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STEM Education: Designing inclusion programs for special Education. Strategies – supportive techniques – technology

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Abstract

As students with disabilities have unique skills and tend to be more interested than their peers in STEM fields, in recent years various interventions and teaching approaches have been developed and evaluated to improve outcomes in each of the STEM disciplines. Given the importance of establishing a process that links these individuals' skills to future employment opportunities, and connects ability with success, special emphasis and attention is placed on enhancing the learning of students with disabilities. Researchers and educators have focused on understanding and designing STEM instruction around the needs of students with disabilities. Although there is a significant lack of research, scholars have begun to highlight how addressing the special needs of students with disabilities can be incorporated into the design of educational programs. Promising instructional strategies and/or interventions have been developed to improve their performance in each of the STEM subjects. The purpose of STEM curricula is to cultivate the distinctive learning differences of individuals with disabilities, with the goal of preparing students to meet and succeed in an evolving job market. These curricula combine social skills with 21st-century skills in a project-based STEM program. STEM education is a critical factor in addressing global challenges in the fields of energy, health, environmental protection, and national security (PCAST, 2010).

Keywords: STEM; Inclusion; Special Education; Learning Disabilities; Robotics; Games

1. Introduction

Employment is recognized as a critical milestone in an individual's adult life and is highly significant for strengthening one's self-concept, persistence, and adaptability (Zikic & Hall, 2011). It provides access to essential aspects of life and opportunities for socialization. STEM careers usually require preparation. As a result, STEM education has become a priority for the United States (Burgstahler & Chang, 2009; Tyson et al., 2007) and for most countries. The number of students with disabilities participating in higher education is increasing (Burgstahler & Chang, 2009; Burgstahler & Doyle, 2005; Henderson, 1999, 2001). However, few students with disabilities graduate from high school and enroll in postsecondary institutions, and even fewer obtain a bachelor's or graduate degree (Burgstahler & Doyle, 2005), indicating that their dropout rate is high (Burgstahler & Doyle, 2005; National Science Foundation, 2000; Office of Disability Employment Policy, 2001).

In the United States, more than 156 million jobs are available, and a 0.7% annual growth in available positions is projected over the next 10 years (U.S. Department of Labor, Bureau of Labor Statistics, 2017). The projected growth for STEM-related jobs between 2014 and 2024 was 28.2%, compared to 6.5% across all occupations (Fayer et al., 2017). Furthermore, 15% of the U.S. workforce is engaged in careers in computing, engineering, and science. These and other STEM-related fields are among the top 30 fastest-growing occupations expected by 2026 (U.S. Department of Labor,

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Bureau of Labor Statistics, 2018). This progressive increase in employment opportunities, combined with technological advancement, creates higher demands for diversity in thought, experience, perspective, and background in the labor market.

Although student motivation to develop knowledge in STEM content areas is high, challenges remain regarding enrollment in higher education and completion at the graduate level. Wei et al. (2013) conducted a longitudinal study examining students on the autism spectrum and found that they were among the populations most likely to choose STEM fields of study. Nevertheless, very few individuals with disabilities enter college preparatory programs, they are twice as likely to drop out of school compared to their typically developing peers, and only 35% of individuals with disabilities maintain full- or part-time employment (Wagner, Newman, Cameto, Levine, & Garza, 2006). Employment rates for individuals with autism spectrum disorder (ASD) are even lower, with estimates showing that college enrollment for students with ASD ranges between 0.7% and 1.9%, and their dropout rate is as high as 80% (Van Bergeijk, Klin, & Volkmar, 2008). Poor organizational, social, and communication skills often act as barriers to entering and maintaining employment in the labor market, as these are characteristics that particularly affect individuals with autism spectrum disorder.

Recent studies indicate an increase in autism diagnoses, with estimates suggesting that 50,000 young adults with autism will soon transition into schooling and adult life (Baio et al., 2018). Over the next 10 years, nearly half a million individuals with autism will reach adulthood, and this generational shift has been referred to as Generation A (Hurley-Hanson et al., 2020). The estimated cost of supporting and serving this population has already exceeded $268 billion in the United States and is expected to reach $461 billion by 2025 (Leigh & Du, 2015). Parents of children with autism report high expenses and healthcare costs, which increase as students age and face unemployment. Despite the fact that individuals with autism possess the ability and desire to pursue employment, approximately 80% are unemployed (Hendricks, 2010; National Autistic Society, 2019). As a result, adults with autism often report lower quality of life, financial hardship, and a lack of daytime activities (Taylor & Seltzer, 2011).

It is estimated that 85% of graduates with disabilities are either underemployed or unemployed as they enter young adulthood. Individuals with disabilities are marginalized in the workforce, and only 21% report being gainfully employed (U.S. Bureau of Labor Statistics, 2018). People with disabilities make up just 7% of the workforce in selected STEM fields and face unprecedented barriers, alongside women and racial and ethnic minority groups (National Science Foundation, 2017). This disconnect between ability and success results in lost opportunities for these individuals, who, for the most part, represent an untapped resource for a nation.

Research shows that maintaining employment for individuals with autism is a challenge. Difficulties with interpersonal skills and interpreting workplace dynamics can lead to increased stress or conflicts (Richards, 2012; Hayward et al., 2018). Studies also indicate that, in most cases, men with fewer autistic traits, less maladaptive behaviors, and no comorbid intellectual or cognitive impairments were more likely to experience positive employment outcomes (Eaves & Ho, 2008; Taylor & Seltzer, 2011). Therefore, individuals with disabilities—particularly those on the autism spectrum who pursue careers in STEM fields—should be positively encouraged throughout their school years and beyond.

There is, therefore, an urgent need to establish a process that links the skills of these individuals with future employment opportunities, and bridges the gap between ability and success. This can be achieved through STEM education, with particular emphasis and attention given to strengthening the learning of students with disabilities. According to the President's Council of Advisors on Science and Technology (PCAST, 2010), STEM education is a critical factor in addressing global challenges in the fields of energy, health, environmental protection, and national security. While only 5% of jobs required specialized knowledge in the early 20th century, more than 70% of jobs required specialized knowledge by 2009 (Mansilla & Jackson, 2011).

Due to the rapidly developing global economy and the resulting changes in the workplace, a nation's competitiveness depends on cultivating citizens who enter the workforce with well-developed STEM abilities and skills (Alper, 2016). In its 2010 executive report, the President's Council of Advisors on Science and Technology (PCAST, 2010) called for the creation of a significant number of STEM-focused secondary schools in the United States over the following decade, particularly in historically underserved and minority communities.

More than ever, there is a need to develop students' "21st-century skills," such as communication, collaboration, innovative thinking, and creativity (Larson & Miller, 2011), and the educational experience must be adapted accordingly. To build a highly skilled and adaptable workforce, STEM education actively contributes in this direction, enabling the development of a more capable and flexible labor force that can compete in a global market.

2. Designing Inclusion Programs for Special Education

Curricula integrate social skills with 21st-century skills (e.g., collaboration, communication, critical thinking, creativity, innovation, knowledge transfer, global awareness, peer support) within a project-based STEM program. Student programs are developed based on the core academic requirements for graduation and entry into higher education, and courses are taught in ways that promote interdisciplinary STEM learning. In addition, elective courses and extracurricular activities related to STEM fields are encouraged and made available.

Both in formal and informal learning environments, skills training and timely feedback on essential competencies are provided throughout the day. As a cornerstone of the Common Core approach, project-based learning is a teaching and learning strategy that emphasizes student exploration of complex problems. The outcome is publicly shared projects created by students (Edmunds et al., 2017).

Below, well-known inclusion programs for special education are presented.

2.1. Universal Design for Learning – UDL

The Universal Design for Learning (UDL) program is a STEM intervention and education program for students with disabilities. Basham and Marino (2013) regard UDL as the appropriate framework for implementing STEM education for students with disabilities.

Initially, universal design was developed in the field of architecture, with the goal of encouraging product designs that support an environment more accessible to all people. Universal design takes into account an individual's ability or skill level, learning style or preference, age, gender, sexual orientation, culture, and disabilities (Burgstahler, 2017).

Universal Design for Learning also incorporates three critical elements, which include providing multiple means of: (1) engagement, (2) representation, and (3) action and expression (Center for Applied Special Technology, 2018). These principles correspond to the why, the what, and the how of learning, respectively.

General guidelines for embedding UDL into teaching and learning have been developed by the Center for Applied Special Technology (CAST). UDL encourages educators to become familiar with recognition networks by offering multiple methods of representation; strategic networks, by offering multiple methods of action and expression; and affective networks, by providing multiple means of engagement that stimulate interest and motivation for learning (National Center on Universal Design for Learning, 2013).

2.2. IDEAS Program

Motivated by the effort to analyze social interactions between autistic and neurotypical students through the use of technology and engineering, and to evaluate self-efficacy and career interest in STEM professions, an inclusive making program was developed called Invention, Design, and Engineering for All Students (IDEAS) (Martin, Wei, Vidiksis, Patten, & Riccio, 2023). An interdisciplinary team of maker educators, autism inclusion specialists, engineers, teachers, and researchers worked to create an inclusive maker program for middle school students.

The Invention, Design, and Engineering for All Students (IDEAS) project was initially designed as a way to bring interest-driven designer programming into autism inclusion public schools in New York City, providing opportunities for diverse, low-income adolescents to participate in the Engineering Design Process (EDP). The project employed a collaborative co-design research and development model (Penuel et al., 2007; Roschelle et al., 2008), drawing on experts in maker education with different forms of expertise, with the goal of adapting a museum-based maker program so that it could be integrated into public middle schools to support autism inclusion. The theoretical framework guiding the program's design is based on the idea that engagement in iterative design and making—encompassing both physical and digital experiences and artifacts—can be valuable for the development of a range of academic, social-emotional, and interpersonal skills (Halverson & Peppler, 2018). The program was adapted and tested for more than two years as a pilot museum-based maker program, with the eventual goal of functioning as an informal club in middle schools for autism inclusion in New York City, United States.

A core principle of the IDEAS project, aligned with Universal Design for Learning, was the recognition that well-designed inclusive programming can be beneficial for all participants (Rao & Meo, 2016). This is because the program's strategies can be effective for many students with various types of learning differences. Qualitative analysis showed that all students participated in the program and pursued a wide range of interests, and that autistic students who struggled in typical school environments were able to create their projects and communicate about them with peers. In this way, autistic students could better see what they were capable of achieving, as they were freed from the constraints of traditional classroom instruction.

The program is open-ended, hands-on, and focuses on producing artifacts through the use of tools, guiding participants through the Engineering Design Process (EDP), in which they learn to identify a problem, gather ideas, design, build, test, improve, and finalize skills valued in both formal and informal education as well as in workforce settings (Blikstein & Krannich, 2013; Peppler et al., 2016; Quinn & Bell, 2013). A key feature of the program is that it is interest-driven, allowing participants to connect their personal interests to deeper STEM learning, providing the necessary time and space for self-initiated projects (Bevan et al., 2018; Martin & Dixon, 2016). Such opportunities for pursuing personal interests can benefit a wide range of youth (Honey & Kanter, 2013).

2.3. Inclusive STEM High Schools

Within the broader framework of designing inclusion programs for special education, Inclusive STEM High Schools (ISHSs) have been developed, focusing on integration and support for diverse student populations.

ISHSs aim to prepare underrepresented groups with the necessary skills for STEM careers. Student selection is based solely on interest, without competitive entrance exams. Key findings from studies indicate that underrepresented minorities and female students in ISHSs tend to choose advanced STEM courses. Consequently, ISHSs are indirectly effective in promoting deeper engagement in STEM fields among these groups (Kefalis & Drigas, 2024). According to research (Means et al., 2017), ISHSs focus on developing STEM talent within a diverse student body, often integrating STEM coursework and providing career-related support.

The educational philosophy of ISHSs includes project-based learning and real-world STEM experiences, playing a critical role in fostering student success. Students at ISHSs experience higher levels of support and encouragement from teachers, positively contributing to their academic outcomes.

Another study (LaForce et al., 2016) shows that inclusive STEM high schools emphasize pedagogy, transferable skills, and school culture, not just STEM disciplines. This holistic approach makes these schools resemble maker-education models rather than traditional, specialized STEM education (Kefalis & Drigas, 2024). Research findings by Lynch et al. (2018) demonstrated that ISHSs not only provided adequate preparation for college STEM majors and careers but also facilitated the development of STEM social capital through interactions with STEM professionals and exposure to out-of-class STEM opportunities (Kefalis & Drigas, 2024).

3. Strategies – Supportive Techniques – Technology

As students with disabilities possess unique skills and often face greater challenges than their peers in STEM fields, various interventions and instructional approaches have been developed and evaluated for each STEM discipline (Hwang & Taylor, 2016). Several strategies can be employed to increase students' access to STEM content, including the use of Universal Design for Learning (UDL), technology, and related accommodations.

Marino and Beecher (2010) promoted the use of compensatory assistive technologies. Providing students with such technologies can improve accessibility to educational materials, foster STEM literacy, and enhance students' attitudes and self-confidence toward engaging with STEM content and careers. The use of assistive technologies gives students with disabilities access to complex STEM content and may include elements such as e-books and text-to-speech software (Marino & Beecher, 2010).

Technology appears to be an effective practice for increasing participation of students with disabilities in STEM content (Access STEM, 2007; Dunn et al., 2012). Computers, assistive technology (AT), and networked resources can facilitate communication and accessibility for students with disabilities (Burgstahler, 1994; Dunn et al., 2012). Strategies such as explicit vocabulary instruction (Beck & McKeown, 2007; Scruggs & Mastropieri, 2000), anchored instruction (Glaser, Rieth, Kinzer, Colburn, & Peter, 2000), text adaptations (Bergerud, Lovitt, & Horton, 1988), and other reading strategies across content areas have been shown to improve student outcomes in learning STEM content (Basham et al., 2010). Step-by-step checklists, visual guides, and activity templates can be particularly beneficial for all students, especially those who may have sensory processing challenges (Grandin & Panek, 2013).

Universal Design for Learning (UDL), technology, and related adaptations have been found beneficial for increasing the participation of students with disabilities in STEM curricula (Access STEM, 2007; Dunn et al., 2012). Marino and Beecher (2010) encouraged the use of technology—particularly gaming—in combination with UDL. This combination serves as a compensatory structure to support students with disabilities in accessing scientific content (Bull & Bell, 2008; Marino & Beecher, 2010). They also advocated for gaming as a technology-based compensatory structure. Burgstahler and Doyle (2005) proposed the use of computer-mediated communication (CMC) to enhance access to STEM. CMC is an online method in which individuals use computers and networking technologies to communicate with one another and can facilitate interactions with mentors or peers.

Marino and Beecher (2010) encouraged educators to help students develop organizational clarity and use templates in conjunction with explicit instruction. Mastropieri and Scruggs (2004) supported the use of differentiated instructional materials and collaborative partners. Brozo (2010) emphasized connecting content to students' interests and extracurricular skills. Marino and Beecher (2010) highlighted gaming as a way to engage students with disabilities in STEM content. The National Science Foundation supports the use of networks and mentors to provide support and informal instruction as promising practices for increasing the participation of underrepresented groups in STEM fields (Burgstahler & Chang, 2009).

Assistive technology (devices or services) is used to compensate for functional limitations, facilitate independent living, remove activity restrictions, and leverage the capabilities of individuals with disabilities. The application of assistive technology devices in special education has a positive impact on the well-being and health of children with disabilities and their families more broadly.

Moraiti I. and Drigas A. (2023) report that New Technologies (NT), and more specifically Digital Technologies such as IoT technology, provide tools for accessing, analyzing, and transferring information, as well as for managing and utilizing new knowledge. Information and Communication Technologies (ICT), with the unprecedented technological capabilities they offer, have a transformative impact, creating a new social reality and shaping the Information Society (Pappas & Drigas, 2015; Bakola et al., 2020, 2022; Drigas & Politi-Georgousi, 2019; Karyotaki et al., 2022). The combination of ICT with theories and models of metacognition, attention, mindfulness, and emotional intelligence cultivation accelerates and enhances educational and productive practices, as well as decision-making outcomes (Drigas & Karyotaki, 2014; Drigas et al., 2017; Drigas & Papoutsi, 2018; Drigas & Karyotaki, 2019; Pappas & Drigas, 2015; Papoutsi et al., 2018, 2021; Karyotaki & Drigas, 2016; et al., 2020, 2021; Chaidi & Drigas, 2022; Mitsea et al., 2020, 2022; Galitskaya et al., 2021; Bakola & Drigas, 2020; Bakola et al., 2022; Bamicha et al., 2022).

According to Kefalis, C., Stavridis, S., and Drigas, A. (2023), Virtual Reality (VR) in science education can serve as a valuable tool for promoting hands-on learning and increasing student engagement. The use of VR in STEM laboratories has been shown to lead to higher performance. Furthermore, research findings indicate that VR improves learning outcomes and student achievement compared to conventional instructional methods. Virtual Reality, and particularly immersive technologies, are increasingly used as assistive tools in the education of individuals with special educational needs and disabilities (Mitsea, E., Drigas, A., & Skianis, C., 2023). VR has been found to be an effective aid, providing significant advantages over traditional mindfulness interventions. Mindfulness education supported by immersive technologies has been shown to significantly enhance a wide range of cognitive and socio-emotional meta-skills, including self-awareness, inhibitory control, attention regulation, flexibility, positive thinking, and emotional regulation (Mitsea, E., Drigas, A., & Skianis, C., 2023).

According to Kefalis, C., and Drigas, A. (2019), recent trends in STEM education include the use of the internet not only as a tool for information retrieval but also as a tool that intervenes in and differentiates the educational process. Leveraging connectivity, increasing shareable online media, and fostering collaboration among individuals at a distance create new educational opportunities. People can acquire knowledge remotely, in both formal and informal MOOC environments.

With Web 2.0 tools, communication between learners and instructors is synchronous and promotes collaboration. Virtual laboratories become flexible, user-friendly, and capable of achieving the same cognitive outcomes as physical labs, while saving resources and time. Online tools enable educators and learners to access knowledge easily and efficiently, fostering digital competence. Additionally, online games motivate and engage students, leading them toward playful learning. They promote interaction, reduce stress, actively support educational models, and offer new opportunities for communication, collaboration, and learning, allowing students with autism to participate in a controlled environment (Chaidi, I., & Drigas, A., 2023).

Despite the positive contribution of online learning, further research is necessary to explore its application in advanced subjects related to STEM fields. Finally, the enhancement and integration of ICT with theories and models of metacognition, mindfulness, meditation, and the cultivation of emotional intelligence, as well as with environmental factors and nutrition, further accelerate and improve educational and intervention practices and contribute to the rehabilitation of individuals with Autism Spectrum Disorder (Sideraki, A., Drigas, A., Moraiti, I., & Fotoglou, A., 2023).

Educational (or pedagogical) robotics has gained increasing interest in recent years and has been integrated into school settings, with significant involvement in the learning process. Humanoid robots have recently been introduced in educational environments to support the teaching of programmed lessons. Educational robotics is inherently an interdisciplinary field that introduces and guides students through robotic frameworks, robotic kits, and programmable robots, engaging them in programming, coding, and design.

In STEM education, educational robotics can be applied to hands-on activities using programmable humanoid robots. Humanoid robots mimic human form and movement and are highly versatile. The introduction of humanoid robots in school environments is relatively recent, with the main purpose being either individualized support for students or support for the entire classroom. The integration of robotics into education stems from the documented impact of robots on teaching and learning processes, as well as the social characteristics of humanoid robots, with which students can identify. Consequently, collaborative learning, critical thinking, and reflective skills are strengthened and promoted through research, design, and programming, making them critical and essential skills for a variety of courses within the STEM curriculum.

The integration of educational robotics into the learning process promotes student motivation and interest in scientific and technological subjects, making complex concepts more accessible and understandable. According to a scientific article by Mertzani, V., and Drigas, A. (2023), the positive role of robotics in STEM education is highlighted. Rather than receiving "passive information and knowledge," students are activated and actively participate in the learning process as creators of their own knowledge. Consequently, humanoid robots are considered a critical tool for advancing STEM education.

Nevertheless, most studies focus on the effectiveness of educational robotics in students' oral skills, reading abilities, and engagement with literacy-related topics. Few studies investigate the use of humanoid robots in STEM education, creating a gap in the existing literature regarding STEM education and humanoid robots. However, the benefits of humanoid robots in STEM education within typical school environments have been minimally examined in research, as most studies are conducted in non-traditional school or educational settings.

Concluding, we emphasize the significance of all digital technologies in the field of education, which is highly effective and productive and facilitates and improves assessment, intervention, and educational procedures via mobile devices that bring educational activities everywhere [49-51], various ICTs applications that are the main supporters of education [52-56], and AI, STEM, Games and ROBOTICS that raise educational procedures to new performance levers [57-60]. Additionally, the development and integration of ICTs with theories and models of metacognition, mindfulness, meditation, and the cultivation of emotional intelligence [61-74], accelerates and improves more educational practices and results, especially in STEM education, treating domain and its practices like assessment and intervention.

4. Conclusions

Creation as a pedagogical strategy can be beneficial for inclusion because its transparency and flexibility allow for multiple entry points into learning and action. In particular, it can support in-depth exploration of areas of interest. Leveraging the interests of autistic children has already been shown to be effective in many interventions and creating presentations is one way to extend these interests in a productive manner.

Assistive Technology (devices or services) can be used to compensate for functional limitations, facilitate independent living, remove activity restrictions, and maximize the potential of individuals with disabilities. The application of assistive technology devices in special education has a positive impact on the well-being of children with disabilities. Educational robotics has gained increasing interest in recent years and has been integrated into school settings, with significant involvement in the learning process.

There is limited research on the evaluation of STEM program outcomes for students with disabilities, and efforts are being made to create a comprehensive developmental assessment. Research findings regarding the evaluation of STEM programs for students with disabilities indicate that students demonstrated statistically significant gains in critical thinking, innovation, knowledge transfer, global awareness, collaboration, and communication. Project-based learning assessments have been used to measure whether students successfully learn and apply 21st-century skills and have been found to provide a more holistic view of students' abilities than standardized assessments alone. The problem-solving process used in project-based learning approaches provides a practical framework for educators to teach STEM more comprehensively. The ultimate goal is for students with disabilities to gain both content knowledge and practical skills to solve complex, real-world problems.

For neurotypical youth, programs that leverage established interests focusing on social relationships and peer culture can inspire them to engage in more academically oriented experiences, explore their identities, and see how STEM fields can relate to their lives. However, autistic youth often already have deep interests in academic subjects, including STEM fields and are drawn to STEM specialties at higher rates than the general population.

Finally, research findings can help inform the design of maker programs and create new perspectives on how activities are planned and implemented. The presence of experts and special education teachers in the development and coordination team of maker programs is also considered essential.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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