Improving Executive Functions Using the Engineering Design Process: A Peer-Mediated Problem-Solving Approach for Autistic Adolescents

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Executive functions—specifically, problem-solving skills—are crucial for school success. Challenges in these functions faced by autistic adolescents are often unrecognized or viewed through a behavioral lens that requires correction or normalization. A lack of development of higher order problem-solving skills leads to increased instances of secondary mental health issues, creating further behavioral and social challenges. We propose using the Engineering Design Process (EDP), a flexible, cyclical, top-down, self-sustaining approach that uses peer mediation to teach group problem-solving skills. We then position this cycle within existing occupational therapy models to demonstrate its adaptability and flexibility, describe the distinct features of this problem-solving strategy, and present a real-world case study in which the EDP is used as a problem-solving approach in an after-school program. The EDP develops crucial social and interpersonal skills using interest-driven occupations and can be organically used as a group strategy. This article uses the identity-first language *autistic people*. This nonableist language describes their strengths and abilities and is a conscious decision. This language is favored by autistic communities and self-advocates and has been adopted by health care professionals and researchers (Bottema-Beutel et al., 2021, Kenny et al., 2016).

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Learning in academic contexts is an intricate and dynamic process whereby students are expected to portray knowledge, share experiences, pay attention to information, engage with learning resources, and effectively contextualize information and collaborate with teachers and peers (Bolton & Plattner, 2020; Cahill & Bazyk, 2020; Cahill & Lopez-Reyna, 2013). As more children and adolescents are diagnosed with autism and are increasingly studying in inclusive and mainstream schools, school-based occupational therapy practitioners must facilitate their optimal participation and engagement in the roles related to the school's academic and nonacademic occupations. Hence, there is an ongoing need for school-based occupational therapy practitioners to develop evidence-based interventions that meet the needs of autistic adolescents during this phase of physical, emotional, social, biological, and cognitive growth and transition.

Kornblau and Robertson (2021) noted that "all autistic individuals experience atypical thinking and its associated strengths, talents, and challenges in the areas of language and communication, social interactions, executive functions (EFs), and sensory processing" (p. 1). These differences, including in EFs, must be included when designing interventions for them in various contexts. EFs enable the association of two pieces of information, manipulation, and data comparison; the shifting of perspectives; the initiation, maintenance, and completion of tasks, and the self-regulation of emotions (Cramm et al., 2013a; Gardiner & Iarocci, 2018; Poon, 2018; Vaidya et al., 2020). These skills are an amalgamation of cognitive abilities (working memory and cognitive flexibility)[1] with emotional elements (motivation and emotional control; Poon, 2018; Vaidya et al., 2020). They are also foundational skills for developing complex functions such as planning, organization, and problem solving (Poon, 2018).

[1] *Working memory* is the capacity to hold information mentally and manipulate, associate, and use it (Diamond, 2013). *Cognitive flexibility* refers to the ability to shift and change perspectives by processing multiple information sources and responses, use mistakes as learning opportunities, switch between tasks, and adapt to new demands (Diamond, 2013; Drigas & Karyotaki, 2019).

Considered to be crucial for academic success, goal-oriented performance, and self-regulation, EFs are directly linked to effective participation in the student role both academically and nonacademically (American Occupational Therapy Association [AOTA], 2017, 2020; Cahill & Bazyk, 2020; Cahill & Lopez-Reyna, 2013; Mann et al., 2015).

However, challenges in EFs can hinder progress in learning and engagement in school activities, thus impeding social, behavioral, and emotional participation and leading to poorer academic performance and engagement in nonacademic spaces (Ashburner et al., 2014; Cahill & Bazyk, 2020; Cahill & Lopez-Reyna, 2013; Cramm et al., 2013a, 2013b). Moreover, Cramm et al. (2013a) contended that although EF challenges are prevalent in many autistic children and adolescents, they are often misunderstood or masked because of their outward manifestations in the form of social and behavioral deficits. Developing EFs and problem-solving skills are crucial (Drigas & Karyotaki, 2019) because they can facilitate autistic adolescents' abilities to mitigate their deficits in self-regulation, thus lowering the occurrences of challenging behaviors.

The Engineering Design Process (EDP) is an open-ended problem-solving strategy engineers use to solve complex design challenges by creating tangible products or solutions. This is a cyclical and highly iterative process in that it helps users engage in analytical reasoning and constant social collaboration to solve real-world challenges (Dym, 1994; Dym et al., 2005; Gardiner & Iarocci, 2018; Householder & Hailey, 2012; Kaboski et al., 2015; Martin et al., 2020; National Academy of Engineering & National Research Council, 2009). The EDP has seven steps: Users are (1) expected to define and understand the scope of the problem, (2) brainstorm solutions, (3) develop a prototype (the first iteration of the solution), (4) test the prototype, and (5) iterate the prototype to satisfy the problem. If the prototype fails, the user (6) retests and (7) reiterates it to improve it, and in this way the solution is achieved and disseminated (Householder & Hailey, 2012; Khandani, 2005).

