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Engaging Neurodiverse Youth in Informal STEM Learning: Strategies and Recommendations

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ABSTRACT

The talents that neurodiverse individuals bring to STEM fields are being increasingly recognized, thus it is important to ensure neurodiverse youth have opportunities to experience an array of STEM fields as viable career options. Based on the results of a systematic review, this article provides recommendations for how informal STEM learning programs can effectively engage neurodiverse middle and high school students. The recommended strategies highlight ways that programs can increase student interest and confidence in STEM in an environment that values learning and social differences.

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STEM; youth with learning differences; out-of-school; STEM/science engagement

GRAPHICAL ABSTRACT

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When designed to be inclusive, informal learning opportunities to engage in STEM (science, technology, engineering, and math) programs empower science learning, generate enthusiasm for science, and foster equitable learning experiences. This article focuses on the ways out-of-school STEM learning, commonly referred to as "informal STEM learning," can effectively engage neurodiverse adolescent learners. Neurodiversity is a term that embraces neurological differences as natural human variations, rather than clinical conditions needing to be cured. It encompasses autism spectrum disorder, developmental learning disorders, attention deficit hyperactivity disorder (ADHD), and other neurodevelopmental disorders (Stein et al. 2020). Increasingly, the characteristics of being neurodiverse (or "differently abled") are viewed as advantageous in scientific and technology fields (Austin and Pisano 2017). For example, neurodiverse thinkers sometimes perceive problems and solutions differently from neurotypical individuals, leading to innovation. However, students with neurodivergent conditions often face hurdles associated with managing day-to-day activities; adapting to changes in routines; and navigating social interactions, sensory demands, and barriers posed by bias or social stigma (Chandrasekhar 2020; Mellifont 2021).

Informal STEM learning experiences are opportunities to engage in STEM learning outside of the formal classroom (Roberts et al. 2018; Stanford, Wilson, and

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Barker 2018). Informal learning is beneficial to learners, as it allows them to guide their own learning and pursue their own interests (Bales, Volmert, and Kendall-Taylor 2015). Informal learning settings are often developed with the goal of being accessible for the greatest number of learners and therefore have the potential to create unique opportunities for learners from underrepresented populations. Self-directed learning in an informal setting allows learners to engage in their learning experiences at points that align best with their needs. Participation in informal STEM learning experiences has been associated with increased interest, confidence, motivation, and engagement in science and math concepts for students in general (Bales, Volmert, and Kendall-Taylor 2015; Goff et al. 2019; Graffin, Sheffield, and Koul 2022; Kwon, Capraro, and Capraro 2021).

As part of a larger National Science Foundation (NSF) systematic review, we conducted an academic and grey literature search to identify the methods by which informal STEM programs support the engagement of neurodiverse adolescents (for more details on this work see Jenson et al. 2023). Grey literature refers to documents that are readily available through a robust internet search but are not published or produced through commercial publishers. This systematic review identified seven programs for adolescent neurodiverse students. Table 1 lists the programs, settings, STEM area(s) of focus, ages of middle and high school students, and forms of neurodiversity represented. As noted in Table 1, the forms of neurodiversity varied, and some programs shared data about other conditions students experienced.

A synthesis of these seven programs showed similar strategies used to promote interest and confidence in STEM and provide an environment that values learning and "differently abled" students whose social differences may cause them to feel isolated or stigmatized. Using information from this synthesis, we compiled a list of recommendations that describe strategies for promoting the success of neurodiverse youth in informal STEM programs.

Promoting interest and confidence in STEM

Overall, we found that the strategies used to promote student engagement in STEM activities and programs were associated with reports of increased interest in STEM and confidence as a STEM learner. Programs used strategies such as

- incorporating hands-on activities;

Table 1. Informal STEM programs designed for neurodiverse middle and high school students.

Program	Setting	STEM Area(s) of Focus	Ages of Students	Neurodiverse Conditions
Inventing, Designing, and Engineering for All Students (IDEAS) Maker Program (Chen et al. 2021, 2020; Martin et al. 2020, 2019)	Maker afterschool program	Engineering	10–14	Autism spectrum disorder (ASD)
3D iSTAR Engineering Summer Program (Dunn et al. 2015)	University computer-lab	Engineering, technology, 3D modeling	9–19	ASD
ADHD Engineering Summer Camp (Syharat, Hain, and Zaghi 2020)	University campus	Engineering	10–18	Attention deficit hyperactivity disorder (ADHD)
Virtual Mentoring Program (Gregg et al. 2017)	Intervention took place through digital voice communication applications	STEM (general)	Students in secondary education (unspecified)	ASD; ADHD; learning disabilities and/or other psychological, motor, sensory, and health disabilities
Mentor-Matching Program (Powers et al. 2015; Sowers et al. 2017)	Intervention did not take place in one setting. Could include a variety of settings, including being taken to a local STEM college program or to meet a local STEM professional	STEM (general)	13–18	ASD; ADHD, and/or other emotional, learning, speech, sensory, or physical disabilities
National Aeronautics and Space Administration (NASA) Neurodiversity Network (N3) Program (Cominsky et al. 2022; Elsayed et al. 2022; Valcarcel et al. 2021)	NASA internships, remote astronomy activities	Astronomy	High school students (ages not specified)	ASD
For Inspiration and Recognition of Science and Technology (FIRST) Robotics Club (Fisher, Gallegos, and Bousfield 2019)	After school robotics-based club	Robotics	10–14	ASD

- providing students with a flexible, student-led learning experience;
- incorporating student input into the program to align the activities with student interests; and
- providing accommodations and modifications to improve the inclusiveness of the program.

All seven of the programs incorporated at least one of these strategies.

Many of the programs embedded either engineering design processes and/or scientific methods in their programs and structured the learning as hands-on design projects, experiments, and problem-solving experiences for the students. Programs reported that hands-on activities had many benefits for neurodiverse students, including helping focus student learning and providing students with a glimpse into STEM-related careers. For example, the Inventing, Designing, and Engineering for All Students (IDEAS) program included 12 hands-on activities using an engineering design process model for students. Some of these 12 hands-on activities included exposure to 3D printing, building a 3D model in TinkerCAD, designing a paper circuit that turns on an LED light, and prototyping their final projects. For a detailed outline of the curriculum we direct readers to Inventing, Designing, and and Engineering for All Students (IDEAS) Curriculum (2019).

The programs balanced adult-led and student-led activities, but the program leaders reported that they quickly learned that student-led activities engaged the neurodiverse learners more effectively. Student-led activities give students agency over their own learning, providing opportunities to actively make choices about participating in learning activities. It was not uncommon for students to "check out" during adult-led activities that did not interest them and then become more engaged when the programming was student-led. Program leaders also reported learning about the importance of flexibility, such as schedules needing to change to allow for breaks. The program leaders also learned to ask for student input and be flexible about adjusting the program to match student interests. In programs that provided flexibility for students, neurodiverse students were reported to be more invested in completing projects and learning STEM topics related to their individual interests. For example, in the IDEAS program students chose the topic areas of their culminating projects, which contributed to student engagement and interest in STEM (Chen et al. 2021; Martin et al. 2020).

Accommodations to address individualized learner needs were not typically anticipated by the program leaders; however, as the leaders became more familiar with the student participants and provided more flexibility, they observed ways that neurodiverse students would self-accommodate their learning needs. In the For Inspiration and Recognition of Science and Technology (FIRST) Robotics Club program when autistic students experienced sensory overload, they took breaks or ventured outside to alleviate stress from excessive noise, crowds, or other stimuli (Fisher, Gallegos, and Bousfield 2019). The National Aeronautics and Space Administration (NASA) N3 program allowed students to choose how they want to share their project findings, which resulted in students feeling empowered to share their presentation because they could be creative about the format that fit their learning and communication style (Cominsky et al. 2022).

The combination of these strategies promoted student engagement in the informal STEM programs, resulting in increased interest and confidence in STEM. Students reported being enthusiastic about their projects. Program leaders observed increased student motivation to complete their projects and confidence in their ability to share their projects through presentations. Students also reported an increased awareness of and interest in future careers related to the program's specific STEM discipline.

Providing an environment that values learning and social differences

All seven programs incorporated design elements intended to address the unique learning and social aspects of neurodiversity. The design elements included mentoring, social and collaborative learning, and using a strengths-based approach. Mentoring was typically used to provide students with a role model in a related STEM discipline. Social and collaborative learning was intended as a fun, engaging way for students to connect with other students who share similar neurodiversity traits and interests in STEM. And lastly, a strengths-based approach—framing the different abilities and the interaction systems of neurodiverse students as strengths rather than deficits—was used to maximize student potential and reduce stigma associated with being neurodivergent.

Most of the programs for middle and high school students had mentoring components (3D iSTAR, NASA N3, ADHD Summer Camp, FIRST Robotics Club, Virtual Mentoring Program, and Mentor-Matching Program) and, as noted in their names, the latter two programs included mentoring as a primary program component. In programs that included mentoring, the format was in-person, virtual, or a combination of both. However, in-person mentoring was the more frequently used mentoring format. Most of the programs that integrated mentoring had a model where mentors met one-on-one with students.

As a specific example, in one program high school–age neurodiverse students were matched with mentors in STEM who were employed in STEM careers or had graduated college with a major in a STEM field and shared personal characteristics, including characteristics of neurodiversity and similar STEM interests. Mentoring activities included

- shadowing the mentor at work or college,
- reviewing high school transcripts and developing a STEM course plan, and
- discussing future plans related to choosing and preparing for a STEM career (Powers et al. 2015; Sowers et al. 2017).

To provide a STEM role model who can show neurodiverse students that a career in STEM is possible, some programs designed the mentoring to be a mentor-student match based on STEM interest area and/or characteristics of neurodiversity. The ADHD Engineering Summer Camp program was led by a person with ADHD and the mentors also identified as having ADHD. Participating students with ADHD expressed that having these mentors was a significant benefit to the program because the mentors shared their experiences with ADHD (Syharat, Hain, and Zaghi 2020).

Programs reported that neurodiverse students developed relationships with their mentors and felt comfortable discussing STEM topics, asking for assistance on projects, and exploring STEM career goals. Interestingly, the mentor's ability to meaningfully communicate and connect with the students had more of an impact on student interest in STEM than mentor match based on STEM discipline or shared personal characteristics.

Five of the programs incorporated social and collaborative learning as core components of their programs (IDEAS, 3D iSTAR, ADHD Summer Camp, NASA N3, and FIRST Robotics Club). In one program, students were encouraged to work with their peers on STEM activities before engaging with program facilitators. In some cases collaborative learning was more structured, where students were assigned peers, small groups, or teams to work with on STEM activities or projects. Peer-to-peer interactions contributed to participants building relationships with others who were also interested in similar STEM topics. Program leaders reported that students developed peer relationships that helped them feel more comfortable with sharing their projects and asking questions. One program noted the gradual increase in spontaneous social interactions among students.

Many of the program leaders shared a belief that neurodiverse students are creative thinkers and are well-suited for STEM fields. With this mindset, the informal STEM program leaders aimed to provide learning environments and experiences that embraced the unique abilities of neurodiverse students rather than modify communication and social styles that may typically be considered inappropriate or out of place. To create strengths-based environments and experiences, adult leaders typically had prior knowledge and/or lived experience with neurodiversity and received specific training about adolescent neurodiversity.

An example of this training included the NASA Neurodiversity program, which provided mentors with workshops specifically focused on providing tips for working with neurodiverse youth. Several mentors expressed that how they viewed neurodiverse individuals changed after their training (Valcarcel et al. 2021). Similarly, mentor training was provided in the Mentor-Matching Program in which mentors learned strategies for developing relationships with students as well as disability-related information (e.g., accommodations received at school). Mentors were also trained to provide psychosocial supports to students, offering them opportunities to discuss their struggles, concerns, and fears (Sowers et al. 2017).

Another strengths-based strategy that programs used was seeking and incorporating feedback from students, community stakeholders, and parents. As a specific example, the IDEAS program used a co-develop process to engage the relevant community members, including experts in autism inclusion, maker education, engineering, co-design, and research, which took about two years. Initial pilot programs were implemented and then researchers interviewed principles at pilot schools to discuss the IDEAS program design. Once this feedback was received, the IDEAS project team spent months adapting the programing based on feedback (Martin et al. 2020). The process of working with community members is likely associated with how successful the IDEAS program was.

Discussion

The synthesis of findings from these seven programs reveals consistent and effective strategies for promoting interest and confidence in STEM among neurodiverse middle and high school students. The incorporation of hands-on activities, flexible student-led learning experiences, and accommodation of individual needs emerged as key elements. These strategies—informed by student, parent, and program leader perspectives—not only engaged neurodiverse learners but also enhanced their interest and confidence in STEM. The integration of scientific methods in hands-on projects and experiments further enriched the learning experience, aligning well with the informal nature of STEM learning outside traditional school settings. Particularly noteworthy is the positive impact of hands-on activities on neurodiverse students, focusing their learning and offering a glimpse into potential STEM careers.

The shift toward student-led activities was crucial in maintaining engagement, as neurodiverse learners were more likely to disengage during adult-led activities. The importance of flexibility in program scheduling and the incorporation of student input emerged as valuable lessons for program leaders, contributing to increased investment and project completion among neurodiverse students.

The combination of these strategies resulted in heightened interest and confidence in STEM, with students expressing enthusiasm for their projects and demonstrating motivation to complete them. Furthermore, program leaders observed increased confidence in students' ability to share their projects through presentations, along with an enhanced awareness of and interest in future STEM-related careers. Collectively, the use of these strategies aligns with principles of Universal Design for Learning (UDL). When applying UDL, programs incorporate multiple ways of accessing new information and skills, engaging in learning processes, and sharing or demonstrating what has been learned (CAST 2018). Using UDL assumes that all learners are diverse learners and one size does not fit all.

In addressing the unique social aspects of neurodiversity, all seven programs incorporated design elements focusing on mentoring, social and collaborative learning, and/or a strengths-based approach. The use of mentors as role models in related STEM disciplines, along with social and collaborative learning experiences, contributed to a supportive environment where neurodiverse students felt comfortable discussing STEM topics and exploring career goals. Importantly, the mentor's ability to connect meaningfully with students emerged as a key factor influencing interest in STEM, surpassing the impact of matching based on STEM discipline or personal characteristics. Furthermore, the emphasis on strengths-based approaches, including specific training for adult leaders and the incorporation of student, stakeholder, and parent feedback, contributed to creating environments that embraced the unique abilities of neurodiverse students.

Recommendations

Based on the lessons learned from the seven programs focused on adolescent neurodiverse students, the following list provides suggestions for creating an effective informal STEM learning experience for neurodiverse students.

1. *Hands-On Engagement:* Incorporate hands-on activities into STEM programs to foster active participation and provide neurodiverse students with tangible experiences.
2. *Flexibility:* Implement flexible, student-led learning experiences to accommodate diverse learning styles and interests, promoting sustained engagement. Recognize the importance of flexibility in program schedules, allowing for breaks and adjustments based on student needs.
3. *Accommodations and Modifications:* Proactively anticipate and provide an array of options for participating in program activities as an approach to being ready for variations in learner needs and ultimately fostering inclusivity.
4. *Prioritize Student-Led Activities over Adult-Led Activities:* Emphasize a shift toward student-led activities, recognizing their effectiveness in engaging neurodiverse learners.
5. *Empowerment through Choice:* Provide opportunities for students to make choices, such as choosing their project topics or methods for sharing their findings, fostering empowerment and creativity.
6. *Social and Collaborative Learning:* Incorporate social and collaborative learning experiences to create a supportive environment where students can connect with peers who share similar neurodiverse traits and STEM interests.
7. *Strengths-Based Approach:* Adopt a strengths-based approach in program design to maximize the potential of neurodiverse students, reducing stigma associated with deficit models.
8. *Training for Program Leaders:* Provide specific training for program leaders on adolescent neurodiversity, ensuring a better understanding and appreciation of diverse communication and social

styles. Additionally, provide mentors with training on ways to effectively communicate and connect with neurodiverse students.

9. *Feedback:* Actively seek and incorporate learner, family, and program leader feedback into program development. This empowers these participants in shaping STEM learning experiences.

How many of these recommendations would be beneficial for neurotypical youth? The different ways that neurodiverse youth engage and communicate make it necessary to reconsider the design of STEM learning programs. This research team posits that incorporating these recommendations will improve programs and outcomes for all students, not just neurodiverse students.

Summary

The talents that neurodiverse individuals bring to STEM fields are being increasingly recognized, making it important that neurodiverse youth have opportunities to experience an array of STEM fields as viable career options. Based on our comprehensive, systematic review of articles focused on neurodiverse adolescents, we have made specific recommendations for designing informal STEM programs to be inclusive of neurodiverse youth. We believe that incorporating these recommendations will improve the quality of informal STEM programs for all students, including neurodiverse students.

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