

Research Articles and Essays

**Effective Inclusion Practices for Neurodiverse Children and Adolescents
in Informal STEM Learning: A Systematic Review**

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Author Note

This paper is based upon work supported by the National Science Foundation under Grant No. 2115542.

Abstract

Informal learning settings are valuable environments for students to learn beyond the classroom. This article describes the preliminary findings from a systematic review that explored programmatic elements associated with science, technology, engineering, and mathematics (STEM) learning, knowledge, identity, and self-efficacy for neurodiverse youth in informal STEM learning environments.

Keywords: informal learning, STEM, neurodiverse

Effective Inclusion Practices for Neurodiverse Children and Adolescents in Informal STEM Learning: A Systematic Review

Informal science, technology, engineering, and mathematics (STEM) learning occurs outside the traditional classroom and includes a variety of settings, such as clubs, museums, and public libraries (Roberts et al., 2018; Stanford et al., 2018). Unlike traditional classroom settings, informal learning settings are often accessible to more diverse students from varying backgrounds (Bell et al., 2009). Informal learning environments also provide many different benefits to learning, including exploration of STEM environments with minimal risk (e.g., exploring the STEM environment freely without the pressures associated with testing, making mistakes, or taking additional time or repetitions needed to fully explore and learn) (Bales et al., 2015; Dabney et al., 2012; Denson et al., 2015; Lavigne et al., 2007; Lin & Schunn, 2016; Reich et al., 2010; Roberts et al., 2018; Schnittka et al., 2012).

The term “neurodiverse” comprises individuals with various conditions, including autism spectrum disorder (ASD), developmental learning disorders, or attention deficit hyperactivity disorder (ADHD). Neurodiverse students sometimes face additional challenges in traditional classrooms, such as modified daily routines, understanding social interactions, and barriers associated with their conditions (Chandrasekhar, 2020; Mellifont, 2021; Schindler et al., 2015). Studies reporting on informal STEM learning opportunities in museum settings and makerspace programs with neurodiverse students demonstrated an increase in STEM engagement as well as positive social interaction with peers (Bargagna et al., 2019; Howard & Park, 2014; Langa et al., 2013; Lussenhop et al., 2016; Riccio, 2022).

The purpose of this paper is to briefly present the preliminary results of our systematic review as we aim to answer the following research question: What characteristics of informal

learning experiences correlate with increased STEM identity, self-efficacy, interest, and learning in neurodiverse K-12 students? These preliminary results reveal ways that learning about STEM in informal settings can help neurodiverse youth increase their interest in STEM fields, shape their STEM identity, and increase their self-efficacy for furthering their learning in STEM.

Method

As a systematic review, the project team worked with a social sciences librarian to conduct a thorough literature search. Academic literature was retrieved from seven databases in October 2021: PsycINFO, ERIC, Education Full Text, Academic Search Complete, Cochrane Library, Science Direct, and Web of Science. The project team also completed a comprehensive grey literature search. Grey literature includes work that contains information that is produced by the government, business, and industry sources rather than traditional publication channels (Bonato, 2018). The grey literature search included published conference proceedings, informal science online resources managed by the Center for Advancement of Informal Science Education (CAISE), and final reports from related National Science Foundation grants.

All academic and grey literature was evaluated based on the following criteria:

1. Makes reference to neurodiverse students,
2. Focuses on students between the ages of 5 to 19,
3. Focuses on science, technology, math, or engineering (STEM) informal learning,
4. Focuses on informal learning settings (e.g., after school programs), and
5. Occurs in the United States.

Two independent research team members reviewed all abstracts and articles. If there

were disagreements in the reviews, a third reviewer assisted with reviewing the content.

Results

After data screening, there were a total of 19 products, including 11 studies and eight artifacts. Artifacts refer to content gathered from the grey literature search, which included evaluations, conference proceedings, a case study, and a podcast. The majority of studies included qualitative research designs ($n = 6$, 32%; Chen et al., 2021; Dunn et al., 2015; Ehsan & Cardella, 2019; Fisher et al., 2019; Powers et al., 2015; Syharat et al., 2020) and fewer were quantitative and mixed-method research designs ($n = 5$, 26%; Chen et al., 2020; Gregg et al., 2017; Martin et al., 2020; Sowers et al., 2017; Wright & Moskal, 2014).

Sample Sizes

The sample sizes of the products in this systematic review varied greatly, ranging from a case study of two participants to approximately 400 participants. Students with ASD were the most represented neurodiverse condition across products ($n = 16$, 84%). Students with ASD were the sole focus of 12 of the 19 products (63%). Significantly less research was conducted on other specific neurodiverse conditions, including dyslexia ($n = 1$, 5%; Wright & Moskal, 2014) and ADHD ($n = 1$, 5%; Syharat et al., 2020). In some cases, researchers grouped together a variety of neurodiverse conditions ($n = 5$, 26%). As this study focused on K-12 learners, we found that the majority of products reported on programs designed for middle or high school students ($n = 14$, 73%; Chen et al., 2020, 2021; Cominsky et al., 2022; Dahleh & Jonathan, 2018; Elsayed et al., 2022; Fisher et al., 2019; Gregg et al., 2017; Lesser, 2018; Martin et al., 2019, 2020; Nguyen et al., 2021; Powers et al., 2015; Sowers et al., 2017; Valcarcel et al., 2021).

Description of Informal STEM Learning

Informal STEM learning opportunities occurred mostly in after-school settings such as after-school clubs ($n = 7, 36\%$; Chen et al., 2020, 2021; Fisher et al., 2019; Lesser, 2018; Martin et al., 2019, 2020; McCarthy et al., 2021) or at summer camps/programs ($n = 7, 36\%$; Cominsky et al., 2022; Dahleh & Jonathan, 2018; Elsayed et al., 2022; Nguyen et al., 2021; Syharat et al., 2020; Valcarcel et al., 2021; Wright & Moskal, 2014). Many products included an aspect of mentorship ($n = 7, 36\%$; Cominsky et al., 2022; Elsayed et al., 2022; Gregg et al., 2017; Powers et al., 2015; Sowers et al., 2017; Syharat et al., 2020; Valcarcel et al., 2021) with most interventions lasting a few weeks ($n = 3, 15\%$; Dunn et al., 2015; Syharat et al., 2020; Wright & Moskal, 2014) to a few months ($n = 5, 26\%$; Cominsky et al., 2022; Elsayed et al., 2022; Powers et al., 2015; Sowers et al., 2017; Valcarcel et al., 2021). However, many programs/interventions were of indeterminate length ($n = 9, 47\%$; Chen et al., 2020, 2021; Dahleh & Jonathan, 2018; Fisher et al., 2019; Lesser, 2018; Martin et al., 2019; McCarthy et al., 2021; Nguyen et al., 2021).

Description of Preliminary Findings

When describing informal STEM learning, three categories of program elements emerged: (a) environment/learning structure, (b) learning supports, and (c) learning types. Environment/learning structure refers to the settings and programmatic structures that the informal STEM program put into place to engage neurodiverse students in the STEM content. Examples include how programs incorporated student interest into activities or how flexibility was incorporated into program curriculum. Learning supports are the extra steps that informal STEM programs took to connect the neurodiverse students to STEM learning. Use of mentors and accommodations are examples of learning support. Learning types include the instructional strategies used by the informal STEM program. The use of

technology, hands-on learning activities, and collaborative learning (peer-to-peer) are examples of learning types.

Environment/Learning Structure

In our review, one program demonstrated how the environment and learning structures can have an impact on STEM interest and self-efficacy for STEM learning. The Inventing, Designing, and Engineering for All Students (IDEAS) Maker program, which is described in multiple products ($n = 5$; Chen et al., 2020, 2021; Lesser, 2018; Martin et al., 2019, 2020), was co-created with experts in education, engineering and technology education, and inclusion. A key element to the structure of the IDEAS program was its strength-based approach to neurodiverse students' interests rather than framing highly focused interests as deficits. Facilitators of the program included one special education teacher and one subject teacher (science, art, or math). The program was held in an after-school setting and began with 12 hands-on activities, including learning about motors, light emitting diodes (LEDs), and circuits, which built off one another and led to a culminating final project (Chen et al., 2021). The curriculum also incorporated elements to assist with learning, including explicit strategy instructions to support problem-solving using the engineering design processes (EDP). The EDP provided a structured visual guide for students to utilize and assisted with goal setting and monitoring project progress. The IDEAS program was organized in a manner where students were able to explore their STEM interests in social environments with their peers. Students were given the freedom to build upon their own interests, which were integrated into their final projects, illustrating the provision of agency and autonomy to students. Having a structured yet flexible program was associated with positive STEM outcomes. Positive STEM outcomes were expressed qualitatively through semi-structured focus groups with students that participated in the IDEAS program and