Because deficits in EFs appear to become masked under social and behavior challenges, they can go untreated, hindering the educational performance and participation of autistic adolescents in the student role because of the occurrence of secondary mental health challenges (e.g., anxiety; Kaboski et al., 2015; Webb et al., 2004). To address this gap in the current evidence base, we propose including the EDP, which is illustrated in Figure 1, to help develop EFs along with problem-solving skills. We advocate for the benefits of the EDP by introducing this approach to school-based occupational therapy practitioners. We also present a real-world case study that illustrates how we have implemented this problem-solving approach to develop and expand autistic adolescents' EFs and problem-solving skills.

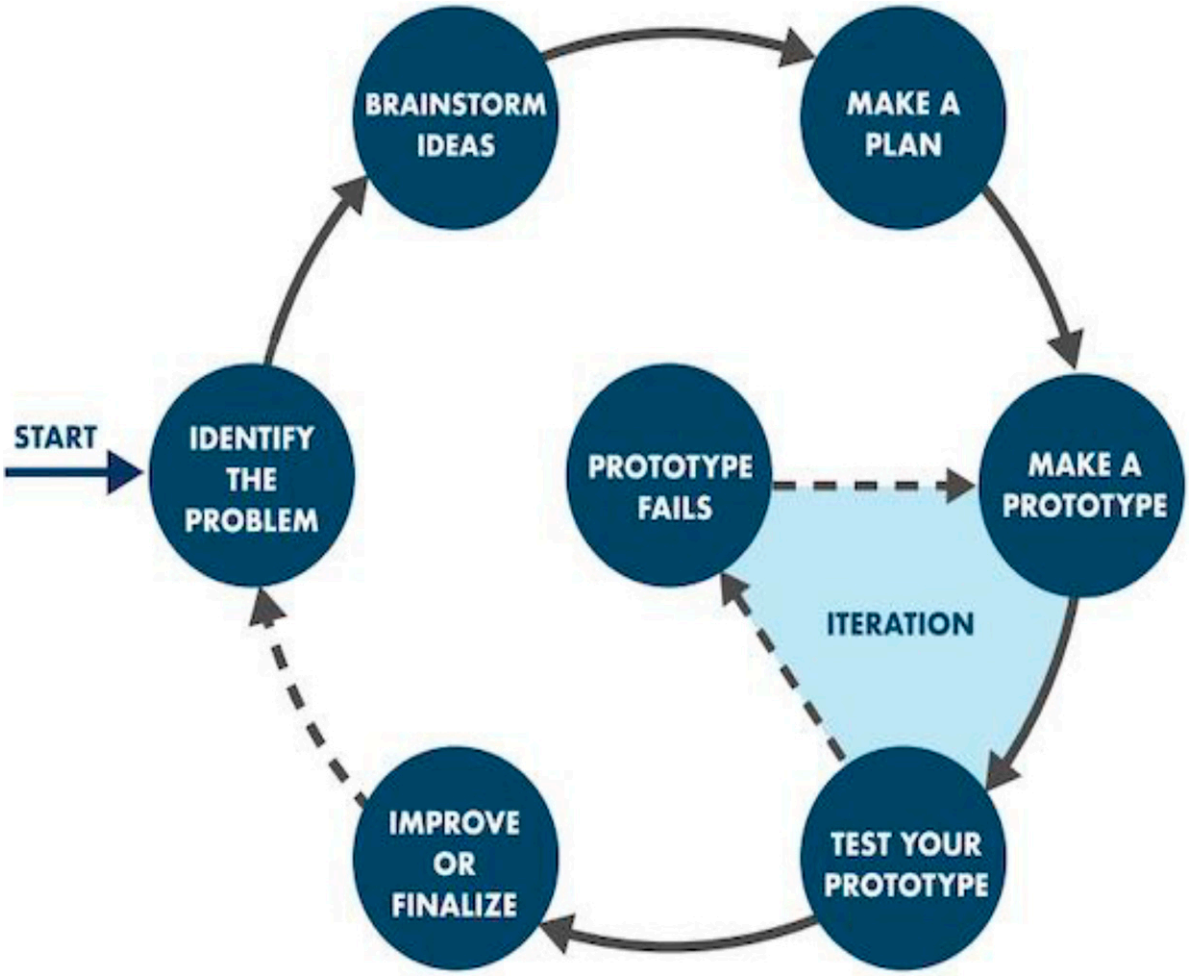
Understanding the Merits of the Engineering Design Process: A Strengths-Based Problem-Solving Approach for Autistic Adolescents

The EDP provides a framework to systematically approach problem solving and EFs by enabling users to identify a problem, find potential solutions by understanding the constraints in the context, and then finalize a solution through communication and collaboration (Householder & Hailey, 2012; Khandani, 2005; Papert & Harel, 1991). This helps users incorporate available resources and work through contextual constraints to solve problems realistically, adapt to failed opportunities, and improvise to develop optimal solutions to design challenges (Ehsan & Cardella, 2020). In addition, when autistic adolescents take part in the EDP, their EFs can improve as they analyze problems from multiple angles, work with peers to use their strengths and insights, and explore creative solutions to problems collaboratively (Chen et al., 2022; Ehsan & Cardella, 2020; Gardner & Iarocci, 2018). The flexible nature of the EDP makes it adaptable to any context, age group, ethnicity, and socioeconomic class (National Academy of Engineering & National Research Council, 2009).

When we compare the EDP with existing occupational therapy models and approaches, we note that this framework can meld with an existing occupational therapy approach: the Cognitive Orientation to daily Occupational Performance (CO-OP; Polatajko, 2017). