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Editorial

STEAM and Deaf Education: Histories, Tensions, and Future Possibilities

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Abstract

This article reflects on the emergence and development of STEAM in education and its impact on deaf education. We present key themes from STEAM and deaf education to provide a broader context in which to situate the articles and introduce the authors featured in this Special Issue: Full STEAM Ahead!

Keywords: STEAM; science; technology; engineering; arts; mathematics; deaf education; accessible education; equitable education

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1. Introduction

Today's world appears drastically different from what it was at the turn of the 21st century. Looking back at where we were technologically in Y2K, or the year 2000, is a reminder of the rapidity of everyday modern life and learning. Accessing the internet and sending emails at that time required a telephone landline and a dial-up modem, a connection method that was slow and frequently interrupted. Cellular phones were not yet mainstream. The term "Artificial Intelligence", or "AI", coined in the 1950s, was just making its way into video games, medical imaging systems, and the cars we drove. And social media… social what? Back then, electronically networking with others consisted of computer text-based forums, chat rooms, and instant messaging. Now, with wireless connectivity, on-demand or live streaming for just about everything, and instant video content creation through social media platforms, the internet is available from the convenience of our "back pockets." Further, AI is increasingly shaping how we search for information, communicate, organize our time, create art, think, and even what we should have for dinner!

Educationally, the early 2000s brought debates between traditional versus child-centered approaches to teaching and learning. It also marked a shift from a narrow emphasis on the 3Rs (reading, writing, and arithmetic) toward a more extensive and inclusive use of the 4Cs (critical thinking, communication, creativity, and collaboration). Teaching-by-telling yielded to teaching-as-facilitating, and students became "lifelong learners." Soon after came renewed emphasis on STEM (science, technology, engineering, mathematics) education, followed closely by STEAM (science, technology, engineering, arts, and mathematics) education, an expansion that included integration, creativity, and human meaning along with disciplinary rigor.

The presence of STEAM education today is hard to miss. Look online, in stores, schools, around your community, and on social media. Everything from commercial books to kits, toys, day camps, mobile field trips, post-secondary programs and certificates, you name it, even episodes on Sesame Street seem to have a STEAM foundation. All advocate for and promote STEAM education as active learning focused on the five disciplinary areas to develop knowledge and skills through authentic applications that engage creativity in connected, expressive, and divergent manners (e.g., Michael, 2006; Zosh et al., 2018).

Within deaf education, STEAM continues to evolve as well, offering conceptual space for integrative ways of knowing, doing, and being. STEAM opens opportunities for study and experiential project-based forms of teaching, learning, and research. As Guest Editors of this Special Issue, we are curious about future meanings, roles, and possibilities for STEAM in deaf education.

This Special Issue

In 2021, two of us (Claudia Pagliaro and Jennifer Thom) co-edited the Special Issue—"Critical Topics in Mathematics Education: Research to Practice with Deaf and Hard of Hearing Learners" in the *American Annals of the Deaf* (Pagliaro & Thom, 2021a). Still a first of its kind in the journal's 179-year history, we, along with eleven authors from the U.S., Canada, and Europe, focused on core mathematics concepts, pedagogy, and possibilities for PreK-college deaf[1] students. The publication was much needed and well-received.

Building on that foundation, we (Thom, Pagliaro, and Chris Kurz), as Guest Editors for this Special Issue, widened the lens to include science, technology, engineering, the arts, and mathematics, STEAM. Our goal for this Special Issue was not additive, simply placing subject areas side by side, but expansive, to broaden perspectives on important concepts, teaching, and learning of STEAM. We have embraced a more diverse group of authors for this Special Issue to include deaf persons, persons of color, and persons who come from different professions and varied viewpoints, both established and emerging, empirical and theoretical. Our hope in publishing this Special Issue with this respected group of authors and in *Education Sciences* as an accessible, open journal is to reach a larger and broader audience to generate discussions on STEAM-related topics and to move the field "full STEAM ahead!", positively impacting deaf students' learning and success in life.

This Introduction highlights key themes within STEAM education and emergent themes from deaf education to frame and provoke readers' engagement with the articles that follow.

2. STEAM Education: Then and Now

2.1. Then (Early 2000s)

STEAM emerged partly in response to concerns about student engagement and self-efficacy in science and mathematics internationally. Results from PISA[2] indicated low student interest, motivation, and self-efficacy in their science learning (OECD, 2007, 2010)[3] among OECD countries. STEAM education was added to the educational bucket of possibilities for improving student performance, particularly mathematics and literacy (Colucci-Gray et al., 2019), to prepare students to solve current and future problems of a rapidly changing world (Breiner et al., 2012; Dakers, 2006; Livingstone & Hope, 2011).

While the new acronym featured the four original disciplinary fields, the addition of "A" for the "Arts" juxtaposed the sciences with the social sciences. Not only did the "A" signal the arts as facilitating greater student engagement and understanding of each discipline but also enabled students to think scientifically, technologically, engineeringly, artistically, and mathematically in wholly integrated and coherent ways (Baek et al., 2011; Yakman, 2008, 2019).

The introduction of STEAM education proposed novel and cutting-edge concepts, like design that included the humanities and expressive communication, as well as broadening

21st-century skills, such as critical thinking, problem-solving, creativity, and innovation. Yet framed in this manner, STEAM might be viewed less about the introduction of novel and cutting-edge concepts and more about recovering ones once had and then lost.

The integration of the arts with the sciences, technologies, engineering, and mathematics was fundamental to Western education before the 20th century. The arts figured prominently in both society and education (Bongaerts, 2022; Isaacson, 2017; Satchanawakul & Liangruenrom, 2025). Understood as interrelated and intertwined, the arts and the sciences, as taught and engaged, emphasized the human desire for creative forms of knowledge and technical skills.

For example, from Ancient Greece through the medieval period, the quadrivium (from Latin, "place where four roads meet, crossroads") of arithmetic, geometry, music, and astronomy, with the trivium of grammar (language and its workings), logic (thinking), and rhetoric (communicating), completed the seven liberal arts for university studies. Doing mathematics meant engaging in the sciences and the arts as wholly integrated disciplines. Proportional reasoning with harmonics was integral to understanding music, physics, the natural world, and architecture. Geometry (from the Greek, meaning "earth measurement") and astronomy (from the Greek, meaning "star-regulating") were born out of the need to locate, survey, and navigate. Projective geometry grew from the work of artists and architects exploring how perspective could be used to represent 3D objects on a 2D plane. Even as recently as the 19th and 20th centuries, the works and contributions of Jules Henri Poincaré, Maurits Cornelis Escher, David Hilbert, and John von Neumann simultaneously engaged in mathematics with other areas such as physics, engineering, art, and computer science.

2.2. Now (2026)

Today, there are many examples of the integration of the arts and sciences. Take, for example, Janine Benyus' scientific studies in biomimicry, which can be characterized as learning and emulating nature to create sustainable designs, innovations, and solutions (J. M. Benyus, 1997, 2012; J. Benyus, n.d.). Or think of the artist, mathematician, and computer scientist George Hart's sculptures, one of which is aptly named STEAM (https://www.georgehart.com/STEAM/Brown-STEAM.html, accessed on 2 September 2025)! Yet, current STEAM discourses, initiatives, and emphases involve different constructs and terms than those of centuries past, which contribute to dialogues involving how STEAM is to be conceived and enacted. Included here is whether STEAM should be considered a phenomenon, teaching approach, and/or an educational movement (Martinez, 2017; Perignat & Katz-Buonincontro, 2019; Rodrigues-Silva & Alsina, 2023). These debates also lead to additional questions, such as which STEAM knowledges and skills should be deemed relevant (Colucci-Gray et al., 2019; Herranen et al., 2021; W. Park & Cho, 2022) and which disciplines constitute the S, T, E, A, and M of STEAM (Costantino, 2018; Mejias et al., 2021; Perignat & Katz-Buonincontro, 2019; Yakman, 2008).

Next, we identify four persistent themes, as well as key preoccupations that emerge from them, as an overview for core coherences and divergences that enable the flux of STEAM education.

3. Themes in STEAM Education

3.1. Theme 1: STEAM Education as a Response to the Limits of STEM Education

Outside of education STEM (Science, Technology, Engineering, Mathematics) has predominantly focused on responding to political, practical, and global economic demands aimed at improving student participation and achievement in the four disciplines for K-12 as well as postsecondary programs; increasing the number of graduates to work in

STEM fields; and train teachers to teach STEM subjects (e.g., Colucci-Gray et al., 2017; Hallinen, 2026; Margot & Kettler, 2019; Montgomery & Fernández-Cárdenas, 2018; Stehle & Peters-Burton, 2019; Surahman & Wang, 2023; Thompson-Lee et al., 2025). In contrast, the emphasis on STEAM fields is largely in response to practitioners and creative industries asserting the importance of the arts for both economic growth and learning (e.g., Quigley et al., 2017). The resulting dichotomy between STEM and STEAM and the debates that arise regarding the "hard" natural sciences and the "soft" social sciences often transpire into back and forths of neoliberal agendas and those focused on human rights. Differently, educators advocating for STEAM argue that the purpose of public education should be to prepare all students for a constantly changing society. As such, educators contend that STEAM education extends beyond the pipeline model of STEM (e.g., Biesta, 2015) towards enabling students to engage with complex issues such as social inclusion, community, and the environment (e.g., Brundtland, 1987; Muller, 2008; UNESCO, 2017, 2018), issues that most often, if not always, require 'this-and-that' kinds of logics, knowing, doing, and being (Colucci-Gray et al., 2019).

A second contention among STEAM educators is that while conventional science training develops subject-specific facts and techniques, rarely is attention paid to the creative and cross-disciplinary knowledge and skills, once integral and fundamental to understanding and engaging in science (or any other discipline-specific area for that matter) (e.g., Madden et al., 2013). STEAM as a multiplicitous "nexus of practice[4]" (Peppler & Wohlwend, 2018) underscores the "convergence and emergence, as new practices overlap key valued practices espoused in prior work" (Peppler & Wohlwend, 2018, p. 4). Take, for example, the ways that fields within agriculture necessitate the overlapping and co-development of the health sciences, technology creation and building, landscape design, data analysis, and modeling.

Further, STEAM, as a part of multiple social worlds, can be conceived and explored as a boundary object (Star & Griesemer, 1989) or rhizome (Ingold, 2014). Doing so not only allows for distinguishing practices within STEAM but also for recognizing practices common across disciplines, such as how robotics involves crafting, circuitry, and coding (e.g., Colucci-Gray et al., 2019). STEAM as a boundary object or rhizome avoids restrictive definitions and thus the subsequent constraints imposed by them. Instead, STEAM is "not entirely part of the ways each community works [which allows STEAM to] remain somehow transparent to the concerns and methods of different communities of practice, [thereby creating opportunities for] producing different interpretations." (Colucci-Gray et al., 2019, p. 5).

Less rigid and static conceptualizations of STEAM also elicit the need to query the ontological and epistemological discourses that underlie the disciplines and forms taken up and taken on within STEAM. Reciprocally, STEAM compels examination of itself in terms of its own cultural, pedagogical, and environmental impacts "without ignoring the economic rationality in education… in order to embrace a more social and democratic conception of schooling" (Perales & Aróstegui, 2024, p. 59). For example, history not only calls attention to real-world scientific, technical, engineering-based, arts-focused, and mathematical issues (Gunckel & Tolbert, 2018), but at the same time prompts queries for "considering them more holistically along the moral and ethical aspects… [so] students [are] able to display their historical knowledge and skills in their interactions with other people." (W. Park & Cho, 2022).

The addition of the "A", such as the arts, opens opportunities to support underrepresented, marginalized, and/or ignored student populations, who have, to date, had limited access to STEM areas (e.g., Catterall, 2017; Marotto & Milner-Bolotin, 2018; Milner-Bolotin & Marotto, 2018). That STEAM engages multiple social worlds, which opens possibilities for it to be "transformative, allowing greater access and broader participation" (Peppler & Wohlwend, 2018, p. 91), and importantly, for STEAM to take on culturally respectful and responsive forms (e.g., Colucci-Gray et al., 2019; Perales & Aróstegui, 2024). Later in this paper, we discuss how this issue impacts deaf students. In more pragmatic ways STEAM can facilitate everyday competencies and skills like applying subject-convergent knowledge; critically thinking and using information in making decisions and solving problems; developing one's emotional wellbeing, self-respect, and social–civil awareness; and communicating, relating, collaborating, and contributing to the larger community (Ge et al., 2015; Hopia & Fooladi, 2019; B. H. Kim & Kim, 2016; K. C. Li & Wong, 2020; Milner-Bolotin & Milner, 2017; Perales & Aróstegui, 2024; Tesconi & De Aymerich Vadillo, 2020). With this wider scope, STEAM education extends beyond the goal of increasing human capacity for STEM fields and towards new ways of understanding and being in the world (e.g., Colucci-Gray et al., 2019; Herranen et al., 2021; Land, 2013; W. Park & Cho, 2022; Y. Park, 2022) that "cannot be solved through science, government or economics alone" (Overstrom, 2013, p. 207).

3.2. Theme 2: Defining the "A" in STEAM

The incorporation of the "A" in STEAM has generated a myriad of meanings, everything from the "arts" to "architecture" (Martínez et al., 2024), to "agriculture" (National Research Council, 2009), to "all" (White, 2014). Within this Special Issue, we refer to the A as "Arts" in its visual, embodied linguistic, and cultural forms. Even with this seemingly broad scope, interpreting what "the arts" mean in STEAM remains wide and varied, given the many disciplines involved (e.g., fine arts, physical arts, liberal arts, language arts, philosophy, sociology, psychology) (Ge et al., 2015).

The arts can also be viewed as supporting STEM disciplines. For example, including the arts as the humanities and the humanities as humanizing, a wider range of perspectives is possible (Belfiore & Bennett, 2007a, 2007b). This broadening of perspectives brought forth by STEAM calls attention to the human and societal dimensions both within each and across the five disciplines as an interrelated whole.

In a complementary way, the arts can be understood as playing a distinct or unique role in the achievement of STEAM such as in educational settings where visual arts elements are central to understanding both the form and function (Watson & Watson, 2013) of digital photography and graphics, games, geometry, as well as software programming where student creativity as design plays out while they learn computational knowledge and skills (Peppler & Wohlwend, 2018). STEAM areas like product development, architecture, and biomedicine all require engineering and design expertise (Perrault, 2016; Segarra et al., 2018; Watson & Watson, 2013; Yakman, 2008). Further, recognizing the role of aesthetics as core to how we come to sense the world and make sense of experiences locates the human body as essential (Gallagher & Lindgren, 2015). Thus, the arts are not an add-on to STEM but an integral part of meaning-making, design, aesthetics, and innovation. The arts shift "STEM's focus from better test scores in the core STEM academic disciplines to better quality of inclusive thinking and from focus on the development of a larger, technically competent workforce to one that is also more innovative." (Watson & Watson, 2013, p. 4). STEAM, as reoriented toward inclusive thinking and expressive competence, further reprioritizes the development of student abilities not only in terms of literacy and communication within STEAM but also creativity within the contexts in which they find themselves (Catterall, 2017).

3.3. Theme 3: Multiple Forms of Integration

When STEAM education is understood as neither the reinvention nor the counterargument to STEM but as humanistic disciplines integral (Colucci-Gray et al., 2017; Guyotte, 2020) and therefore nonhierarchically related to scientific, technological, engineering-centric, and mathematical subject areas (e.g., Rodrigues-Silva & Alsina, 2023), different meanings and models for "integration" are possible (e.g., Corp et al., 2020; W. Park & Cho, 2022). STEAM integration spans intra-, cross-, multi-, inter-, and transdisciplinary approaches (e.g., Baek et al., 2011; Pearson, 2017; Perales & Aróstegui, 2024; Rodrigues-Silva & Alsina, 2023; Sanders, 2006; Thibaut et al., 2018; Vasquez et al., 2013). Simply put, intradisciplinary STEAM teaching and learning focus on connecting different topics within a discipline (e.g., electricity and magnetism in physics). Cross-disciplinary STEAM education involves inquiring into a topic (e.g., environmental degradation) of one discipline (e.g., biology) by considering it from the perspective of another discipline (e.g., engineering). Multidisciplinary forms bring together complementary disciplines (e.g., art, computer science, and mathematics) in which knowledge, skills, and/or meanings particular to each discipline create robust understandings for a given topic or issue (e.g., computer-assisted design/CAD). In contrast, interdisciplinarity STEAM focuses on the understanding of each discipline and its intersections (Thibaut et al., 2018), promoting types of STEAM education that lie between different subject areas (e.g., technology, environmental sciences, and engineering) to generate collective spaces in which the integration among two or more disciplines becomes the topics for teaching and learning (e.g., criteria for eco-centric, efficient, and regenerative community buildings). And transdisciplinary STEAM approaches seek to develop knowledge (e.g., biomineralization) and skills (e.g., materials research, biomaterials, prototyping, and life-centered design) holistically, so they can be applied to complex topics for tackling real-world challenges (e.g., carbon-neutral alternatives to traditional cement). These models differ in purpose and depth but share an emphasis on connected knowledge and problem-solving. No single model is prescriptive. Integration is contingent on context, goals, and learners.

3.4. Theme 4: STEAM as an Educational Initiative and Policy

Globally, STEAM appears in policy initiatives, industry-funded and not-for-profit cooperatives, national curricula, and teacher training programs. More than an instructional approach, STEAM as education seeks to inspire innovation (Liao, 2019) and enable possibilities for transforming both school learning and communities around the world (Belbase et al., 2022).

In this section, we highlight a few examples for readers.

South Korea (Hong, 2021; Kang, 2019; S.-W. Kim & Lee, 2015; H. Park et al., 2016), China (J. Li et al., 2022; Wang et al., 2018), and Japan (Cheng, 2022) are three countries that have promoted STEAM through policy initiatives, school curricula, extracurricular programs, and teacher training. For example, in Hong Kong, emphasis and government funding of STEAM programs in primary and secondary schools began in 2016. The renewal of Key Learning Areas (KLAs) then appeared in curriculum guides in 2017. And from the 2022 Policy Address, all schools were required to have a STEAM coordinator to increase information technologies (IT) within the curriculum while enhancing teacher training. By the end of 2022, nearly 96% of the local schools in Hong Kong had implemented STEAM education in the classrooms or as extra-curricular learning. Identified needs include continued training for practicing teachers, particularly multidisciplinary approaches for teaching STEAM, as well as integrating STEAM into already full school curricula (Legislative Council Secretariat of Hong Kong, 2023).

In Japan, since the initiation of the 2016 Society 5.0 government policy, further policies and development in STEAM areas have given rise to hundreds of "Super Science High Schools" focused on the innovations in the humanities, science, technologies, and engineering (Cheng, 2022). There are also other programs which connect high school students with university researchers to conduct research (e.g., Global Science Campus), and for Grade 5–9 students, "Junior Doctor Training School" serves as "a next-generation human resource development project, aiming to develop outstanding human resources who will drive future science and technology innovation." (Asahikawa National College of Technology, n.d.). And at the prefectural government level, school boards are increasing STEAM education to practicing teachers (Kumano et al., 2023).

Promoting women and girls in STEAM fields is a priority around the world. Countries including Bulgaria, Finland, Belgium, Germany, France, Spain, Switzerland, the UK, Estonia, and Austria have created educational and career-related programs (e.g., mentorship, scholarship, and outreach) to overcome systemic obstacles and promote the participation of females in STEAM areas (Roinioti et al., 2025). Similarly, organizations for STEAM education in African countries, such as the Women Entrepreneurs for Africa (WE4A), offer mentorship, coaching, online learning, and networking for women. These opportunities focus on enabling women to expand their enterprises sustainably while increasing positive impacts in their communities (WE4A, 2022).

In 2015, U.S. President Barack Obama signed the Every Student Succeeds Act (ESSA) into law, setting the premise and enabling funding for the innovation and implementation of STEAM into educational programs and putting a focus on deeper and more practical learning. In addition to STEAM programs in elementary through high school levels, including extracurricular and postsecondary institutions, the 2022 U.S. Department of Education's Raise the Bar Initiative for Grades K-12 highlighted the need for both qualified STEAM teachers, as well as diversification of STEAM educators, particularly in mathematics and science. Registered Apprenticeship programs, as a response to address these needs to date, involve 46 states, including the District of Columbia and Puerto Rico. These K-12 teacher apprenticeship programs provide paid, on-the-job mentorship and further education to prepare apprentices for a teaching career in STEAM (Blad, 2025; Herron, 2025; Merod, 2026; Mirmina, 2025; Vargas, 2025; Ulin, 2025).

In Canada, the presence of STEAM is evident in provincial curricula, partnerships between not-for-profit organizations and schools, as well as within the context of the International Baccalaureate (IB) program. For example, currently in British Columbia, the Applied Design, Skills, and Technology (ADST) K-9 curriculum (2016) features competency standards and learning outcomes for technology (e.g., robotics, media arts, devices that transform energy), digital literacy (e.g., digital citizenship, information search and evaluation, digital content management, ethical and legal technology use), and computational thinking (e.g., writing algorithms, debugging and problem decomposition, visual and text-based programming). In 2019, the BC Ministry of Education and Science World launched Symbiosis as a cross-sector initiative. This program, a first of its kind in Canada, now known as Symbiosis-STEM ecosystems (https://stemecosystems.org/symbiosis/, accessed on 18 November 2025), works to provide BC youth, regardless of geographic location, ethnic background, or family income, with equal and increased educational opportunities to prepare them for STEAM-related careers. Key priorities are to: increase the number of teachers, scientists, technologists, and entrepreneurs who can be STEAM mentors to students and engage with them on personalized learning projects; create STEAM connections and networks for students and educators through classroom visits, volunteer opportunities, internships, camps, school-based clubs, and the Girls and STEAM Symposium; provide a digital hub where students, parents, teachers and mentors for sharing learning materials and educational opportunities, all linked to the new ShareEd BC tool, which became available for BC teachers in the spring of 2020 (STEM Ecosystems, 2025). And in Ontario, the International Baccalaureate World School for girls will open the Karen L. Jurjevich Innovation Center and Studio Theater (iCAST). The Centre will offer "leading-edge spaces to expand STEAM opportunities for its students, helping to close the gender gap by giving them the tools to thrive in a dynamic, tech-driven world" (New Facility to Expand Educational Innovation, 2025).

4. STEAM Within Deaf Education

STEAM has gained traction within special education and deaf education as part of the general curriculum as well as a means of addressing inequities in access, participation, and representation (Amor et al., 2019).

Limited access for certain populations to STEM areas, as mentioned previously, negatively impacts participation, retention, and success of students with disabilities (e.g., Marotto & Milner-Bolotin, 2018; Milner-Bolotin & Marotto, 2018). Students with disabilities in kindergarten through postsecondary STEM programs are reported among those who are underrepresented and not provided with equitable opportunities to engage as non-disabled students (Ariza & Hernández Hernández, 2025; Cech, 2023; Griffiths et al., 2021; Lee, 2022; Shattuck et al., 2014; Singer, 2016). deaf students are counted among the students with disabilities group. Despite interest in STEM-related professions as reflected by the number of DHH students enrolled in STEM programs, the low percentage of deaf STEM professionals appears to correlate with low completion rates among deaf students in STEM undergraduate programs (Ariza & Hernández Hernández, 2025). Deaf students remain underrepresented in STEM fields, not due to a lack of capacity or cognitive abilities, but because of systemic barriers related to language access, culturally relevant pedagogy, identity affirmation, and experiential opportunity (Braun et al., 2018).

Next, we discuss Themes 2–5 (above) with respect to deaf education as they relate to and emerge from Theme 1.

4.1. Mathematical Proficiency

STEM, and subsequently STEAM areas and professions, require mathematical concepts and competencies associated with understanding mathematics (Marshall et al., 2016).

While research studies in the past reported deaf students performing less well than their hearing peers in terms of mathematical proficiency on average and for all ages (e.g., Kritzer, 2009; Marschark & Spencer, 2009; Pagliaro, 2010; Pagliaro & Kritzer, 2013; Qi & Mitchell, 2012; Traxler, 2000), researchers have also indicated that the processes with which DHH students access the world and learn mathematics differ from those of hearing students (Pagliaro, 2015; Pagliaro & Ansell, 2012). These differences, when not attended to, present challenges for deaf individuals, even before they begin formal schooling (Kritzer & Pagliaro, 2013). Thus, the academic gap between deaf and hearing students is not because deaf students are less intelligent but rather because of a whole host of experiential differences beyond their control, both inside and outside formal education. For example, while hearing individuals are constantly exposed to indirect opportunities to learn (i.e., incidental learning via conversations and interactions in the environment or verbal and/or auditory cues), deaf persons may be precluded from such opportunities (Hopper, 2011). Thus, many contexts essential for all students' learning may critically disadvantage deaf students from developing contextual knowledge and experience (including in mathematics) necessary for making inferences, posing conjectures, identifying patterns, or creating generalizations, all of which serve as requisite skills when solving situation-specific and open ended problems (e.g., Henner et al., 2021; Kritzer & Pagliaro, 2013; Marschark & Everhart, 1999; Marschark et al., 2006; Pagliaro & Kritzer, 2010; Pagliaro & Ansell, 2012; Pagliaro & Thom, 2021b). It has been shown, however, that when these conflicts are mitigated, such as through accessible language or early interventions, deaf students can significantly close the gap or perform on par with their hearing counterparts (e.g., Henner et al., 2021; Kritzer & Pagliaro, 2013; Nunes et al., 2009).

Longstanding studies emphasize the role of embodied and spatial cognition in mathematical thinking (e.g., Healy, 2015; Lang & Pagliaro, 2007). Recent work across STEM disciplines further suggests important implications for research and pedagogy in deaf education (e.g., Thom & Hallenbeck, 2022). For example, studies on spatial processes and skills demonstrated by deaf children in mainstream classrooms present exemplars of students' understanding and activity in mathematics as not necessarily dependent upon linguistic proficiencies (verbal or sign) and at the same time, extend beyond grade-level curriculum outcomes (Thom & Hallenbeck, 2021; Thom & Weber, 2025). Here lies opportunity for deaf students, given that spatial activity and embodied cognition are inherent aspects of STEAM, not only in STEM disciplines but also in the visual arts (Watson & Watson, 2013), digitally based design work (Peppler & Wohlwend, 2018), and subject or topic areas which foreground aesthetics (Perrault, 2016; Segarra et al., 2018; Watson & Watson, 2013; Yakman, 2008).

4.2. Related Theme 3: Digital Literacy

Success, whether at school, work, or simply carrying out daily routines, requires literacy not only in terms of traditional forms of reading, writing, and communicating but also in terms of digital knowledge (e.g., cyber safety and security, coding, cloud computing); creative and critical thinking associated with these; and skills such as conducting online searches, using spreadsheets, or collecting, organizing, and displaying information. Both types of literacy are vital for deaf students' everyday lives, educational achievement in the workplace today, and for the future (e.g., Maiorana-Basas & Pagliaro, 2014).

Current technologies like real-time environments, live written communication, video-based applications, and tablet devices (Wauters & Dirks, 2017) offer deaf students opportunities for improved skills in literacy (e.g., Garberoglio et al., 2015) and, importantly, access, interaction, and communication, previously limited or unavailable to them (Kožuh et al., 2016). For example, one study by Mystakidis et al. (2023) explored the experiences of deaf high school students as they participated in a multi-school transdisciplinary STEAM museum project exhibited in a web-based 3D online environment. The researchers highlighted the social affordances (e.g., enhanced self-esteem, motivation, peer interactions inside and outside school time; see also Theme 4) that virtual reality provided the deaf students, empowering them as they produced analog and digital artifacts emphasizing digital literacy and future citizenship on topics such as environmental sustainability, social justice, the human brain, internet safety, and culture.

Research focused on digital literacies, technologies, and computational thinking offers 21st-century approaches, curricula, pedagogical practices, and learning opportunities for deaf students (Kritzer & Smith, 2020; Nikolaraizi et al., 2020). Important to include here are physical features in classroom environments where moveable furniture, multipurpose spaces, and readily accessible technological devices make it possible for deaf students to work on tasks while also being able to interact and collaborate with their peers (Kritzer & Smith, 2020). Settings like these, which incorporate DeafSpace features, ensure open and visually accessible environments for sign language users (Edwards & Harold, 2014; Humam et al., 2024).

Deaf students' development of digital literacies (Eden, 2020; Kritzer & Smith, 2020) within STEAM emphasizes authentic technology-based experiences paired with knowledge and skill development (e.g., Kelly & Mousley, 2001; Kritzer & Smith, 2020). Learning coding skills, for example, hone in on deaf students' ability to systematically solve problems, work across different literacies (e.g., textual, cultural, and technological), and think critically, sequentially, and reason algorithmically (Denner et al., 2012; Kafai & Burke, 2013; Lye & Koh, 2014).

4.3. Related Theme 4: Language, Experiential Learning, and Identities for STEAM

Access to language and real-world situations is vital to deaf students, not only in terms of their ability to identify and see themselves contributing to STEAM fields, but also, importantly, in terms of innovating these fields. Doing so will promote deaf student enrollment, retention, and achievement in postsecondary STEAM programs (Clark et al., 2022; Ross et al., 2019).

One area of emphasis is providing deaf students with access to STEAM-based concepts, meanings, and content through signed languages. Similar to STEM concepts (Bigham et al., 2008; K. Kurz & Kiselgof, 2024; Reis et al., 2015), signed words for STEAM concepts (Clark et al., 2022; Renken et al., 2021) will provide linguistic access to deaf students in their learning of STEAM-based knowledge, thinking, and skills, for instance, mathematics (Kurz & Pagliaro, 2020; Pagliaro & Kurz, 2021). And while language development and research, including the creation and instructional implementation of vocabulary for science concepts such as organic chemistry concepts, are in the early stages of development, advancements like this show potential for facilitating deaf students' academic performance and achievements (Clark et al., 2022). A second area of priority involves DHH students' comprehension of written information. Understanding written text is critical for solving problems and, particularly, as a potential source from which to draw upon when gathering useful information (Marschark et al., 2009; Pabis & Catalano, 2023; Traxler, 2000).

4.4. Creating Identities and Experiential Learning Within STEAM

Studies in deaf education report on the pivotal role that identity can play in the interest and success of deaf students in postsecondary STEAM programs (Marchut & Gormally, 2019). Researchers examining the importance of experiences regarding what it is like to work in laboratory settings attribute authentic learning contexts to enabling deaf students to see themselves as STEAM scientists. Having role models who work in STEAM fields and who have disabilities is another way in which students with disabilities can benefit, especially in terms of how those with disabilities not only participate in STEAM professions but also positively contribute in unique ways to these fields (Ross & Yerrick, 2015). Other studies emphasize the need to connect the personal experiences of deaf students with instructional content (Bao, 2019; Franklin et al., 2018; Marchut & Gormally, 2019; Ross et al., 2019), facilitating identity forming and engagement in STEAM (Franklin et al., 2018). As described in the study conducted by Mystakidis et al. (2023), the experiences of American deaf junior high school students in the museum project showed a positive impact on student self-confidence, sense of worth, and value of work, as well as on enabling interactions between deaf and hearing peers in a virtual STEAM environment.

A study on farming with deaf junior high students in the SLBN Karangrejo Medium Regency (Indonesia) presents different possibilities for deaf students' experiential STEAM learning and independence (Darmadi et al., 2023). These included growing kale crops as science, adapting and implementing materials and tools for harvesting kale as technology, developing an irrigation system for crop watering as engineering, maximizing space for seeding kale as arts-based design, and devising optimum land allocation as mathematics. Findings report increased independence in terms of deaf students' demonstration of criteria-based behaviors focused on responsibility, initiative, and independence over the course of their farming education on preparing, planting, caring, and harvesting of crops.

Academically demanding and real-world project-based STEAM-focused learning facilitates deaf students to take risks while actively working in creative, critical, and collaborative ways (Knoors & Marschark, 2014; Kritzer & Smith, 2020).

We now discuss pedagogical considerations essential to deaf students' STEAM learning.

4.5. Interrelated Theme 5: Pedagogical Practices

Having overviewed the four themes, Theme 5 interrelates with Themes 1 through 4, focusing on teaching practices and 21st-century education. STEAM education as inherently part of these two topics whether about teacher education for general preservice teachers (e.g., Easterbrooks & Stephenson, 2006; Love & Strimel, 2016; Luna Scott, 2015; Mannila et al., 2014); teachers of the deaf (e.g., Kritzer & Smith, 2020); professional development for practicing teachers such as applied technologies (e.g., Knoors & Marschark, 2014; Peppler & Wohlwend, 2018); or improving education regarding the prescribed curricula at the classroom level (e.g., Anwar et al., 2024; Coppola & Walker, 2025) call for changed perspectives, foci, and approaches. Ultimately, "good STEAM teaching" is simply "good teaching" for all students, including those with specific needs (e.g., Butera et al., 2016). For example, teaching that fosters social awareness, relationships, and cooperation towards students' self-respect, positive emotion, consideration, and abilities to contribute positively to their communities (B. H. Kim & Kim, 2016). Within deaf education specifically, such kinds of teaching also prioritize communication and instruction through the language used by deaf students; making use of technology and visuals that enhance accessibility, instruction, and communication; presenting specialized vocabulary in various modes (e.g., signed or captioned); having teachers with the requisite content knowledge and authentic critical thinking and problem-based pedagogy, as well as the ability to bridge the gap and variability between student reading level and written content and, as previously discussed, engage deaf students in experiential interactive collaborative learning (Easterbrooks & Stephenson, 2006). These pedagogical practices set the stage for Deaf student success in STEAM as rich teaching for robust learning (Colucci-Gray et al., 2019). For this section, we highlight teacher questions, Universal Design for Learning (UDL), and models for intentional teaching as important subthemes for Theme 5 in deaf education.

4.5.1. Questions and Questioning

Because questions are commonplace in teaching, it is easy to overlook them as a moot point (J. O. Kim, 2015). However, teacherly questions and pedagogical questioning that occasion student engagement, curiosity, and empower students to take their learning creatively in different directions are anything but natural, simple, or straightforward.[5] Thus, "a teacher's questions and ways of questioning are] one of the most valuable instructional skills to stimulate students' thinking, and serves several purposes, such as finding relevant things from learners, inferring relationships, facilitating the reasoning process, examining knowledge, and challenging thinking" (Y. Park, 2022, p. 206). The questions a teacher asks, and the ways questions are posed, can be considered a core professional competency that contributes to the linguistic interactions between a teacher and their students who are deaf (Choi, 2012).

The role pedagogical questions play in 21st-century STEAM learning, especially those with deaf students, is an underexamined area of research (Kritzer & Smith, 2020; Pagliaro & Kritzer, 2010). A recent study conducted by Y. Park (2022) in South Korea, while involving Grade 1 and 2 students with intellectual disabilities, identifies types of teacher questions in science-focused STEAM classes. Question types are identified across four main categories, with the latter three types compatible with STEAM for promoting student creativity and problem-solving skills. The four categories are: recall, convergent thinking, divergent thinking, and evaluative thinking (e.g., justifying, planning, and making a judgment). Cawthon's past study, which examined teacher questions in inclusive elementary classrooms with deaf students, reported two relevant findings (Cawthon, 2001). First, like in the study conducted by Y. Park (2022), Cawthon (2001) emphasizes the importance of open-ended teacher questions consistent with those emphasized in STEAM classes, as prompts that require students' thought, planning, and elaboration. Second, engaging DHH students in questioning and active inquiry is paramount in inclusive classrooms (Cawthon, 2001).

4.5.2. Universal Design for Learning

Universal Design for Learning or UDL shifts attention from positing shortcomings attributed to learner deficits to the way an environment, teaching approach, or curriculum is designed that may enable or disable student learning (Orndorf et al., 2022). Thus, UDL as an educational framework seeks to ensure all students have access to information and can demonstrate their knowledge through multiple representations, actions, expressions, ways to engage, and modes of interaction. UDL is to help teachers and educational professionals remove barriers (Tobin & Behling, 2018) that disadvantage some learners, adapt to individual student strengths and needs, and facilitate the success of all students. For educators, UDL promises to decrease the need for individual learner accommodations and increase student engagement by addressing a wider range of student needs. For students, UDL promotes a more inclusive, diverse, and accepting environment in which they can focus on learning rather than having to always navigate around obstacles that get in the way of their learning and/or risk falling through the cracks. For example, providing standard and meaningful signs for STEAM concepts not only provides deaf students with access to information and improved performance in STEAM and science content areas (Barroso et al., 2017; Orndorf et al., 2022) but also provides all students with a multilingual approach from which they can benefit (Golos et al., 2024; C. Kurz et al., 2021).

4.5.3. Intentional Teaching

At the same time that the UDL framework can accommodate a wider range of student needs, specific pedagogical considerations for deaf students, in addition to language access for STEAM education, must be kept in mind. These include pedagogy that supports deaf culture while also fostering student diversity, teaching and learning that is deaf-accessible, and instructors who have the knowledge and expertise to teach STEAM subject areas (Orndorf et al., 2022). With respect to content knowledge and expertise, there are, in some countries, inherent challenges when elementary or early years teachers are prepared as generalists. While generalist teachers may be able to teach all STEAM subjects, it is unlikely they will have the expertise to teach any of the subjects in depth. At the upper or secondary grade levels, teachers are often prepared as single-subject specialists and may only teach one STEAM area (e.g., López et al., 2021), thwarting the multiple forms of integration discussed in Theme 2 above.

While it would be ideal for every teacher to possess all these qualities, currently this is not the case, nor is it likely to be the case in the foreseeable future. Researchers focused on general education and deaf education who recognize the unlikelihood of general or deaf education classroom teachers to "have it all" instead advocate for teacher programs and professional development that focus on 21st-century practices and, at the same time, promote teacher knowledge and expertise through collective ways of collaborating, networking, and interconnecting pedagogical approaches (Gardiner-Walsh, 2025; Kritzer & Smith, 2020).

Two STEAM-focused frameworks in deaf education—Plan-Do-Act-Check (Marshall et al., 2016) and co-teaching (Gardiner-Walsh, 2024)—present potential ways forward.

The Plan-Do-Check-Act or PDCA approach, which originated from industry to improve the quality of the manufacturing process (e.g., automobiles in Japan), is one example of a STEM/STEAM-related framework that builds upon deaf postsecondary student learning styles (e.g., Lang et al., 1999); it has been explored with postsecondary deaf engineering students (Marshall et al., 2016). The approach engages deaf students in problem-solving learning environments that require their active participation. Learning modules are designed as a spiraled curriculum focused on problems (identification, current state, target or goal setting), root causes (i.e., observing, collecting, and analyzing), and implementation (i.e., countermeasure improvements). Instruction follows an iterative pattern in which ideas are presented using different modes (e.g., lecture, lab) and contexts (theoretical, simulation, real-world) to develop and deepen deaf students' conceptual thinking. Further research is needed to determine the extent to which the individual intervention aspects are beneficial; however, overall findings indicate that the PDCA approach featuring best practices and active and collaborative learning results in positive results regarding the problem-solving skill development of deaf engineering students.

Differently, several approaches for co-teaching deaf students have been proposed to optimize the expertise of both the classroom/STEAM content area teacher and the teacher of the deaf (Gardiner-Walsh, 2024). Each approach is designed for traditional, cross-categorical, and self-contained deaf classrooms. Within each of the classrooms, six co-teaching approaches are proposed. These are: one teach, one observe; one teach, one assist; parallel teaching; alternate teaching; teaming; and station teaching. For example, within a cross-categorical classroom, *one teach, one observes* involves either the STEAM teacher or the teacher of the deaf leading the content instruction, while the other teacher circulates to monitor student progress. *One teach, one assist*, teachers share taking the lead in STEAM content instruction while the other teacher assists individual students. *Parallel teaching* occurs when teachers teach different student groups and co-plan their instruction according to content goals and IEP goals. Student groups are composed of those who have different hearing statuses, modalities, and/or abilities. *Alternate teaching* is characterized as when teachers rotate, taking on more of the instructional role while the other supports student learning. *Teaming* features whole-class instruction where both teachers teach for the entire lesson. *Station teaching* involves students grouped according to interest, ability, and communication who work at a teacher-guided station to develop specific skills. For all approaches within the cross-categorial model, both teachers collaboratively integrate student IEP goals and protocols for student instruction, observing, and assessing.

The articles in this Special Issue, some of which are authored or coauthored by deaf scholars and promote deaf ways of knowing (Holcomb, 2010), extend the themes featured in this Editorial through empirical studies, theoretical analyses, and practice-based reflections spanning early childhood to postsecondary contexts. Collectively, they illustrate how STEAM can be enacted as multilingual, multimodal, culturally relevant education for deaf learners.

We now invite you to read on and explore the ways the authors in this Special Issue (re)imagine STEAM through deaf-centered lenses, challenge assumptions, offer novel frameworks, and enable new ideas for both research and practice, all the while pointing toward more equitable futures.

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Notes

1 "Deaf" is used throughout this article to encompass the broad range of individuals with cultural and linguistic characteristics. Our choice of "Deaf" is intended to include, rather than exclude, those deaf individuals who do not refer to themselves with this designation.

2 Program for International Student Assessment.

3 Organization for Economic Cooperation and Development.

4 The term, first coined by linguist Scollon (2001), refers to the dialectical ways in which human language, as "languaging" (Berger & Luckmann, 2023), and action are discursively interrelated and materialize dynamically as and through social–cultural relationships (e.g., worldview, gender roles, the ways and forms of knowledge that are recognized or ignored).

5 Parallel to questions and questioning, the chapter titled "Listening" by Davis (1996), pp. 33–53, provides frames which the author characterizes as "evaluative", "interpretive", and "hermeneutic" kinds of listening. The three frames are also informative in terms of understanding the intentionality of teacher questions and how they influence students' thinking and responses.

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