teachers who facilitated the IDEAS program (Chen et al., 2021) and quantitatively with a STEM self-efficacy career interest survey (Chen & Usher, 2013).

Indication of how engaging the IDEAS program was for neurodiverse students was captured in a quote from one teacher: “[Teachers] observed that some students who normally would complete the bare minimum to get through their classes would create careful and detailed projects when they were allowed to pursue what they cared about (for example, memes, food, video game characters, anime)” (Martin et al., 2020, p. 15). Some students commented on how the IDEAS program influenced them to consider STEM careers or determine that they might want to have a future job with elements they were exposed to in the IDEAS program. One student with autism commented, “[An engineer] might be something I want to be when I grow up.” Another student stated, “What I’ve enjoyed doing is coming up with a bunch of ideas of what could potentially become successful ... engineering products” (Chen et al., 2021).

Overall, the IDEAS program had an effect on student self-efficacy for STEM learning. Researchers involved in the IDEAS program assessed students at the beginning and end of their engagement in the program activities, using a researcher-developed instrument shown previously to yield strong reliability coefficients. The results showed that the IDEAS maker group had higher scores than the comparison group (no participation in the IDEAS maker group) on engineering and technology self-efficacy with a Hedge’s g effect size of .82 (Martin et al., 2020).

Learning Supports

Learning support primarily included mentoring, accommodations, and modifications to programmatic elements ($n = 9$; Cominsky et al., 2022; Dunn et al., 2015; Elsayed et al., 2022; Gregg et al., 2017; McCarthy et al., 2021; Nguyen et al., 2021; Powers et al., 2015;

Sowers et al., 2017; Syharat et al., 2020; Valcarcel et al., 2021), where mentoring was the most commonly used learning support across all products ($n = 5$; Dunn et al., 2015; Gregg et al., 2017; Powers et al., 2015; Sowers et al., 2017; Syharat et al., 2020). Two products evaluated a STEM mentoring program for youth with disabilities on career planning outcomes. Researchers randomly assigned 78 youth with disabilities to either mentors with disabilities, mentors without disabilities, or a control group (Powers et al., 2015; Sowers et al., 2017). Mentors with disabilities were either employed in a STEM career or in a post-secondary STEM education program and were provided with coaching that emphasized the importance of mentors engaging in fun interactions as well as STEM career exploration. Examples of these activities included the student shadowing the mentor at work, reviewing high school transcripts together, and coming up with a course plan for college. One study used focus groups with students who had mentors with disabilities and mentors without disabilities to evaluate the impact of the mentoring program (Powers et al., 2015). The other study administered quantitative questionnaires at three different time points to determine if there were differences between the students with mentors with disabilities and students with mentors that did not have disabilities on career planning outcomes (Sowers et al., 2017).

Many neurodiverse youths in the mentoring program described how their mentor exposed them to STEM career opportunities in addition to contributing to STEM career aspirations. One student discussed how mentors exposed them to different types of STEM jobs: “This taught me, like, all the different types of jobs out there, like engineering jobs and just all the possibilities” (Powers et al., 2015, p. 30). Another student commented on how their mentor made obtaining a STEM job seem more achievable:

My mentor just kind of like opened my eyes to the possibilities of getting into a STEM career. And like helped me realize that it’s not impossible to do stuff like that.

