent thinking, allowing freedom to explore new methods, and providing ample resources and space rather than imposing rigid controls or limitations. In this context, this paper makes significant contributions to the development of a theoretical framework which also reveals its limitations of lacking empirical cases. This also reflects the need for intentional and positive support for diversity in pedagogical design, as well as the importance of encouraging various approaches to open-ended exploration. Such practices can make STEM teaching and learning more engaging and enjoyable, ultimately promoting creativity in pedagogical practice.

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RESEARCH REPORT

# STEM Research Experiences for Teachers: A Feasibility Study of The Sustainable Energy for Empowering Rural Communities Program

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**Abstract**

*Evaluating teacher STEM education programs is an essential but sometimes overlooked step in enhancing STEM education for students in the United States. The current study evaluated a novel STEM education program for rural teachers in sustainable energy engineering (SEER) to address basic program feasibility and teacher perceptions of the experience. A quantitative approach examined teacher (n=10) report of program engagement, utility, learning for the classroom, research for the classroom, and engineering principles. A qualitative approach gathered teacher responses about their experiences in the SEER program, including program activities, feelings, challenges, and benefits. Findings reveal that teachers were generally engaged and enthusiastic about the utility of the program, including its relevance for teaching in the classroom and growth of knowledge of engineering principles. Teachers also reported that they were excited but initially anxious about their ability to engage in STEM research. Towards the end, teachers reported enhanced confidence in their abilities, as well as broadened STEM networks and new curriculum for the classroom. Results provide support for the SEER program's ability to provide quality rural STEM teacher education.*

**Keywords:** *STEM, teacher education, rural schools*

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## Introduction

Interest in Science, Technology, Engineering and Mathematics (STEM) education has surged over the past few decades as global leaders have recognized the increased importance of educating the future labor force for tomorrow's challenges (Chai et al., 2021; Li et al., 2020). Although interest in improving STEM education for students in the United States has risen, there has been comparatively less attention focused on evidence-based STEM teacher education (Li et al., 2022; Jong et al., 2021). This oversight is unfortunate, as specialized education and training, evaluated empirically, is needed for STEM teachers to be successful in the classroom (Al Salami et al., 2017; Lo, 2021). Indeed, it is likely that multiple otherwise promising STEM reforms and innovations to-date have failed as a direct result of the insufficient focus on teacher education and preparation (Jong et al., 2021; Milner-Bolotin, 2018). When it comes to quality STEM teacher education, there are notable challenges that need to be addressed.

First, STEM itself is an interdisciplinary field, but many teachers do not receive training for integrated STEM but rather for the individual subject areas, such as mathematics, technology, etc. (Honey et al., 2014; Lo, 2021). Indeed, one recent study of teacher perceptions of barriers indicated that a lack of understanding of how to teach integrated STEM was the single biggest obstacle (Shernoff et al., 2017). Relatedly, an additional challenge with STEM teacher education is the perceived confidence and ability of teachers to translate that education into the classroom. Teachers often report concerns about how to implement STEM education, especially with respect to needed materials and appropriate pedagogy (Margot & Kettler, 2019; Lo, 2021). Of note, Du et al. (2019) examined STEM teaching quality, perceptions of STEM teaching ability, and teacher-identified STEM supports needed following teacher participation in a three-year professional development program. This study found that participating in the STEM professional development program resulted in enhanced STEM teacher effectiveness and knowledge, as well as identification of additional challenges, including the need for material resources and further technical training (Du et al., 2019). Similarly, Estapa and Tank (2017) reported that teachers in their applied STEM teacher education program, which paired teachers with engineers, struggled to translate learned knowledge into the classroom. A need for support around lesson planning and enactment was identified (Estapa & Tank, 2017).

STEM teacher education programs designed to address these issues must be evaluated to ensure that STEM teacher education and preparation adequately keep pace with the demand for STEM education (Lynch et al., 2019; Milner-Bolotin, 2018). To that end, many novel programs for STEM professional development have been piloted in the United States but only a fraction of these programs have been evaluated for their ability to prepare teachers to 1) teach STEM as an integrated topic and 2) implement STEM education in the classroom (Cavlazoglu & Stuessy, 2017; Lo, 2021). To date, no single STEM teacher education program has emerged as the gold standard in the United States, perhaps due to the absence of rigorous evaluation data but also likely due to

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the necessary tailoring of program features to meet specific school, district, or regional needs (Lynch et al., 2019; Milner-Bolotin, 2018). Indeed, the benefit of tailored STEM teacher education programs is that they can more flexibly address unique educational characteristics and contexts than their more rigid programmatic counterparts (Bentley & Cason, 2019; Matsko & Hammerness, 2014). Tailored STEM teacher education for rural schools is one such context in need of special consideration.

*Rural STEM Educators*

Rural STEM educators face distinct challenges in comparison with their suburban and metropolitan counterparts (Cain et al., 2024; Crain & Webber, 2021). For example, rural STEM educators may have comparatively fewer instructional resources, and their schools may have less overall capacity for teaching STEM (Saw & Agger, 2021; Showalter et al., 2017). These limitations may be further confounded by geographic isolation, preventing rural STEM educators from collaboration with peers at other institutions or availing themselves of nearby external resources (Jenks et al., 2015; Schafft, 2016). Additionally, there may be fewer accessible professional development opportunities for rural STEM educators than their counterparts (Downes & Roberts, 2018; Lavalley, 2018). These barriers faced by rural STEM educators, among others, warrant consideration with respect to the tailoring of STEM teacher education programs. In addition to challenges, rural STEM educators also have other specific characteristics which may be considered potential assets to leverage in the creation of tailored STEM teacher education programs.

Although rural education research has traditionally focused on challenges or perceived deficits, examining rural characteristics which may function as strengths for STEM educators is also important (Biddle & Azano, 2016; Sherfinski et al., 2020). For example, rural STEM educators may demonstrate resourcefulness and ingenuity in their teaching, abilities perhaps cultivated in educational conditions of inadequate support or resources (Chambers et al., 2019; Crumb et al., 2023). Rural STEM educators often live in the same communities where they teach, making them knowledgeable about both their students' rural background and any local STEM opportunities for their students (Lakin et al., 2021; Rivera et al., 2019). Relatedly, many rural communities have strong ties to local ecology, sustainability efforts, and STEM-related industries, such as wind, natural gas, and biomass, helping to facilitate career pathways for STEM students (Avery, 2013; Weber et al., 2014). Taken together, these characteristics of rural STEM education and educators helped to inform the novel professional development program Research Experiences for Teachers: Sustainable Energy Engineering for Empowering Rural Communities (RET: SEER; Nanny, 2016).


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*Oklahoma's Rural Educational Context*

With 52% of Oklahoma public-school children residing in rural communities, significantly higher than the national average of 29% (State-by-State results, 2023), Oklahoma's rural student population is notably diverse, ranking second nationally in diversity. Over 70% of the state's school districts reside within one of the 39 sovereign Tribal Nations, with American Indian students comprising 13.5% of the student population (Oklahoma State Department of Education Diverse Learner Team, 2020). This rural concentration, combined with the state's geographical diversity encompassing 12 defined ecoregions, underscores the need for autonomous, place-based STEM professional development opportunities for rural teachers (Staff, 2021).

The National Rural Education Association's research priority of Teacher and Leader Preparation, Recruitment, and Retention (2022) aligns closely with Oklahoma's rural context. While some studies have investigated teacher certification and new policies to address teaching vacancies, there is a pressing need for more research on effective programs to enhance retention, particularly as rural schools face challenges in recruiting and retaining STEM educators. Recent reports highlight the severity of this issue in Oklahoma, where rural districts struggle significantly to staff secondary science and math positions with highly qualified teachers. Lazarev et al. (2017) and Watson (2022) note that more than half of the state's districts have reported resorting to emergency measures to fill open teaching positions, underscoring the critical need for innovative solutions to address this persistent problem in rural STEM education.

Oklahoma's teacher shortage revealed over 500 teacher vacancies in 2016, escalating to 1,019 in 2022 (Lazarev et al., 2017; Oklahoma Education Facts, 2022). To address this issue, Oklahoma has implemented emergency teacher certification measures and lifted restrictions on adjunct teaching hours in K-12 schools (Camper, 2022). However, these measures have raised concerns about the potential "de-professionalization" of teaching, as evidenced by the low retention rate of only 19% of emergency-certified teachers remaining in the profession for three years (Wallis, 2023). Emergency teacher certifications for the 2023/2024 school year topped 5,000 compared to 40 in 2013 (Stockett, 2024) and is a growing issue for schools in the state.

Oklahoma's STEM industry pipeline is transitioning from fossil fuel to renewable energy production. The state ranks third in the nation for total renewable energy production between wind, solar, hydro, geothermal and biodiesel, with the preponderance of these production locales situated within rural communities (Renewable Energy, 2019). The state now accounts for 45% of electricity production from renewable energy sources (Energy Information Administration, 2022) accentuating the critical need for professional development opportunities for rural STEM educators such as the Research Experience for Teachers. Such initiatives are essential to ensure quality STEM instruction, long-term retention of qualified educators, and the development of skills and knowledge necessary for rural residents to capitalize on emerging renewable energy opportunities in their communities.

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*Evaluating RET: SEER*

The National Science Foundation (NSF) funds Research Experiences for Teachers programs with the express purpose of facilitating long-term collaborations among higher education institutions, school districts, and industry (RET; https://www.nsf.gov/). Previous STEM RET programs, including those targeting rural teachers, have proved beneficial in enhancing teacher report of STEM basic and applied knowledge, as well as strategies for translating this learning into the classroom and perceived teacher efficacy for STEM teaching (Bowen et al., 20221; Lux et al., 2024). SEER is an RET program designed specifically for rural teachers in Oklahoma. As part of this program, rural Oklahoma teachers participated in an authentic six-week summer research experience, learning hands-on skills from mentoring University of Oklahoma faculty conducting sustainable energy engineering-related research. Additionally, SEER includes training in STEM pedagogy with support for teacher creation of new STEM-related lesson plans and classroom applications. During the week, participating teachers alternated between dedicated laboratory time with PhD faculty working on one or more aspects of sustainable energy engineering and STEM pedagogy-focused instruction and lesson plan creation. At the end of the summer experience, teachers taught their lessons to other participants. The lesson plans and videos are housed in the Institute for Math & Science Education website. Additionally, teachers also prepared a research presentation or poster to present to their research professors and/or graduate students.

In order to assess the usefulness of this unique program, the current evaluation study employed a mixed methods analysis. Mixed methods refer to the general combination of both quantitative and qualitative data to address questions of interest (Cevik et al., 2024; Clark & Creswell, 2008). The benefit of collecting quantitative data for the SEER program is that individual's responses are easy comparable and can be directly examined using descriptive statistics, including variable means and standard deviations. The benefit of also collecting the qualitative data is that teachers can share more depth and detail about feelings and experiences during the program, with the potential to shed light on barriers or concerns previously not anticipated by program facilitators.

*The Present Study*

The aims of this study were two-fold. The first aim was to address basic feasibility questions concerning the ability of the program to engage and educate teachers, and in turn, teachers' commitment to translate that learning into their classrooms. To this end, we used a quantitative approach to examine participating teachers' self-reported engagement in the program and their perception of the program's utility, alongside teachers' reported intentions and perceived abilities to translate their experiences into secondary education teaching. The second aim was to gather free-response data about teachers' experiences during the program, including how they felt about activities, how they dealt with challenges, and how well they felt the program aligned with their goals and/or what benefits they felt the program provided. For this aim, we utilized a qualitative approach to gain more insight into the teacher's experiences during the summer program, including activities they participated in each week, their affective responses, perceived challenges, and their personal and professional goals for their time in the program.

## Method

*Participants*

Data were derived from a subsample of STEM teachers participating in the Sustainable Energy for Empowering Rural Communities program in the summer of 2024 (N=10, Mage = 45, SD = 8.86 years; 57% women). These teachers reported an average of 11.42 years of teaching experience (SD = 5.99). The majority (57%) reported having earned a bachelor's degree, and the remaining 43% reported some graduate-level education, including a master's degree or some doctoral-level education. Reported annual income varied, as 28.6% reported earning less than $60,000, 14.3% reported earning between $60,000-89,999, 28.6% reported earning between $90,000-119,999, and 14.3% reported earning more than $120,000. Two teachers declined to report income and race/ethnicity. While most teachers self-reported as White (50%), 7.1% identified as American Indian or Alaska Native, 14.3% identified as Asian or Asian American, and 14.2% identified as multi-racial.

*Procedure*

On the first morning of the SEER program, trained evaluation personal provided informed consent for teachers, highlighting that participating in assessment of the SEER program was not a requirement of SEER program. Data collection utilized SurveyMonkey (https://www.surveymonkey.com) and took place at the end of each of the six weeks of the program in summer 2024, with weekly follow-ups distributed via email to teachers participating in the assessment. Assessments took approximately 5-10 minutes to complete. No compensation was provided for assessment participation. East Central University institutional review boards approved all study procedures (IRB #24-32).

*Measures*

After week 1, teachers completed a short demographic questionnaire and open-ended questions about that week's program activities, experiences and challenges. Teachers answered these same open-ended questions again for weeks 2-6. After week 3 (midpoint) and week 6 (end), teachers also completed additional questionnaires on program engagement, utility, applying learning, research, and engineering principles in the classroom.

*Teacher Program Engagement:* Teachers completed a 12-item measure of perceived engagement in the Sustainable Energy for Empowering Rural Communities program created for program feasibility assessment. Instructions prompted teachers to indicate "how true each

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statement is from your perspective" using a 7-point Likert-type scale ranging from 1 (not at all true) to 7 (very much true). Example items include "I intentionally get involved in what is going on at RET" and "When I am doing RET activities, I feel interested." Internal consistency was high ($\alpha$ =.96 at midpoint and .96 at endpoint, respectively).