She made me like science and math even more. (Powers et al., 2015, p. 31)

Researchers that conducted the mentoring programs examined changes in self-efficacy for participating students (Sowers et al., 2017). They measured STEM self-efficacy and confidence by adapting the Disability Related Self-Efficacy Scale (Powers et al., 1995). The authors used the adapted scales to evaluate the degree to which students believed they could get into college, do well in STEM classes, and obtain a STEM job. Students in the intervention group made greater improvements in STEM career planning confidence than the control group; however, this effect was less apparent over time.

Learning Types

Learning types included collaborative learning (peer-to-peer), hands-on learning, and real-world STEM applications. Collaborative learning was the most frequently cited learning type, in which some element of peer-to-peer STEM learning occurred in most products. Collaborative learning was observed in multiple formats, most frequently occurring informally as students worked together based on how the program was set up rather than being paired up or grouped by program facilitators. In the IDEAS program, program facilitators noted when relationships would form where there was a common interest or as students started to assist others in the program (e.g., peer teaching). Over time, participants were seen as valuable to their peers.

One observation drew a connection between the social aspects of the program and STEM learning. The program facilitator describes this informal collaborative learning:

Students were comfortable and willing to share their projects with peers and with adults and were enthusiastic to offer help and suggestions to each other. Teachers also reported observing spontaneous social interactions in students on the spectrum during the program. (Chen et al., 2020, p. 8)

A student with autism implicitly draws the connection between the social aspects and STEM learning by noting how the program allowed for students to not be fearful of failing. As he explains, “We’re always testing our prototypes. If it fails, it’s not a big deal because we have plenty of time to try it” (Chen et al., 2021). As another example, a program facilitator described how learning about the EDP was beneficial for students as they all were experiencing the same challenges, and that the EDP outlines the next steps if an experiment does not go as planned:

For us, we go over the engineering design process, we go over the steps, and we name them . . . It’s more comforting for them to say, “Oh, OK, so we go through this when a prototype fails. We go through iteration. We change it and then we improve it.”

(Martin et al., 2020, p. 11)

Discussion

These preliminary findings provide evidence of some programmatic factors being key to positive outcomes for neurodiverse students. The programmatic factors included hands-on learning, goal-setting activities, collaborative/social-driven learning, mentoring, and program flexibility to allow students to follow their interests. Common across these programmatic factors is that each is a way of fostering student engagement in STEM. Each of these programmatic factors has a long history of being applied to formal learning settings and to instruction of non-disabled students. But collectively, they illustrate the theoretical relationship between informal STEM learning experiences that provide options for student engagement and positive effects on STEM learning, STEM self-efficacy, and STEM identity. With roots in Social Cognitive Career Theory (Maiorca et al., 2021), this theoretical relationship between forms of social engagement in STEM learning and positive outcomes is not new. However, for neurodiverse students, it is interesting how these programmatic factors

are fine-tuned to increase the likelihood of their engagement. For example, receiving mentoring from someone who shares similar interests, whether that be in STEM or other topics, was effective for neurodiverse students. As another example, offering social learning opportunities provided enriching STEM learning experiences for neurodiverse students, who can often feel excluded from social learning formats in school.

Some programs used a control group of students without neurodiverse conditions, where in many cases it was evident that both groups of students benefited from these programs designed for neurodiverse learners, indicating that many aspects of these STEM interventions could be beneficial to a wide variety of students. Students with ASD were represented significantly more than other types of neurodiverse conditions; future informal STEM programs should consider recruiting students with other types of neurodiverse conditions to expand our knowledge on the impact of informal STEM learning programs for different neurodiverse students. Surprisingly, most of the informal STEM programs did not take place in public settings such as a public library or local museums. Most informal STEM programs were offered in collaboration with schools. To be more accessible to a wide variety of neurodiverse students, including those with varying backgrounds, future informal STEM programs should consider how to integrate their programming into public programs that could reach a wider audience.

As we continue with our analysis, we will probe further into the nuances of the programmatic features that distinguish the programs and outcomes for neurodiverse students and the features that are commonly indicative of informal STEM learning. Being able to distinguish important nuances will provide further recommendations for future informal STEM programs on improving their programs for neurodiverse students. Additionally, it is expected that many of the recommendations will also be enhancements that would improve

programs overall for all students.

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