*Teacher Program Utility:* Teachers completed an 18-item measure of perceived program utility in the Sustainable Energy for Empowering Rural Communities program created for program feasibility assessment. Instructions prompted teachers to indicate "how true each statement is from your perspective" using a 7-point Likert-type scale ranging from 1 (not at all true) to 7 (very much true). Example items include "I see how the ideas I have learned and reviewed here are valuable to me as a teacher" and "I recognize how these skills will be valuable in my teaching." Internal consistency was high ($\alpha$ =.99 at midpoint and .99 at endpoint, respectively).

*Teacher Learning for the Classroom:* Teachers completed a 25-item measure of perceived classroom applicability for the Sustainable Energy for Empowering Rural Communities program created for program feasibility assessment. Instructions prompted teachers to indicate "how true each statement is from your perspective" using a 7-point Likert-type scale ranging from 1 (not at all true) to 7 (very much true). Example items include "I see these skills as feasible to use in my teaching" and "These ideas fit well with what I do in my classroom." Internal consistency was high ($\alpha$ =.98 at midpoint and .98 at endpoint, respectively).

*Teacher Research for the Classroom*: Teachers completed a 6-item measure of perceived classroom research application for the Sustainable Energy for Empowering Rural Communities program created for program feasibility assessment. Instructions prompted teachers to indicate "how true each statement is from your perspective" using a 7-point Likert-type scale ranging from 1 (not at all true) to 7 (very much true). Example items include "RET is increasing/has increased my confidence in integrating research into my classroom" and "The RET program is helping me/helped me see the value of implementation of integrating research into my classroom." Internal consistency was high ($\alpha$ =.98 at midpoint and .98 at endpoint, respectively).

*Teacher Engineering Principles for the Classroom*: Teachers completed a 6-item measure of perceived engineering principles classroom application for the Sustainable Energy for Empowering Rural Communities program created for program feasibility assessment. Instructions prompted teachers to indicate "how true each statement is from your perspective" using a 7-point Likert-type scale ranging from 1 (not at all true) to 7 (very much true). Example items include "Because of this experience I have greater ability to integrate engineering principles into my teaching" and "I am seeing/I saw how to implement engineering principles into my classroom teaching." Internal consistency was high ($\alpha$ =.95 at midpoint and .95 at endpoint, respectively).

*Plan of Analysis*

A parallel mixed methods approach was utilized to address the dual aims of the study (Clark & Creswell, 2008). For aim 1, descriptive statistics and basic bivariate analyses were performed in IBM SPSS Statistics (V. 27; IBM, 2024) using study-specific measures for teacher program engagement, teacher program utility, teacher learning for the classroom, teacher research for the classroom, and teacher engineering principles for the classroom. Because of the small sample size, no inferential tests were performed. For aim 2, qualitative analyses were performed utilizing modified Qualitative Content Analysis (Roller, 2019) to identify prominent themes within teachers' reported program activities, experiences and challenges. The lead investigator generated the coding framework using a combination of inductive and deductive approaches. All themes were coded manually. In the first stage of analysis, recurrent themes were identified related to teachers' activities, emotional experiences, and challenges/response to challenges. These themes were then refined for the main analysis, including grouping together similar content.

## Results

*Aim 1: Descriptive Statistics and Bivariate Analyses*

Table 1 includes means and standard deviations for all study measures at week 3 and week 6, as well as bivariate correlations between these measures. Means across measures were high at both week 3 and week 6 ($M>5.37$, 5= More true than not). All study measures were positively correlated within each time point ($\beta>.68$, $ps<.05$), including teacher program engagement, teacher program utility, learning for the classroom, research for the classroom, and engineering principles for the classroom. There were no statistically significant stability correlations for measures between time points, likely a reflection of the small sample and variability across time. These midpoint and end point results indicate that teachers felt generally positive about the experience and specifically about their engagement in the program as well as the program's ability to inform their STEM teaching in the classroom.


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Table 1.
*Descriptive Statistics and Correlations for Study Variables at Week 3 and Week 6 (n=10)*

| Variable | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Week 3 Teacher program engagement | 6.20 | 0.98 | — | .79** | .73* | .68* | .70* | .07 | .22 | .20 | -.08 | .07 |
| 2. Week 3 Teacher program utility | 5.70 | 1.33 | | — | .79** | .88** | .92** | .29 | .50 | .44 | -.01 | .27 |
| 3. Week 3 Teacher learning for classroom | 5.68 | 1.01 | | | — | .89** | .91** | -.30 | -.03 | .04 | -.44 | -.30 |
| 4. Week 3 Teacher research for classroom | 5.38 | 1.22 | | | | — | .92** | -.10 | .19 | .32 | -.15 | -.08 |
| 5. Week 3 Teacher engineering principles for classroom | 5.65 | 1.17 | | | | | — | -.06 | .16 | .14 | -.32 | -.09 |
| 6. Week 6 Teacher program engagement | 6.53 | 0.70 | | | | | | — | .84** | .74* | .72* | .87** |
| 7. Week 6 Teacher program utility | 6.39 | 0.93 | | | | | | | — | .82** | .75* | .94** |
| 8. Week 6 Teacher learning for classroom | 6.18 | 0.83 | | | | | | | | — | .76* | .73* |
| 9. Week 6 Teacher research for classroom | 6.25 | 0.76 | | | | | | | | | — | .87** |
| 10. Week 6 Teacher engineering principles for classroom | 6.33 | 0.92 | | | | | | | | | | — |

*$p < .05$. **$p < .01$

*Aim 2: Qualitative Analyses*

With respect to weekly activities, most teachers reported that they were engaged in hands-on learning and experiments with their PhD mentors, including "create[d] a Winogradsky column," "set up a reactor to separate the hydrogen from the methane," and "creat[ed] and test[ed] fiber/carbon reinforced concrete and plastics." The most common emotion that teachers reported experiencing during the initial week activities was excitement (n=6); however, this excitement was frequently coupled with some worry or trepidation, especially about individual ability (n=4). For example, one teacher states that they initially experienced feelings of "optimism and validation peppered with moments of confusion and doubt." Similarly, another teacher reported experiencing "a mix of excitement and apprehension." A third teacher explains that their feelings of insecurity stemmed from a "complete and utter lack of knowledge and experience with the subject matter." A fourth teacher echoes similar concerns, stating that "I felt that some of it [the science] was way above my science education level." However, these initial feelings after the first week gave way to reports of increased confidence and ability in the following weeks. By week 4 teachers no longer report any feelings of anxiety. Instead, they now reported finding

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pleasure in their scientific activities (n=4) and pride in their accomplishments (n=6). For example, one teacher relates that they felt "happy and excited to see [their] hard work pay[ing] off." Another explains that they felt "very much more confidant… in my lab and pedagogy work. Finding our stride…" Importantly, several teachers (n=4) reported feeling like a "[real] scientist," because of their experiences, highlighting just how much they perceived their knowledge, and skills grew during the SEER program.

Teachers also reported that their experiences were not without challenges. Teachers commonly relayed after the first week that the perceived gap between their science education and expectations in the lab was a notable obstacle (n=8). As an example, one teacher related that they "faced challenges understanding complex lab safety protocols and grasping technical aspects of the project." Similarly, a second teacher echoed that "I didn't understand a lot of terminology discussed in the lab. I had to take notes and go back and look up specific terminology and processes." Later in the program teachers moved on to highlight specific research project challenges (n=6) such as "using [the] glove box," "maintaining consistency and being careful when dealing with chemicals…," and running out of "polytungstate chemical." A few teachers noted that working with specific individuals was challenging (n=2).

With respect to goals for their SEER program experience, teachers most reported that they wanted to inform their teaching with current STEM research (n=7). One teacher reported "For my RET experience, I aim to integrate new STEM research into my curriculum, develop engaging, inquiry-based lessons, and enhance my teaching through collaboration with researchers and educators." Another teacher echoed "I am looking for lessons and activities to take back to my classroom." Yet a third stated that "Mostly I just want to be at the cusp of current research and better convey the excitement new discovery generates to my students." When asked to reflect at the end of the SEER program experience on their earlier goals, teachers generally responded positively. Three specific components emerged, including increased contacts and connections (n=3; e.g. "I added people to my network."), enhanced confidence in STEM teaching (n=3; "Confidence in my abilities."), and new/improved curriculum (n=5, "Creat[ed] new curriculum to help students understand the engineering process."). Taken together, the qualitative data demonstrated that teachers had enthusiasm and excitement for the SEER program, often mixed with apprehension about their perceived inexperience, that ultimately gave way to increased confidence, knowledge and applicable skills for the classroom by the end of the summer program.

## Discussion

This study utilized a mixed methods approach to evaluate the feasibility of SEER, a novel research experience for rural teachers utilizing a sustainable energy engineering program. The first aim used a quantitative lens to address foundational feasibility questions about the program's ability to engage and educate teachers, as well as teachers' commitment to translate

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that learning into their classrooms. These results indicate that participating teachers felt positively about the program, including high levels of engagement and perceived utility. Teachers also indicated that the SEER program was relevant and informative of their learning for the classroom context, applying research in the classroom, and for using engineering principles in the classroom. These findings help demonstrate that the SEER program is a practically useful one for rural STEM teachers, lighting that teachers see the utility generally and its specific application to teaching STEM and STEM-focused research in the classroom. Findings from this program resonant with those findings from other RET STEM programs targeting rural educators. Indeed, the basic model of intensive summer STEM education training for teachers seems a sound one for enhancing teacher readiness to teach STEM in the classroom (Bowen et al., 2021; Lux et al., 2024). Replicating these findings in the specific area of rural Oklahoma helps to establish the usefulness of such programs across varied rural contexts.

The second aim of the study was to gather qualitative data about teachers' experiences during the program, including emotions related to weekly activities, perceived challenges, and program benefit. These findings indicate that teachers were excited about the program, although they also experienced some apprehension about not feeling fully prepared for the advanced research aspects of the program. The excitement reported by teachers parallels the teacher enthusiasm and engagement in the SEER program supported by the quantitative measures. The concomitant apprehension, however, along with the specific identified gap between perceived skills and needed research abilities, is a unique contribution of the qualitative data, highlighting the value of this approach. Other work examining barriers to STEM education has previously identified anxiety as a cause of STEM avoidance (Christensen & Osgood, 2023). Indeed, teachers may feel unprepared by their earlier education to teach STEM, or in this case, engage in STEM research. That apprehension quickly ebbed and was replaced by growing self-efficacy, likely reflecting the benefits of the SEER program. Enhanced self-efficacy for teaching STEM, likely related to enhanced knowledge and experience, has been reported in similar rural-focused STEM RET programs (Bowen et al., 2021; Lux et al., 2024). In particular, the immersive nature of such summer programs may help participating teachers build confidence rapidly. This increased confidence is also specifically cited by multiple teachers as a key benefit of the program, alongside building STEM connections and curriculum. Such benefits, identified by the teachers participating in the program, underscore the value of the SEER program for preparing rural STEM educations to teach the next generation of STEM students. That these rural teachers specifically identified connections and growing their STEM contacts as a program benefit is important to note, as it highlights the ability of SEER to address rural education challenges related to isolation and limited resources.

The benefit of the mixed methods approach to this evaluation lies in the dual ability of this data to address basic feasibility questions about implementing the SEER program for teachers as well as to uncover unexpected challenges and experiential aspects of teachers' participation in the program. To that end, results from aim 1 helped to establish the general utility of the program, demonstrating that teachers found it useful for strengthening their ability to teach research-based STEM in the classroom. While this information is essential and replicates similar findings from other STEM RET programs (Bowen et al., 2021; Lux et al., 2024), it does not shed much light on the unique challenges and characteristics of the program as experienced by teachers. Results from aim 2 help to address these questions. Understanding that teachers found the scientific content of the program initially daunting before developing a sense of mastery may further help to make sense of the variability in aim 1 measures, as it is possible that this qualitative change in teachers was not well assessed with the basic feasibility questionnaires. Indeed, understanding how immersive teacher STEM education programs may help shift the teachers' sense of content mastery and educational identity represent important next steps for future evaluation. In the future, novel RET programs may wish to incorporate psychological skills training, such as emotion regulation or mindfulness techniques (Wimmer et al., 2019), to combat anxiety and facilitate teacher success in the summer program and ultimately the classroom beyond.

### Limitations and Future Directions

This evaluation study has multiple strengths, including examination of program participation at multiple time points, as well as the utilization of a mixed methods approach to address study aims. No evaluation study is without limitations, however. It is important to note that these data only gather teachers' perception of the program and their self-report of future transferability of learning into the classroom setting. Future research should follow up with teachers during the school year to examine the actual application process and classroom learning. Additionally, the measures used in this study were specifically designed to address the SEER program. While the advantage of creating measures for this evaluation is that questions could be tailored specifically to the STEM-related teacher education constructs of interest, the question remains concerning the broader psychometric properties of these new tools. Future work, if continuing to utilize these measures, should also examine convergent validity with similar measures and divergent validity with different measures, among other considerations. Lastly, it should also be noted that these measures did not demonstrate stability correlations from the midpoint to the endpoint. Future work should also examine the measures' reliability over time in a larger sample.

### Conclusions

By evaluating the rural STEM teacher education program SEER, this study helped to illuminate the perceived usefulness of the program and teachers' report of their experiences as program participants. Such data help to establish the basic feasibility of the SEER program, including uncovering specific challenges indicated by teachers during their summer

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participation. More broadly, evaluating STEM teacher education programs such as SEER help to ensure that resources invested in advancing STEM education are directed towards evidence-based efforts likely to succeed.

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RESEARCH REPORT

# A Text Analytical Study of STEM Inquiries in Grad Slam Competition

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**Abstract**

*Grad Slam competitions offer a unique opportunity for students to showcase their STEM research. As a popular platform to promote STEM education in the United States, the competition limits presentations to three minutes, demanding rigorous training to improve graduate students' presentation skills. This research incorporates text analytics to extract the substance of Grad Slam projects across 2019-2022 and assess the effectiveness of Grad Slam training. Videos of Grad Slam presentations are transcribed to enable the use of Natural Language Processing to transform the unstructured text into normalized data suitable for processing by machine learning algorithms. R scripts are developed to disentangle the overall features of the Grad Slam outcomes. Survey data are analyzed to report student feedback about workshop preparation for project presentation. The text mining not only shows strong connections between Grad Slam presentation contents and STEM subject inquiries but also reflects a trend of strengthening research culture at a Hispanic Serving Institution in the United States. The survey feedback reconfirms the benefit of workshop training. The Grad Slam competition and its related workshops emerge as a unique platform, aside from STEM coursework, to help graduate students excel in their specialty fields, as well as establish confidence in communicating their research to a general audience.*

**Keywords:** *Grad Slam, Three Minute Thesis, Text Analytics, Communication Skills.*

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## Introduction

A Grad Slam is an academic competition that challenges graduate students to concisely present their research in an engaging manner to a general audience. It has gained increasing popularity in higher education because effective communication skills are critical for academic and professional success (Bishop, 2014). The event also contributes to the enhancement of science, technology, engineering, and mathematics (STEM) education by allowing participants and audiences to obtain insights across various subject-based inquiries. Therefore, the competitive aspect of Grad Slam not only inspires higher levels of academic performance but also creates a collaborative community to build learning capacities within and between departments. The competition further pushes students to establish a deep understanding of the challenges they may face in research dissemination. Held at a Hispanic Serving Institution (HSI), this event can help promote role models and shatter stereotypes in STEM education. Eventually, it paves the way for increased Hispanic representation to enhance a more inclusive and diverse scientific community.

Prizes and/or recognitions for Grad Slam presentations strengthen the institutional visibility among key stakeholders, including faculty, peers, and the public. As a result, the positive image can attract high-caliber students and faculty, advancing the institution's overall academic excellence. In addition, as a platform to accommodate diverse scholars, it enables the institutions to incorporate their cultural heritage in enriching the meaningfulness of STEM inquiries. Based on the overall impact at both student and institution levels, this research is designed to fit the interest of a dual target audience, i.e., the future STEM researchers who participated in Grad Slam competitions and the university leaders who cared about the development of campus research culture.

Research undertakings are inseparable from the population's ethnic composition. As the Latino population grows in higher education, assisting HSIs to become powerhouses of STEM research, especially at the postbaccalaureate level, supports the nation's global competitiveness and technological advancement. Beyond the subject competency, Good et al. (2010) identified "communication gaps as the major barrier that impeded [Latino] student achievement" (p. 327). In this context, Grad Slam competitions at an HSI can foster subject belonging for traditionally underserved students who are hampered by language barriers in STEM education (Rodriguez et al., 2022).

To date, however, studies have yet to be conducted to assess the value of Grad Slam preparation and extract the essential information from student presentations. Meanwhile, text analytics has emerged as a new and powerful research tool in data science that encompasses a suite of computational techniques aimed at extracting meaningful information from unstructured textual data. Central to these techniques are Natural Language Processing (NLP) and machine learning, which collaboratively facilitate the aggregation, analysis, and interpretation of qualitative data. On the one hand, NLP is positioned in a subfield of artificial intelligence that focuses on the interaction between computers and human language (Stryker & Holdsworth, 2024). On the other hand, machine learning involves training algorithms on data to automatically categorize text, identify patterns, extract relevant information, and make trend predictions (Lexalytics, no date). In combination, text analytics becomes a useful tool that leverages NLP to interpret human language and machine learning to analyze and derive insights for evaluating educational programs.

Due to its capacity to process vast amounts of unstructured text, the advancement of text mining has demonstrated tremendous potential for systematic examination of qualitative feedback in educational research. For instance, Dake and Gyimah (2023) applied sentiment analysis to educational data, providing insights into students' emotional states during presentations. Ferreira-Mello et al. (2019) also provided an overview of educational text mining applications, highlighting their role in uncovering trends in educational data. Huang et al. (2020) further discussed the use of text analytics to examine large-scale educational data for student engagement. These past examples provided additional background on text analytics applications in educational research.

Built on the extensive actionable capacity of text analytics, this article begins with a brief literature review to specifically clarify the context of Grad Slam competitions in STEM education. In a subsequent method section, an innovative approach to text analytics is described for investigating the features of student inquiries demonstrated in Grad Slam presentations. In addition, student survey data are employed to delineate the feedback about the learning opportunities. The implication of research findings is clarified in a discussion section to reflect on key questions derived from the current research literature.

## Literature Review

Academic contests for graduate students have been around for quite some time, but the specific term "Grad Slam" and its organized competitions may have varying origins in different countries. In the United States, the University of California (UC) system is often credited with popularizing Grad Slam (see Aguilera, 2019). For instance, it was reported that "UC Santa Barbara was the first UC campus to implement the Grad Slam format in 2013" (Cohen, 2015, p. 6). The idea was to have graduate students from different disciplines present their research to a panel of judges and a general audience. This platform is aimed at training students to communicate the significance of their research in a clear and understandable way to non-specialists. The competitions are sometimes branded as "Grad Slams" in California, referencing "poetry slams" during which poets perform spoken word to a live audience, as well as the term "grand slam" which designates a championship athletic contest, except for using the term "grad" as an abbreviation for "graduate student" in place of "grand."

In Australia, similar competitions can be tracked further back to 2008 when the University of Queensland launched a Three-Minute Thesis competition, or 3MT, as an innovative academic contest in graduate education. It challenged graduate students to present their research in 180 seconds or less to a general audience using one static slide. This competition has grown in popularity, with over 900 universities across 85 countries hosting the event each year (Three Minute Thesis, no date). In particular, 3MT competitions are celebrated for their exhibition of graduate students' academic, presentation, and research communication skills (Three Minute Thesis, no date). As White (2021) acknowledged, the competition "stands out as a particularly important professional development activity" (p. iv). While there is a body of research examining the rhetorical strategies used by presenters during 3MT competitions (Carter-Thomas & Rowley-Jolivet, 2020; Hu & Liu 2018; Hyland & Zou, 2022; Kathpalia 2024; Ma & Jiang 2025), little is documented about participant experiences of participation (Muslimin & Zaki, 2024) or the impact of training and preparation activities on the content and quality of their presentations.

The Grad Slam or 3MT competitions are frequently recorded and posted on university and social media websites. For many participants, this can be intimidating as fear of public speaking is common both inside and outside of higher education settings (see Grieve et al, 2015; Lall & Biswas 2020). Students are expected to distill compelling STEM information into clear and common-sense explanations, which might trigger language barriers for some presenters. As Bell (2023) observed, "for graduate students who spend hundreds of hours on their research, Grad Slam is a challenge because they have to communicate the highlights in just 3 minutes!" (p. 1).

Nonetheless, the availability of Grad Slam presentations for viewing by a wider audience provides benefits. It allows viewers to pause and rewind, which can be particularly beneficial for understanding the projects of a group of Hispanic students who have English as their second language. Video recording also fits the needs of adult learners, including graduate students, who often balance their studies with work and family commitments. Knowing their presentation will be recorded and potentially viewed by a large audience can motivate them to refine their communication skills and deliver a clear presentation. Further, in STEM education inquiries, incorporating video recording is considered an effective approach. For instance, Gerald Bracey (2003), a columnist of Phi Delta Kappen, openly praised the TIMSS 1999 Video Study, "in which videotapes of teachers actually teaching eighth-grade mathematics in seven countries were studied" (p. 253).

While the UC system is a notable leader of Grad Slam support, the California State University (CSU) system serves many more Hispanic students in California. Unlike the high selectivity across UC campuses, CSU is known for its accessibility and focus on providing affordable and quality education to a broad range of minority student groups. Video recording of STEM activities offers a visual illustration of role models for future students, particularly those of Latino origin as the largest minority in the state. The method is effective because the digital materials can be presented to large numbers of students "without any additional effort on the

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role model's part and are at least as effective as live interactions" (Gladstone & Cimpian, 2021, p. 15). It also empowers Hispanic graduate students by bolstering their confidence in STEM subject inquiries.

Under Title V, Part B (Title Vb) provision of the federal government, the U.S. Department of Education established a Promoting Postbaccalaureate Opportunities For Hispanic Americans (PPOHA) Program to address a two-fold purpose of expanding (1) postbaccalaureate opportunities for, and improve the academic attainment of, Hispanic students; and (2) the postbaccalaureate academic offerings as well as enhance the program quality in the institutions of higher education that are educating the majority of Hispanic college students and helping large numbers of Hispanic and low-income students complete postsecondary degrees. This study receives funding from PPOHA to support Grad Slam preparation at California State University, Bakersfield (CSUB), an HSI with a service area as large as the state of New Jersey. As a former university president announced, "Grants and programs throughout the university's four schools seek to improve Latinx representation, particularly in STEM professions" (Zelezny, 2022, p. 3). In supporting the PPOHA grant alignment with the commitment of CSUB to improving STEM education, dual questions are adduced to guide this investigation:

1. What are the top features of Grad Slam presentations prior to and during the period of program funding?
2. What is the student feedback about the learning experiences from workshop preparations for the Grad Slam?

While survey data are collected from Grad Slam workshops to address Question 2, Question 1 demands rich information extraction through text mining, which includes (1) the creation of an online portal to transcribe the video content into text files, (2) the application of NLP to transform the unstructured text into normalized data suitable for processing by machine learning algorithms, (3) development of R scripts to extract the overall features of the Grad Slam outcomes.

From the methodology perspective, the impact of text mining in educational research has been expanded in recent years, but not for the Grad Slam information extraction. For instance, a study by Yang et al. (2023) utilized text mining to analyze educational studies, providing insights into how scholars employ text mining in their research. By examining the transcripts of presentations, researchers can identify prevalent themes, jargon usage, and the complexity of language. This analysis aids in understanding how effectively students convey complex ideas to a general audience.

It has also been generally agreed that "Compared to information obtained through surveys and interviews, the information provided by video analysis tends to be more objective" (Wang et al., 2023, p. 6). According to Ranjan and Mishra (2022), the adoption of text analytics holds immense value for video information extraction. In comparison to traditional methods in qualitative investigations (Best & Kahn, 2010), R can process large datasets, such as the ones from

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Grad Slam videos, much faster than manual coding. More importantly, it can ensure consistent result replications and has robust packages for data visualization. Built on the power of computational linguistics and machine learning, text mining techniques have largely revolutionized the way researchers aggregate a rich source of information from unstructured data to summarize student presentations of STEM inquiries (Baker & Yacef, 2009). Details of the data selection, information cleaning, and R-based analytics are elaborated in the method section.

**Methods**

*Data Selection*

To strengthen the impact of this investigation, it is important to note a learning gap in which Latino students often face unique challenges in higher education, particularly in a public event like Grad Slam that requires science communication skills to present complex research succinctly to diverse audiences. Since HSIs play a pivotal role in educating Hispanic students, choosing an institution with a strong Hispanic serving mission can shed light on the unique challenges and strengths of the Grad Slam competition. According to Excelencia in Education (2024), the Hispanic full-time equivalent student ratio has been retained at 60.8% across CSUB's graduate programs, while the concurrent average ratio in the nation was 36.7% in Academic Year 2023-2024. Built on the data indicator for strong Latino student services, Grad Slam videos are selected from CSUB to address Question 1 during the period of Title Vb funding.

As a result, the video archives are gathered online and transcribed verbatim using Otter.ai, an AI-based transcription platform, to ensure accuracy and consistency. The texts were manually reviewed to correct errors in presenter identification, punctuation, and terminology. The transcription files were exported in txt format for compatibility with R scripts and subsequent preprocessing steps of data cleaning.

*Information Cleaning*

Meticulous data cleaning is indispensable for improving the reproducibility of research outcomes from text analytics (Upadhye, 2020). Techniques such as tokenization, stemming, lemmatization, and stopword removal are applied to strengthen the format uniformity. More specifically, each token (word) is defined as a sequence of alphanumeric characters. A heuristic approach is taken to trim prefixes and suffixes through word stemming to reduce the tokens to their root forms. Tokens are further simplified into the base structures in a lemmatization process to ensure that the resulting configuration is a valid word in English. Stop words (e.g., "and," "the," "is") are removed using predefined stop word lists from the stopwords package in R. Custom stop word lists are applied to exclude terms that are not analytically meaningful. Text cleaning also involves converting all characters to lowercase, removing numbers, punctuations, and special symbols, as well as replacing contractions with their expanded forms (e.g., "isn't" → "is not").

Correction of misspellings and wrong data entries has added another layer of protection for maintaining data integrity.

Altogether, the data cleaning process has reduced noise, enhanced consistency, corrected errors, and facilitated reproducible workflows to make the analyses both reliable and replicable. Tokenization and text preprocessing standards adhered to best practices in NLP, enabling accurate, reproducible, and insightful analysis of presentation transcripts from academic competitions. By integrating precise transcription methods with robust text analytics techniques in R, this study ensured the comprehensive processing of textual data.

In summary, the data choice is designed to foster more inclusive Grad Slam support for STEM success among graduate students, particularly those of Hispanic origin, to promote diversity and advance STEM research communication. The ability to achieve consistent results using quality data and reliable methods is also a general cornerstone of scientific research, which demands the reduction of irrelevant information, inconsistencies, discrepancies, and non-standard abbreviations. Cleaning processes like text restructuring, tokenization, stemming, lemmatization, stop word removal, and spell-checking help mitigate these issues, leading to more accurate analyses. Upadhye (2020) emphasizes that text data cleaning is a crucial preprocessing step in NLP and text data analysis aimed at improving the quality, reliability, and usability of textual information.

*Method Choice*

The method choice is aligned with two questions for this investigation. While student feedback about workshop preparations for the Grad Slam competition is gathered from a participant survey (Question 2), the text analytical methods are relatively new. To address the objective of extracting the substance of Grad Slam projects across 2019-2022 in Question 1, this study followed Kellogg's (2024) classification of data analysis for studying (1) outcome differences, (2) variable relations, (3) trend descriptions on the time dimension.

As a result, a lexical dispersion plot (LDP) is employed to visualize the difference in content emphases among different data corpora. It displays the occurrences of target words across multiple documents to highlight where and how frequently terms appear (Svartzman et al., 2020). Hutchinson (2022) recommended LDP, which "each strike along the word offset axis signals that a specific word is mentioned within the corpus of data" (p. 56). Due to the focus on extracting essential information, the density of strikes in LDP is an important outcome. However, the specific time a word appeared depends on the sequence arrangement of the Grad Slam presentations, which has nothing to do with the content coverage. In other words, it does not matter whether the word appeared relatively early or late if it occurred. Hence, labels are omitted for the axis of the relative token index in LDP to avoid unnecessary distraction from the occurrence time. This practice follows the LDP literature to focus on the strike density. As Amin et al. (2022) asserted, LDP allows researchers to determine "how many times the word (or multiple words) occurs from the beginning to the end of the text" (p. 25).

The examination of Grad Slam outcome differences is further extended from the token tracking in LDP to a broad summary of multiple documents in a word cloud plot. Highlighting frequently mentioned words helps identify trends and gain an overall picture of the topic coverage from 2019 to 2022. According to Mostafa et al. (2023), "A word cloud plot is an appealing visual tool that can be used to summarize textual data" (p. 12434).

Another feature of text mining hinges on keyness plot construction. "Unlike frequency counts, the keyness of a word does not necessarily anticipate a high, but rather an unusual, frequency" (Đurović, 2023, p. 188). Koch et al. (2022) and Weinberg (2021) recommended the keyness method to contrast the text features, which permits this study to make a comparison between Grad Slam 2022 and the previous competitions. In addition, a plot of the most frequent words (MFW) is needed to visualize repeated themes through text data aggregation (e.g., Kostelej & Bagić Babac, 2022). Therefore, an MFW plot is constructed to identify common themes across Grad Slam presentations.

In terms of the relationship perspective, plotting token-indicator relations involves picturing the associations between specific words or phrases (tokens) and particular variables or outcomes (indicators), which is a powerful technique for uncovering meaningful patterns within textual data. "This analytic technique allows for evocativeness and interpretation as well as attunes the research to dynamic interrelationships in and across themes" (Scharp, 2021, p. 549). Therefore, a plot of Token-Indicator Relations (TIR) is created in this investigation. Due to its computing intensity, however, the Quantitative Analysis of Text Data (Quanteda) package in R limits the number of tokens for the network construction (Watanabe & Müller, 2023). In this study, STEM subject terms of environmental, nursing, health, and mental health sciences are extracted for the TIR plotting. The token selection is based on the graduate program offerings in geology, biology, nursing, and psychology at CSUB (2023).

In summary, the Quanteda package is employed to support the R script execution for key information extraction in Question 1. According to Benoit (2018), "Using C++ and multithreading extensively, quanteda is also considerably faster and more efficient than other R and Python packages in processing large textual data" (p. 774). Meanwhile, the data collection is protected by a research protocol of the Institutional Review Board (IRB). Starting in 2020, four workshops have been offered to prepare students for the Grad Slam competition. While Workshop A is designed to help students familiarize themselves with Grad Slam features, Workshops B, C, and D address specific themes of Crafting a Memorable Message, Designing a Compelling Visual Presentation, and Communicating with Confidence, respectively. Due to the pandemic impact in 2020 and 2021, inadequate survey data were gathered from the workshop attendees. Hence, feedback for this study is delimited to the workshop evaluation in 2022 (Question 2). All participants of Grad Slam were recruited from the graduate student group at CSUB. Per IRB stipulation, the survey

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did not collect individually identifiable data, and thus, it did not involve consent form administration or demographic information gathering. Statistical findings and qualitative comments are analyzed to summarize the survey results.

## Results

*Findings from Text Mining*

After data cleaning, an LDP has been drawn from the text data to compare meaningful tokens across the four Grad-Slam events. Some of the tokenized terms, such as nurs[s] and scienc[e], are shown as truncated words in LDP to reduce the matrix sparsity. As Katre (2019) put it, "Lexical Dispersion Plots effectively depict how multiple topic keywords appear throughout the corpora" (p. 8579). In Figure 1, keywords are extracted from the presentation content to indicate STEM topic coverage among the Grad Slam sessions. Details of the result interpretation are elaborated across 2019-2022 in the discussion section.

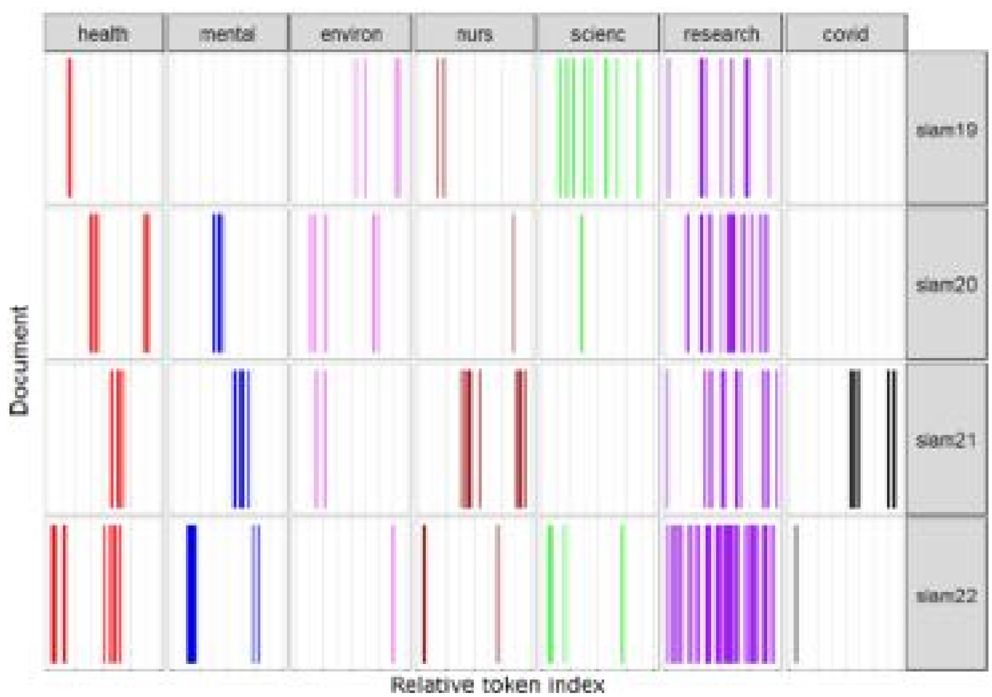


*Figure 1.* Dispersion of Content Coverage in Grad Slams

In Figure 2, a word cloud plot is constructed in such a way that "The size of each word and its closeness to the cloud center determine its significance" (Mostafa et al., 2023). The tokenized terms are closely related to biology, geology, and other STEM fields to echo the topic identification from a keyness plot in Figure 3. In comparison to Figure 2, Figure 3 leans toward the probabilistic inference because "Keyness analysis introduces the term 'key word', which is a word that occurs in a text more often than we would expect to occur by chance alone" (Rao & Taboada, 2021, p. 30).

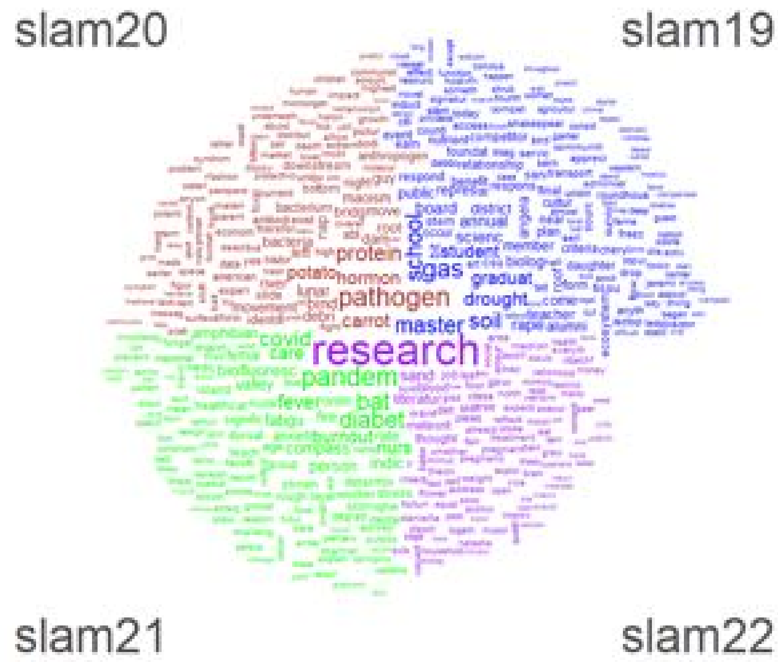


*Figure 2.* Word-Cloud Plot on Key Components of Grad Slams

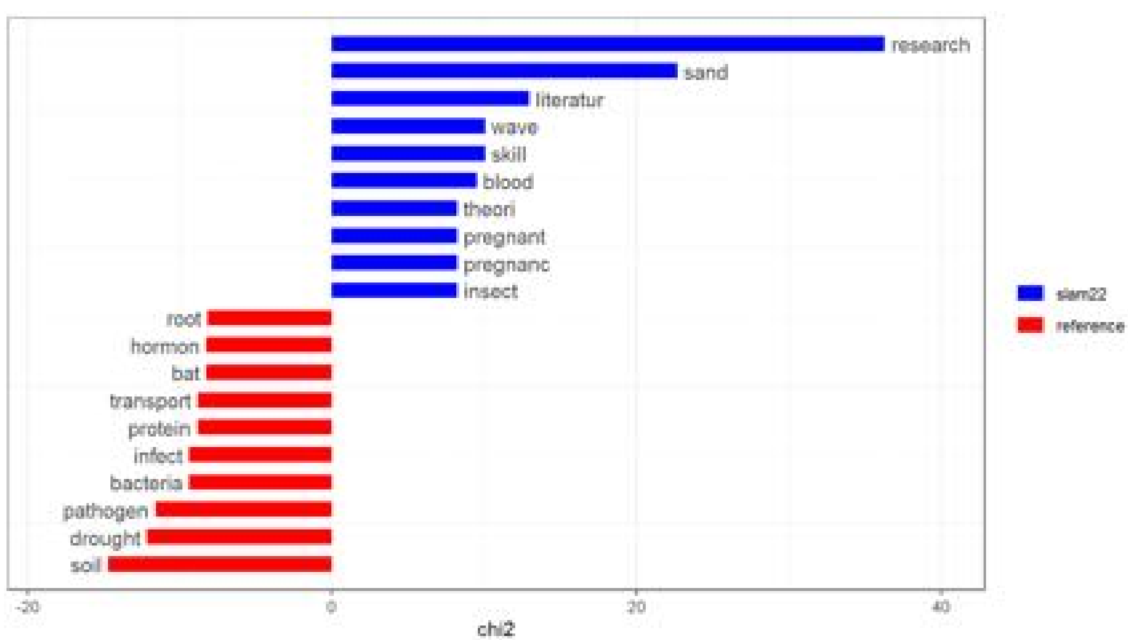


*Figure 3.* Contrast of Grad Slam 2022 on Year 3 Outcomes

With the Title Vb funding, student presentations in 2020, 2021, and 2022 consistently addressed topics in mental health, an area missed in Grad Slam 2019 before the pandemic. The increase in nursing research projects also coincided with the peak of COVID-19 impact in 2021. Unlike the baseline count in 2019 (Figure 1), "research" is the tokenized term that shows the most coverage across the projects in Grad Slam 2022 (see Figure 3). Therefore, the grant funding from 2020 to 2022 is not only linked to the expansion of STEM topic coverage but also strengthened the research emphasis of the Grad Slam competition.

The text data are further aggregated across Grad Slam sessions to display a plot of the top impact words in Figure 4. After the text data cleaning, tokenized terms exhibit more project emphasis in the fields of biology, geology, and nursing. In part, this is because these departments have more graduate student enrollments at CSUB. These STEM program offerings are aligned with the need to enhance pollution control and health support that are essential for sustaining agricultural and petroleum industries in local communities. The emphasis on health and mental health also demonstrates how the Grad Slam competition has served as a dynamic platform that has evolved in response to global challenges over the years. The data reflect not only the adaptability of graduate researchers but also the importance of academic competitions in showcasing a timely and impactful investigation.

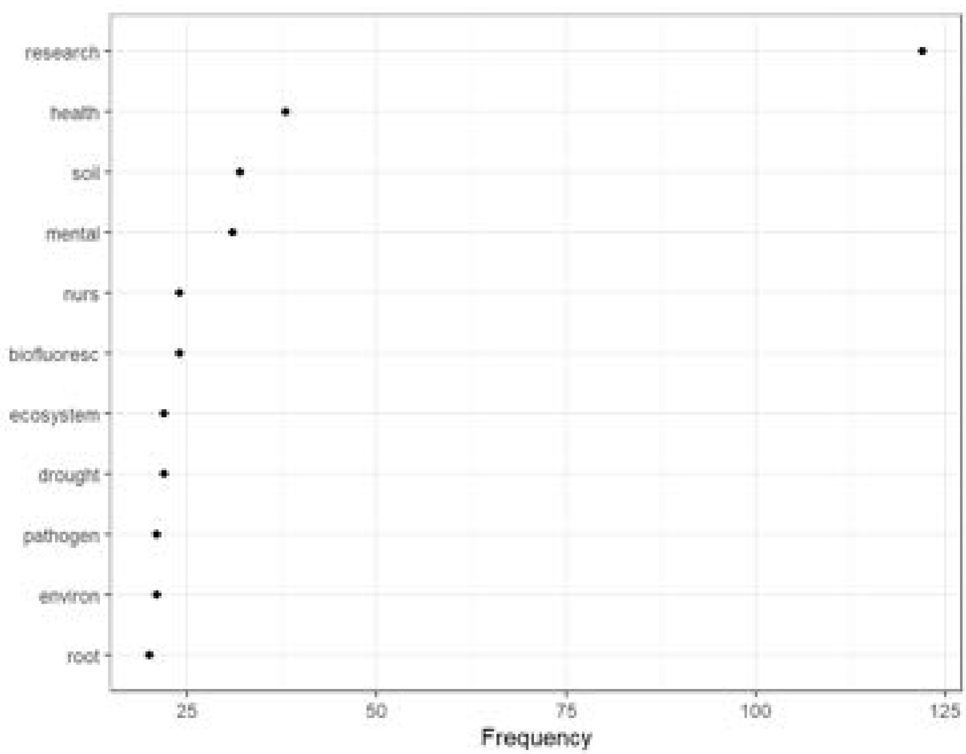


*Figure 4.* Most Frequent Words across Gram Slam Presentations

In alignment with the topic trend, a token-indicator relation plot further reveals the core role of research that articulates different field-based inquiries across the Grad Slam presentations. In Figure 5, the term "research" is located at the center to link multiple STEM fields of health, mental health, scienc[e], environ[ment], and nurs[ing]. Clearly, the analysis of Grad Slam presentations reveals a notable increase in the prominence of health and mental health-related themes in the years following the onset of the COVID-19 pandemic. This pattern reflects a shift in research focus and public interest, driven by the global health crisis.

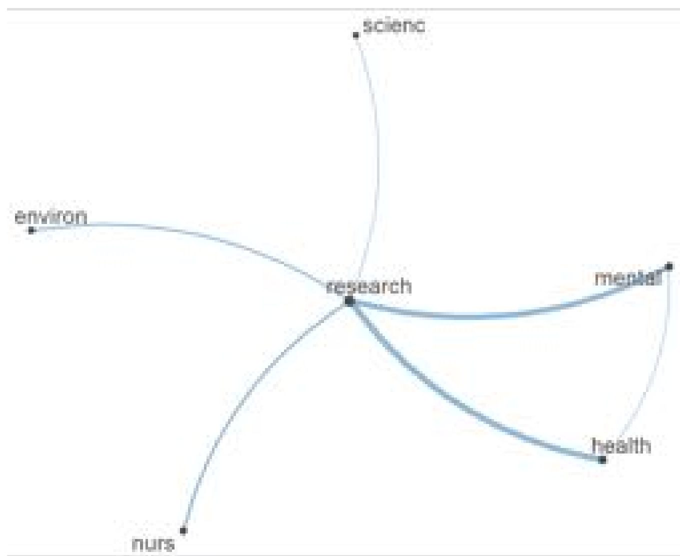


*Figure 5.* Token-Indicator Relations in Grad Slam Projects

**Survey on Grad Slam Preparation**

In preparation for the Grad Slam presentation, four workshops were offered to describe effective strategies for handling the competition. Workshop A is intended to offer an introduction and help students understand the Grad Slam features. In contrast, Workshops B and C are more specific, focusing on useful techniques for Crafting a Memorable Message and Designing a Compelling Visual Presentation. Workshop D addresses Communicating with Confidence in general. As a result, 95% of the respondents believe that Workshop A is easy to understand, and all respondents rated Workshops B, C, and D in an extremely useful or very useful category. Meanwhile, 90 – 100% of respondents claimed the learning experiences met their expectations (Table 1).

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Table 1.
*Student Feedback about Grad Slam Training*

| Workshop | N | Results |
|---|---|---|
| A | 21 | - 95% reported the topic "easy to understand"<br>- 90% claimed "meeting their expectations" |
| B | 3 | - 100% reported "extremely useful" or "very useful"<br>- All believed that the event met their expectations |
| C | 7 | - 100% reported "extremely useful" or "very useful"<br>- All believed that the event met their expectations |
| D | 29 | - 100% reported "extremely useful" or "very useful" |

Students also provided the following short comments to confirm the effectiveness of Grad Slam preparation:

- Thank you so much for putting this workshop together today. It was very empowering, useful and practical.
- This is good to boost confidence. I wish we have more of this!
- Great experience. Learned so much about so many different topics.

In summary, the survey results and text analytic findings have resulted in credible evidence to substantiate the benefit of student preparation for the Grad Slam presentations during the Title Vb grant funding. The results of text mining repeatedly indicated the focus of Grad Slam presentations on STEM fields. Additional support from the grant funding has led to more research emphasis on the Grad Slam competitions. The learning experiences from workshop training are considered useful according to the complimentary feedback from a participant survey.

**Discussion**

This research has a dual focus to (1) disentangle the top features of Grad Slam presentations and (2) evaluate student feedback about the learning experiences from the workshop preparation. These emphases correspond to two research questions that are derived from the needs assessment in the literature review section.

Regarding the first focus, a more detailed discussion is needed to interpret the trend of Grad Slam presentations over 2019-2022, especially concerning health and mental health topics, to highlight the impact of COVID-19 on the project themes. In particular, the heightened awareness of health issues has led graduate students to align their research involvements with the unprecedented challenges of society. Across the United States, the impact was felt by all students who faced campus shutdown and had to take classes online (Lee et al., 2021). The aftermath inevitably reduced social interactions, decreased learning engagement, and created feelings of isolation. Meanwhile, universities and funding agencies have prioritized health-

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related research in response to the pandemic, which enabled students to pursue projects in these areas for Grad Slam competitions. As indicated in the results section, the pandemic has catalyzed a substantial shift in graduate research interests driven by personal experiences, societal needs, and institutional support.

To clarify the trend in Grad Slam coverage, Figure 6 is created from Figure 1 to highlight the "Health" and "Mental Health" topic counts in 2019-2022. Prior to COVID-19, the trend showed no student presentations on mental health and one mention of health in 2019. The pattern grew to eight presentations in mental health and seven projects in health in 2022. This outcome is corroborated by the word plot in Figure 2, which incorporates all words from the Grad Slam presentations into consideration. The tokens of larger size indicate research as the primary feature of the STEM inquiries in 2022, while Pandem[ic] gained more project coverage in 2021 after the eruption of COVID-19 in 2020. Besides the trend description, a summative examination of the keyness plot in Figure 3 reconfirmed the enhancement of inquiry emphasis by indicating "research" and "literatur[e]" among the top three most important tokens in 2022. It also highlighted "theori[es]" along with tokenized terms in biology [e.g., blood, insect, pregnant, preganc(y)], physics, and geology [e.g., wave, sand] to show enrichment of confirmatory STEM inquiries in student projects in the same year. In contrast, no such features were extracted from the video recording of Glad Slam presentations before 2022. When the most frequent words were aggregated across Gram Slam presentations, Figure 4 shows that "research" was mentioned more than three times than the second most frequent term of "health", making it the token of paramount importance in this period.

These findings jointly supported the positioning of "research" at the center of the token network in Figure 5, which involves STEM inquiries in science, environments, nursing, health, and mental health across the Grad Slam projects. Hence, the top features prior to and during the period of program funding not only show timely alignments of the Grad Slam topics with the contemporary issues of the pandemic and the consequences of mental health stress but also consistently promotes the strengthening of research culture per encouragement of the federal program funding (see Wang, 2023).

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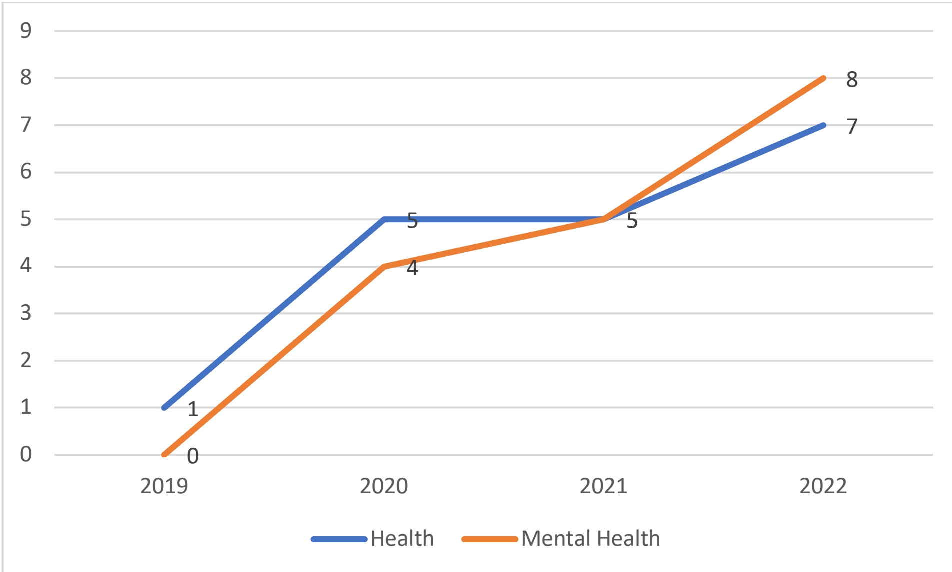


*Figure 6.* Trend of "Health" and "Mental Health" Topic Counts in Grad Slam Presentations

For Question 2, the quantitative results in Table 1 indicate that the learning experiences from the Grad Slam preparation were useful and meeting student expectations. The workshop training is also related to the competition setting. Sadlowski (2018) observed, "With only three minutes to present, summarizing and simplifying years of research can be a challenging task for Grad Slam participants" (p. 2). A student recapped the benefits from both Grad Slam participation and workshop preparation:

> The Grad Slam competition was a rewarding experience and instrumental in providing me with the confidence to discuss my research. Engaging with my fellow Grad Slam participants and watching everyone discuss their research was very enriching. Collaborating on my research with my mentor has provided me with important skills and knowledge to enhance my career. I'm very fortunate to have received this grant and the opportunities it has provided.

By introducing text analytics in this study, the student learning experiences can be enriched in future investigations to facilitate Grad Slam preparation. More specifically, the past Grad Slam performance can be disentangled through an examination of the presentation transcripts to evaluate clarity, coherence, and the effective communication of key concepts. The NLP approaches also enable evaluators to identify the use of technical jargon, assess the logical flow of ideas, and determine the alignment of the content with the intended audience's comprehension level. The tool can provide immediate, personalized feedback for the student to better engage their audience and convey enthusiasm for their subject matter in alternative ways, thereby enhancing communication skills. Furthermore, the machine learning mechanism incorporated in text analytics can help train and extract textual features from presentations to predict performance outcomes for additional support and timely interventions.

In summary, the in-depth analysis of text data and student feedback indicated effective learning experiences from the Grad Slam workshop training that have been rarely studied before. To fill the void of research literature, an innovative approach has been taken to explore features of extracurricular learning with the cutting-edge method of R-based text analytics. By providing objective, scalable, and insightful analyses of presentation content and delivery, text analytics contributes to a more comprehensive assessment process for evaluating student competitions like Grad Slam.

**Conclusions**

Findings from this investigation have a strong implication in STEM education, particularly for graduate students at HSIs. It is well-known that STEM education, traditionally viewed as a domain for experts, is increasingly recognized as vital for all. Thus, the Grad Slam competition emerges as a unique platform to help graduate students not just excel in their specialty fields but also establish confidence in communicating their research to a general audience. Improvement of communication skills also enhances a sense of belonging to STEM inquiries, which is essential for career advancement, interdisciplinary collaboration, and leadership preparation (Morreale et al., 2000). Hence, studies of Grad Slam competitions have tackled a unique platform, aside from STEM coursework, to help graduate students excel in their specialty fields, as well as establish confidence in communicating their research to a general audience.

Drawing from the methods and findings used in the Grad Slam analysis, implementing text analytics in other educational competitions can offer valuable insights to improve participants' preparation, presentation quality, and audience engagement. More specifically, LDP can be recommended for identifying patterns in the timing and recurrence of impactful words to ensure consistent use of key terms in strategic locations of debate competitions. The word cloud plot can help visualize the central themes of a presentation to guide participants' attention to profound topics that resonate with judges of STEM fairs. The keyness plot is effective in highlighting the importance of distinctive words with strong associations to specific judging criteria that are aligned with the competition's goals. The MFW plot supports workshop designs by replacing overused terms to enhance originality for audience attraction. The TIR plot is a useful tool for training participants to use tokens with strong positive correlations to performance metrics, such as clarity, relevance, engagement. Hence, the methods of text analytics illustrated in this study represent a powerful tool in elevating the quality of participation and evaluation in a wide range of educational competitions. These approaches directly help participants meet judging expectations while fostering innovation and clarity in their presentations.

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While the value of this investigation has been adequately justified, three limitations are adduced for future improvement. First, this study relies on textual data from Grad Slam presentations, excluding non-verbal elements such as body language, tone, and visual aids, which are integral to effective communication. The partial information analysis might lead to an incomplete understanding of what contributes to successful presentations. Secondly, each presentation in Grad Slam has a limited scope due to the three-minute constraint. Consequently, findings may not fully capture the breadth of topics for a broad generalization across the STEM educational contexts. Thirdly, the analysis is built on automated techniques such as tokenization, keyness, and word frequency, which may miss subtleties like sarcasm, metaphors, or cultural references that contribute to the richness of the presentations. This limitation might imply that important qualitative aspects of the content could be overlooked for a comprehensive information extraction.

To address these gaps identified from this study, future investigations may incorporate new tools from R-based text analytics, such as sentiment analysis of audience reactions, to identify the elements of presentations that spark the most interest or confusion. The outcome could be culture-dependent, which supports more comparative studies across different cultural or institutional contexts to optimize the STEM project communication. Similar to the highlight of COVID-19's impact in this study, additional attention needs to be devoted to examining how the focus of Grad Slam projects evolves over time, particularly in response to global challenges such as climate change, pandemics, artificial intelligence, and other technological advances. By tackling these limitations and pursuing the outlined future research avenues, the PPOHA grant funding is expected to further strengthen its positive influences in improving the effectiveness of STEM education events like Grad Slam and, thus, ultimately bridge the gap between academic competency in specialized subjects and scientific communication to the public.

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RESEARCH REPORT

# Gender and Diversity Awareness among STEM-Teachers: Mono Makes the Difference

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**Abstract**

*The discrepancy between the use and understanding of technological artifacts clearly illustrates the need for a contemporary general education in technology. This is seen as a fundamental prerequisite for citizens to be able to act independently, reflectively, and responsibly in a world increasingly shaped by technology. While technological devices and digital applications are used as a matter of course in everyday life, a deeper understanding of how they work is often lacking. This is precisely where the demand for a solid education in technology comes in. Gender and diversity aspects play a particularly important role here, as it is essential to ensure that all students are addressed in a broad and equitable manner. Numerous studies show that there are differences in students' interest in technology and in their career choices. These differences reinforce the need for gender-sensitive and diversity-conscious concepts that do not perpetuate existing inequalities but specifically seek to reduce them. This study therefore examines teachers' attitudes and knowledge of gender and diversity in STEM education. Based on an online survey of N = 511 teachers, it analyses the extent to which gender, subject affiliation, and experience in mono-educational settings reveal differences (ANOVA, t-tests). The aim is to identify potential for further developing teacher training and to provide impetus for gender- and diversity-sensitive technical didactic approaches.*

**Keywords:** *Gender and Technology, STEM, diversity, mono-educational teaching, attitudes and knowledge.*

## Introduction

The Austrian Federal Ministry of Education, Science and Research (BMBWF) emphasizes that schools have a special responsibility not only to accept diversity, but also to proactively shape it (BMBWF, 2023). Teachers play a central role in promoting diversity and challenging gender-specific role stereotypes. Through their expertise, attitudes, and teaching

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methods, they have a significant influence on whether traditional gender stereotypes are critically reflected upon or – often unconsciously – reproduced and reinforced.

Education, in its modern sense, can promote the independence and self-determination of every individual person (Raithel et al., 2009), which will become increasingly important in relation to technology. The discrepancy between the use and understanding of technical artifacts (Acatech & Körber-Stiftung, 2021) highlights the urgent need to promote a contemporary general technical education that serves as the foundation for responsible citizens. There is a particular need for action regarding gender and diversity aspects. As studies show there are significant differences between male and female students in terms of their interest in technology and career choices. Gender and diversity in technical education can thus be understood as the exploration of diverse methods, working media, content areas, and teacher-student interactions that aim to address heterogeneous student groups (Goreth & Windelband, 2020). It is therefore imperative that teachers develop an elaborate awareness of gender and diversity.

**Theoretical Background**

In the scientific debate on gender, different perspectives can be distinguished from one another. The term *science of gender* refers to research into gender-related stereotypes and their effect on individuals (Bartosch & Lembens, 2012). The focus is on the extent to which socially conditioned ideas of masculinity and femininity influence people's behavior, self-perception, and social interactions. In contrast, the focus of the *gender of science* is on how gender relations shape scientific structures, discourses, and research processes (Augustin-Dittmann, 2017). It examines the extent to which certain disciplines are shaped by gender-specific patterns of thought and attributions. Another research perspective is *Women in Science*, which deals with the continuing underrepresentation of women in STEM professions (Augustin-Dittmann & Gotzmann, 2015; Statistisches Bundesamt, 2018). Despite numerous initiatives and support measures, the proportion of women in scientific and technical professions remains significantly lower than that of men, which is often attributed to structural barriers and persistent stereotypical role models.

Gender and diversity in technical subjects at school can be understood as a heterogeneous student group, which unites, for example, different gender groups, students with and without a migration background, or students with or without special education needs (Goreth & Windelband, 2020); here, a major focus is on the area of gender. In recent decades, one approach to teaching has been the separation of boys and girls in mono-educational settings. Gender-homogeneous learning environments open the possibility of acting independently of socially traditional role expectations and trying out alternative forms of gender roles, thereby potentially creating expanded spaces for individual development and self-expression (Graff, 2014). In contrast, *coeducation* is the joint learning of both genders, which long

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served as the educational standard but is now increasingly being subjected to differentiated and critical reflection (Stecklina & Spies, 2008).

From the 1950s onwards, little attention was paid to the topic of gender and diversity in the context of technical education, and it was only discussed superficially. From the 1990s onwards, research interest within diversity and gender studies shifted towards gender theory and empiricism, and the pedagogical approach was characterized by efforts to achieve equality (Krüger, 2011; Faulstich-Wieland, 2011; Klinger, 2014). While research on boys and men became increasingly prominent around the turn of the millennium (e.g. Budde, 2005; Helbig, 2010; 2015; Horstkemper, 2000; Pech, 2009; Preuss-Lausitz, 2005), the number of studies on socialization research declined from 2000 onwards, although interest increasingly focused on the results of gender differences in empirical educational research (TIMSS, PISA, IGLU, PIRLS) (Popp, 2011). In recent years, there has been an increasing focus on the education-gender segment in the context of diversity (or heterogeneity) (Faulstich-Wieland, 2011; Klinger, 2014; Krüger, 2011;), and currently, unequal treatment is the predominant topic of discussion in society (e.g., BMBF, 2021; BMBWF, 2021).

Within technical (and scientific) subject didactics research, groups of researchers are showing great interest in school content areas (or topics or subjects) and how they relate to students' interests. Interest in different content areas is reflected in students' self-assessment responses. Gender-specific differences emerge in the scientific/technical context (e.g., Brown, 1993; Goreth et al., 2021; Kosack, 1994; Mammes, 2004; Virtanen et al., 2015).

Technical artifacts and textbooks have also been analyzed and found to be predominantly male-oriented (Colette & Marjolaine, 2017). Furthermore, higher motivation levels have been demonstrated among female students when social and human dimensions are considered in the classroom (Holstermann & Bögeholz, 2007; Marth & Bogner, 2019). Although there have been few studies on gender-specific aspects in technical education to date, those that do exist show that teachers should be more aware of gender-sensitive teaching.

Another broad field of research in the context of gender and diversity is language and interaction processes. Linguistic debates often focus on the correct naming of gender roles or gender-sensitive choices in image examples (Bath, 2015; Pädagogische Hochschule Bern, 2007; Stadt Wien, 2007), which are rarely empirically proven or have insufficient effect sizes (Vervecken & Hannover, 2015). Groups of researchers specializing in teaching methodology examine school interaction processes (mostly between students and teachers, e.g., Augustin-Dittmann & Gotzmann, 2015; Faulstich-Wieland, 2004).

It is striking that teachers are severely underrepresented in this area. However, initial empirical findings show that teachers' interest in different subject areas and, therefore, their self-assessed level of knowledge in these areas are strongly gender-specific (Goreth, 2021). The model of professional competence highlights the importance of professional knowledge (Baumert & Kunter, 2013; Voss et al., 2015). However, beliefs/values and motivational orientations about gender and diversity must also be addressed centrally in general technology education. Krebs (2023) shows that the degree of awareness within diversity and gender competence varies greatly among teachers in teacher training courses. Addressing gender beliefs in the context of technology education can help to promote high-quality teaching, especially in general education. There is currently a lack of empirical studies dealing with teachers' attitudes towards gender and diversity in the field of science and technology.

## Method

### *Research Question & Hypotheses*

The aim of this study is to examine whether teachers differ in their knowledge of and attitudes towards gender and diversity in the school context. On the one hand, it looks at whether there are differences between male and female teachers and, on the other hand, whether there are differences between teachers at different school subjects, such as STEM subjects for example technology and design (formerly technical and textile crafts); physics; and mathematics. The aim is also to find out to what extent teachers' experiences in mono-educational education influence their self-assessments around gender and diversity.

The following hypotheses should be tested for specific groups:

While students in individual fields have relatively good knowledge of feminist theories and consider it important to incorporate them into their teaching (Lucas-Palacios et al., 2022), findings from Spanish teacher training students show that gender-specific topics are only moderately integrated into the curriculum and that individuals who have received gender training feel a higher level of self-efficacy in gender education (Miralles-Cardona, 2025). To date, no subject-specific studies have been conducted in the field of STEM teacher training.

Hypothesis 1 therefore examines the question of whether the integration of gender-sensitive teaching into teacher training curricula has an impact on teachers' perceptions and whether they consider themselves better prepared for gender aspects in the teaching profession because of including this topic in their studies.

H1: There is a difference in the perceived preparation for gender-sensitive teaching between teachers who completed their studies some time ago and those who have only recently completed their studies (due to an increase in the topic of gender-sensitive teaching in the curricula).

While studies focus on the proportion of women in STEM professions (e.g., these women are more strongly represented in manual routine tasks within automation/digitalization) (Leitner et al., 2023) or analyze students' motives for choosing STEM professions (Hartmann, 2014), there are also findings on the effects of mono-educational teaching settings. A large meta-analysis shows that (small) differences in mathematics performance and


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science performance can be identified (Pahlke et al., 2014). There are currently no studies on whether the focus on mono-educational educational experiences has an impact on teachers' own teaching practices.

Hypothesis 2 examines the extent to which individuals with and without mono-educational teaching experience take gender aspects into account in their teaching.

H2: Teachers who have already had mono-educational teaching experience have a different attitude towards incorporating gender aspects into their teaching than individuals who have not yet had mono-educational teaching experience.

Female teacher training students show higher pedagogical, altruistic, and idealistic motivations, while male teacher training students show higher subject-related motivation. In addition, female students show greater openness, e.g., interest in students' social and cultural diversity (Kammermeier et al., 2025). In the field of physical education, results show that the perceived importance of achieving gender-equitable goals in sport—in the sense of diverse content delivery—is strongly gender-dependent (Hoven, 2018). No comparable empirical data is available for the STEM field.

Hypothesis 3 therefore examines the question of the extent to which the gender of the teacher influences attitudes towards gender-sensitive teaching.

H3: Women and men differ in their attitudes towards gender-sensitive teaching.

Finally, hypothesis 4 will examine the extent to which, in an overall picture, mono-educational educational experiences and STEM-related training have an influence on attitudes towards gender-sensitive teaching.

H4: There are main and interaction effects when examining the above variables in terms of their influence on attitudes towards gender-sensitive teaching.

*Survery instrument*

Knowledge and attitudes about gender and diversity influence lesson planning towards gender- and diversity-sensitive subject teaching. Knowledge and interest in content areas are gender-dependent (Goreth, 2021). To expand these findings to include gender and diversity aspects, an online questionnaire on attitudes and knowledge about diversity and gender was developed. *N* = 511 teachers from general education schools in Tyrol participated. The Department of Education Tyrol sent the questionnaire to all currently working teachers and a reminder email was also sent out. Double entries cannot exist. While the first part of the questionnaire asks about teaching experience and training paths, the core of the questionnaire covers attitudes and knowledge about gender and diversity as well as experience with and implementation of different teaching methods. In addition, the questionnaire asks about gender and diversity content in training courses and identifies potential for development. The sample was determined as a quantitative online survey via *soscisurvey*. The survey took approximately 15 minutes to complete.

The questionnaire includes a socio-demographic section on education and professional experience, as well as a subject survey and specific subject questions on knowledge and interests (which will not be considered in this article). For the topic of gender and diversity, items were adapted based on Payer & Petritsch (2015) and Hoven (2018), which enables an interdisciplinary analysis.

Structure of the questionnaire:

- Sociodemographic and questions about teaching activities and completed education
- Four-point Likert scale on *gender in general* comprises 5 items (Cronbach's $\alpha$ = 0.81), example item: *I believe that the topic of gender is overused.*
- Four-point Likert scale on *gender content in one's own studies*, comprising 5 items (Cronbach's $\alpha$ = 0.93), example item: *Through my studies, I have learned to act in a gender-sensitive manner.*
- Questions about the organization of one's own teaching activities
- Final questions on knowledge

For the present article, only a selection of the data from the questionnaire is described here. The data was primarily evaluated using t-tests for independent samples and one- or two-factor analyses of variance (ANOVA) to test the hypotheses. The questionnaire mainly contained four and five-point Likert scales, which were treated as interval scales in the analysis. This allows the calculation of means, standard deviations, and the comparison of groups using t-tests and ANOVA.

The t-tests were used to test mean differences between two independent groups, for example, in the analysis of gender-specific differences. For comparisons of more than two groups, such as age or educational background, one- or two-factor analyses of variance (ANOVA) were performed. The statistical analyses were performed with a significance level of $p < .05$.

**Results**

The sample has an average age of $M$ = 45.4 years ($SD$ = 10.6) and is predominantly *female* (68.4%), with a smaller proportion of *males* (30.9%) and *diverse* genders (0.6%). For the statistical analysis of gender differences, individuals who answered "other gender" had to be excluded due to low absolute numbers (3). No statistical conclusions can be drawn from the study data for these individuals. (Figure 1).

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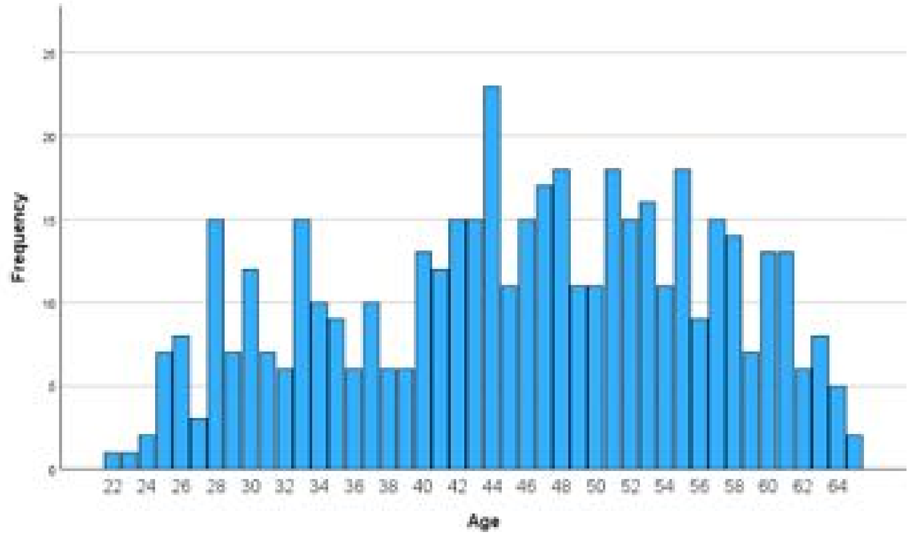


*Figure 1*. Age distribution of surveyed teachers

There is currently a shortage of teachers in STEM subjects, which compete most strongly with attractive jobs in industry (Brodbelt, 1990; Robinson, 1985). The continuing increase in the shortage of STEM teachers points to a worrying international trend: for example, South Tyrol (Italy) is expected to have a high demand for STEM teachers at secondary level in the coming years (Bildungsdirektion Bozen, 2022), which cannot be met by the current number of graduates. In North Rhine-Westphalia (Germany), only 29% of the demand for chemistry teachers, 17% for physics teachers, and 4% for technology teachers will be met by the 2030/31 school year. All teacher numbers are declining sharply between 2025/26 and 2030/31 (Klemm, 2015, 2021). By 2030/31, there will be a shortage of 2,161 STEM teachers (Klemm, 2021). “In all [German] federal states, the development of demand will be similar to that in North Rhine-Westphalia – albeit to varying degrees – and will be characterized by rising numbers of [students]” (Klemm, 2021, p. 4). In Tyrol (Austria), too, demand and demand trends are currently not being met. For example, in 2020, there was a shortage of 14.9 full-time teaching positions in technical and textile crafts and 12.8 in art education, with demand growing rapidly (in 2027, there will be a shortage of 29.7 full-time teaching positions in technology and design (formerly technical and textile crafts) and 21.0 in art and design (formerly art education) (BMBWF, 2020). The proportion of teachers without specialist training is very high (55% in technology and design), with a sharp upward trend until 2026 (Landesschulrat Tirol, 2016).

By dividing the sample into three age groups (39 years or younger: $n = 132$), middle-aged teachers (40-48 years: $n = 151$), and older teachers (49 years or older: $n = 181$), the results indicate that the composition is changing. Younger teachers are less likely to have studied STEM subjects, while in primary education all subjects are covered in training at a rudimentary level. The composition of the study thus reflects the data from the federal government.

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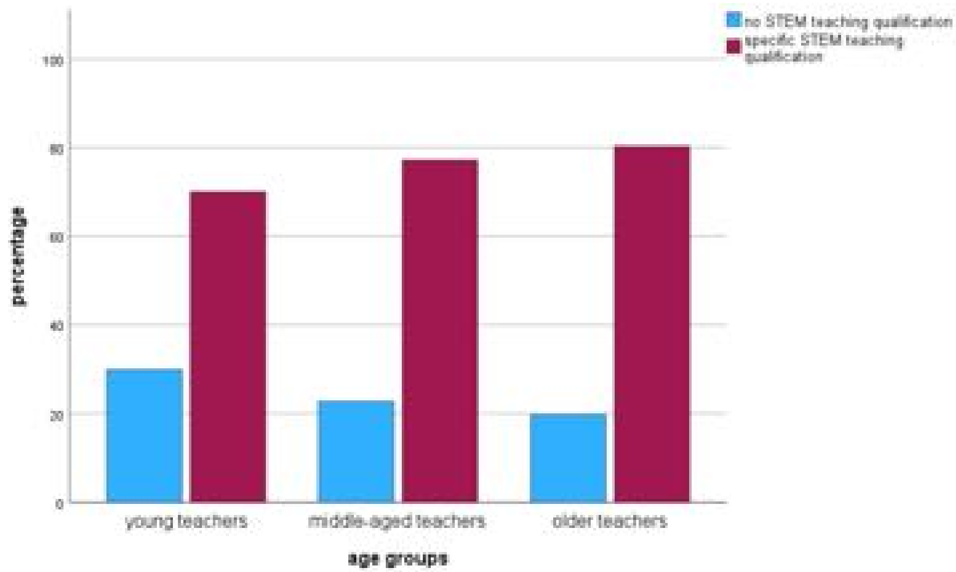


*Figure 2*. Distribution of subject background (sorted by age group)

If the teachers surveyed had the choice, the majority would prefer to teach *mixed-gender classes* (68.7%), while 27.6% *express no preference* and only 3.7% say they would *prefer to teach mono-educational classes*. *Gender mainstreaming* is the best-known concept among teachers (44.6%), while *reflective coeducation* is the least known (31.2%).

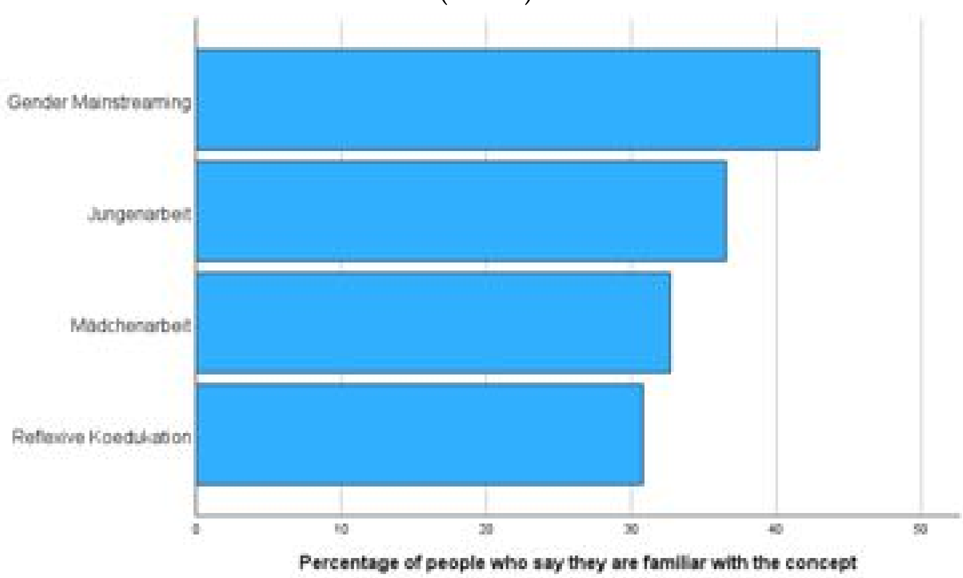


*Figure 3*. Awareness of different gender concepts

An ANOVA is performed to examine H1. It examines whether the participants in the study, divided into three professional age groups, differ in their assessment of the course in relation to gender-sensitive teaching. The non-significant Levene's test confirms the homogeneity of variance for the ANOVA.

The age groups (length of service) have a highly significant influence on the assessment of whether gender-sensitive teaching is reflected in the training. A strong effect is observed ($\eta^2 = 0.14$).

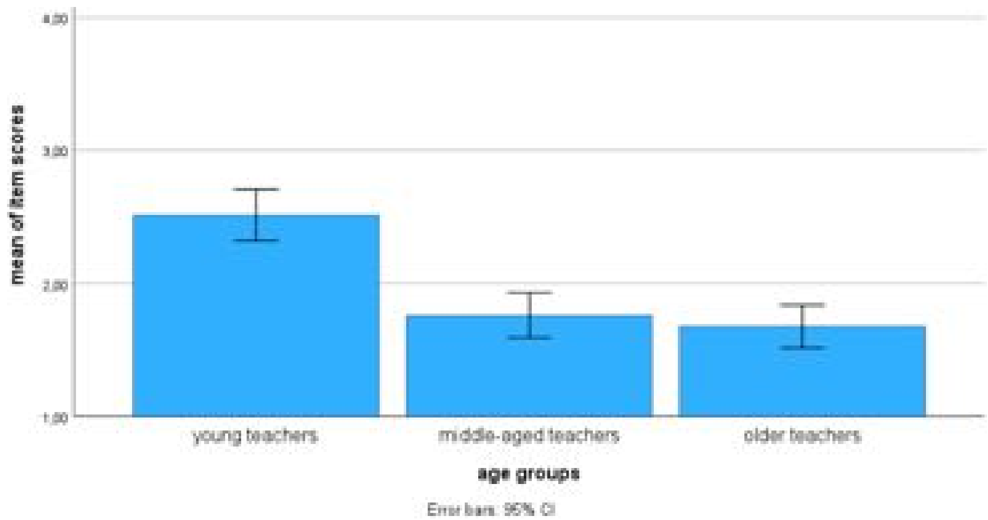


*Figure 4*. Teacher training contains gender aspects (four-point Likert scale from *1 = "Does not apply at all"* to *4 = "Applies"*)

On average, individuals from the groups who completed their degree further in the past (see Figure 4) describe that their degree did not focus on gender-sensitive teaching (young teachers: $M$ = 2.51, $SD$ = .82; middle-aged teachers: $M$ = 1.76, $SD$ = .86; older teachers: $M$ = 1.68, $SD$ = .89). Individuals who recently completed their degree describe that their degree did focus on gender-sensitive teaching.

This corresponds with the grades given: young teachers give their training in gender-sensitive content significantly better grades ($M$ = 2.94, $SD$ = .99) than middle-aged ($M$ = 3.53, $SD$ = 1.17) and older teachers ($M$ = 3.70, $SD$ = 1.22).

However, it is apparent that even young teachers tend to make cautiously positive statements about the integration of gender-sensitive teaching. On average, young teachers give their degree a grade of 3 (C) "satisfactory" about the *integration of gender-sensitive teaching*, while the two groups whose studies are further in the past give a grade of only 4 "adequate." Here, too, the difference between the young and middle-aged groups is highly significant (t-test assuming equal variance tested with Levene's test) with $t(-3.456, 174) < 0.001$ and Cohen's $d = -0.53$.

The next step is to examine the extent to which the changes to the training curricula perceived by young teachers can be further intensified to enhance the perception of these elements in their studies. The aim of including these elements in training curricula should be to promote the desire for further development of practice. As established in the theoretical

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section, it can be considered certain that lasting and sustainable change in practice requires a change in teachers' attitudes. In hypothesis 2, therefore, mono-educational education, which was identified as a possible influencing factor in the theoretical section, will be the subject of further analysis.

Mono-educational education experiences could influence attitudes towards gender-sensitive teaching design. In the following, a t-test will therefore be conducted to test the influence of *mono-educational education experiences* on *attitudes towards gender-sensitive teaching design*.

The test will examine whether the group of teachers who have already *taught in mono-educational classes* differs from the group of teachers who have never taught in mono-educational classes. Their statements on the following item will be compared: *"It is important to me to include the gender aspect (of girls and boys) in my teaching."*

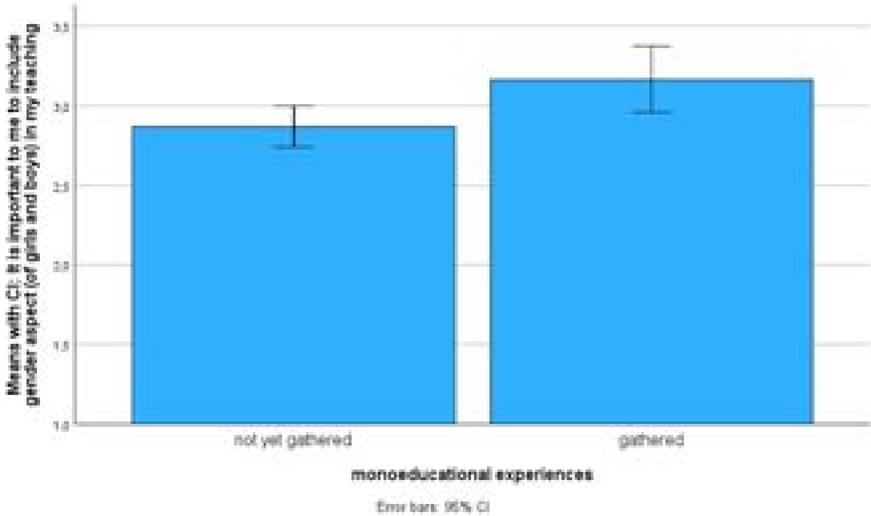


*Figure 5*. Attitude towards gender-sensitive teaching (four-point scale from *1* = *"Does not apply at all"* to *4* = *"Applies"*)

In preparation for the t-test, it is determined that the Levene test is not significant, meaning that the analysis can assume equality of variance (a prerequisite for an unmodified t-test). Teachers who have already taught gender-segregated classes indicate that it is more important to them to incorporate gender aspects into their own teaching ($M_{gender\text{-}segregated} = 3.17$; $SD = 0.96$; $M_{not\ gender\text{-}segregated} = 2.87$; $SD = 0.97$) with $t(2.83, 298) < 0.01$ and an effect of Cohen's $d = 0.31$.

As explained in the theory section, Statistics Austria data has shown that there is a particularly acute shortage of newly trained teachers in the STEM field, which is also reflected in the present sample. Hypothesis 3 therefore examines the interaction between these factors. For the analysis, a three-factor analysis of variance is now performed in an overall view.

The Levene test is not significant. The analyses therefore assume variance homogeneity. The three-factor ANOVA is significant and yields small main effects for two of the three variables examined, as well as a small interaction effect between the three variables.

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The description of the main effect of mono-educational education experiences has already been provided in Hypothesis 2. The following section therefore focuses on the second main effect and the observed interaction effect.

Regarding the second main effect, the correlation derived at the outset is confirmed for the gender variable. Gender has a significant influence on attitudes towards gender-sensitive teaching. Women consider the integration of gender-sensitive aspects into their teaching to be more important than men.

There is a small interaction effect between the three variables examined. This is to be interpreted graphically in a summary of three interaction diagrams. To interpret the interaction effect, descriptive explanations are provided for the diagrams below.

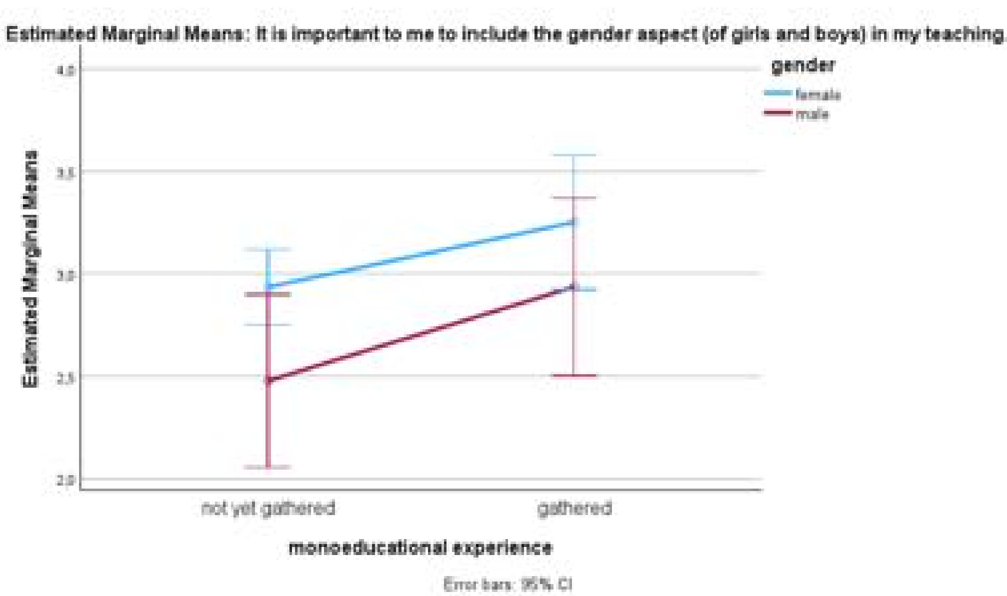


*Figure 6*. Attitude towards gender-sensitive teaching (four-point Likert scale from *1 = "Does not apply at all"* to *4 = "Applies"*)

Figure 6 shows the average number of points, including error bars, for the four groups: *females without mono-educational teaching experience, females with mono-educational teaching experience, males without mono-educational teaching experience,* and *males with mono-educational teaching experience*. Essentially, both main effects can be seen here.

Table 1.
*Tests of between-subject effects considering the variables Monoeducational experience, Gender and STEM qualification*

Dependent variable: *"It is important to me to include the gender aspect (of girls and boys) in my teaching."*

| Source | Type III Sum of square | df | Means of squares | F | Sig. | partial Eta-square |
|---|---|---|---|---|---|---|
| Corrected model | 27.500[a] | 11 | 2.500 | 2.871 | .002 | .129 |
| Constant Term | 898.317 | 1 | 898.317 | 1031.516 | <.001 | .829 |
| Item_ monoeducational_ experience | 4.000 | 1 | 4.000 | 4.593 | .033 | .021 |
| Gender | 3.983 | 1 | 3.983 | 4.573 | .034 | .021 |
| STEM_qualification | 3.546 | 2 | 1.773 | 2.036 | .133 | .019 |
| Item_ monoeducational_ experience * Gender | .134 | 1 | .134 | .154 | .695 | .001 |
| Item_ monoeducational_ experience * STEM_qualification | .219 | 2 | .109 | .126 | .882 | .001 |
| Gender * STEM_qualification | .343 | 2 | .171 | .197 | .821 | .002 |
| Item_ monoeducational_ experience * Gender * STEM_qualification | 9.548 | 2 | 4.774 | 5.482 | .005 | .049 |
| Errors | 185,495 | 213 | ,871 | | | |
| Total | 2232,000 | 225 | | | | |
| Corrected total variation | 212,996 | 224 | | | | |

a. R-square = .129 (corrected R-square = .084)

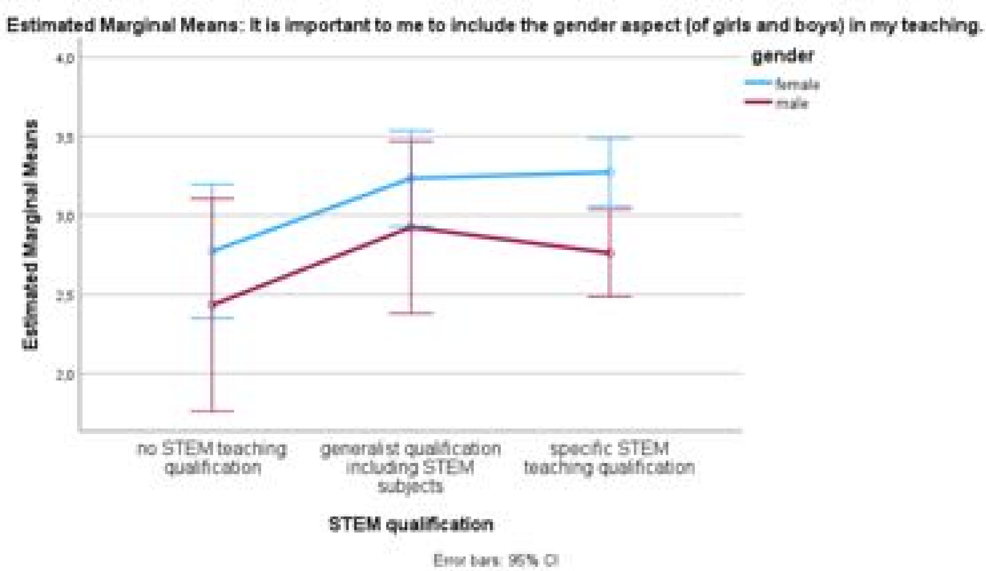


*Figure 7*. Attitude towards gender-sensitive teaching (four-point Likert scale from *1* = *"Does not apply at all"* to *4* = *"Applies"*)

Figure 7 shows six groups formed by varying the variables subject with STEM participation and gender. It is interesting to note that, on the one hand, the presence of a STEM subject promotes gender-sensitive teaching, but on the other hand, the differences in the gender of teachers are more pronounced, especially when choosing to study a specific STEM subject. While women with generalist training (especially at the primary level) also value gender-sensitive teaching more than men, this difference seems to become even more pronounced when studying specific STEM subjects.

There are several possible interpretations of the diagram shown above. The educational situation in STEM subjects, in which gender-sensitive teaching methods are clearly anchored in the curriculum, also seems to be emerging among generalist primary school teachers. One possible explanation for the visible increase in differences between male and female teachers could be that children in primary school are largely still being taught before puberty, so that gender-related differences only become more pronounced in secondary school. While female teachers with a specific STEM subject (i.e., secondary school teachers) have a similar attitude to female teachers with a generalist education, this may not be the case for male teachers.

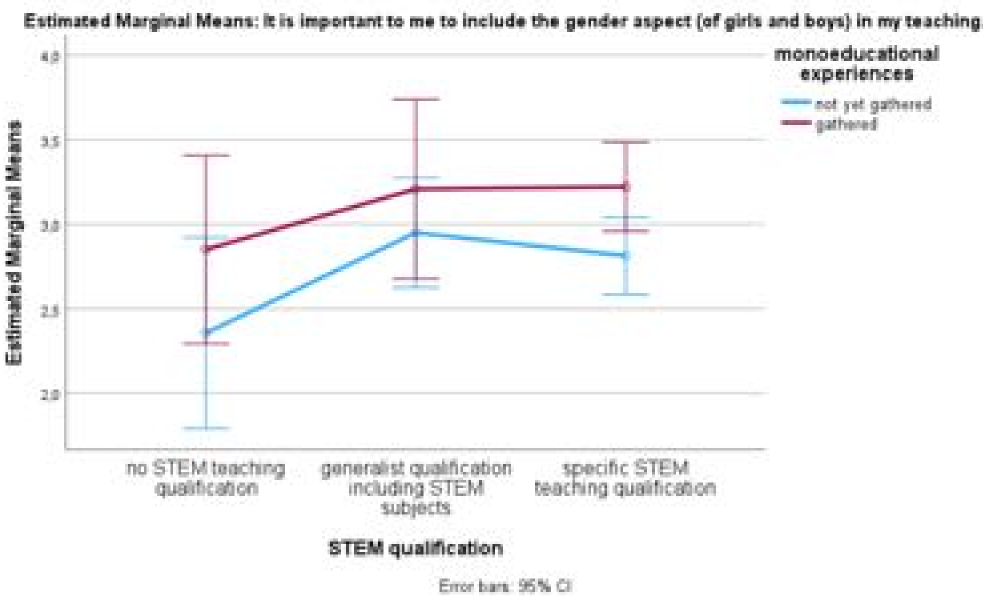


*Figure 8*. Attitude towards gender-sensitive teaching (four-point scale from *1 = "Does not apply at all"* to *4 = "Applies"*)

Figure 8 shows that, descriptively, all groups, regardless of whether they are STEM-related or not, benefit from mono-educational educational experiences in terms of their attitudes towards gender-sensitive teaching. More, individuals without a STEM subject benefit most from mono-educational teaching experiences. The overall level among teachers with a STEM background is higher than among teachers without a STEM background.

These findings are consistent with the theoretical assumptions. Since the aspect of gender-sensitive teaching is much more strongly integrated into study curricula and STEM support measures than in non-STEM subjects, non-STEM teachers apparently learn, albeit at a lower level, to reflect on their own practice when they have gained mono-educational teaching experience.

**Discussion**

It has been shown that young teachers have already had experience with incorporating gender-sensitive content into their training. This observation supports the assumption that curricular reforms are having an effect and that gender-sensitive teaching is not only a formal part of study programs but is also actually being implemented by graduates. Nevertheless, young teachers' assessment of this content is cautious: although they differ significantly from older cohorts who completed their studies before the reforms (especially between the young and middle-aged groups), the average rating of gender-sensitive components in training is only satisfactory. It can be concluded from this that the progress achieved so far is relevant, but not yet sufficient to generate an overall positive assessment of gender-sensitive teaching in teacher training.

Supplementary analyses on the significance of mono-educational teaching experience show that these experiences are associated with a higher attribution of relevance to gender aspects in one's own teaching. Although the effect is small by conventional standards, it points in a significant direction. It is therefore worth discussing whether the targeted integration of mono-educational teaching and learning scenarios into teacher training, for example through teaching and learning laboratories, could contribute to promoting positive attitudes towards gender-sensitive teaching.

Furthermore, the results show that the gender of the teacher has small but measurable effects on attitudes towards gender-sensitive teaching. Of particular interest, however, is the interaction of these variables with the teachers' STEM background, as this has a higher explanatory value. This indicates that measures to further develop gender-sensitive teacher training should not only be general in nature, but also specific in several respects—for example, in terms of subject contexts, the gender of the teacher, and their teaching experience.

The present results should be viewed in light of several limitations. First, the sample is limited to Austria, which means that the findings can only be generalized to other countries to a limited extent. Second, the size of some of the subgroups is small, which limits the statistical power of the analyses and requires cautious interpretation, particularly in the case of interaction effects.

In summary, it can be said that both the gender of the teacher and monoeducational teaching experience have small effects on attitudes towards gender-sensitive teaching. The role of teachers' STEM background is also of particular interest: In interaction with the other variables, it has greater explanatory value, pointing to the need for targeted and differentiated continuing education and training programs. The findings are not only interesting for the Austrian education sector, as many European education systems focus on coeducation and address the requirements for gender-sensitive teaching. Such programs should not only be designed to be gender-sensitive but also offer the opportunity to address gender-specific aspects within and outside the STEM field. Implications for practice-oriented design could include offering video-recorded self-evaluation in teacher training programs, which contributes to the professionalization of teachers. In addition, teachers could be encouraged to try monoeducational settings in the classroom (e.g., in group work phases during technical experiments).

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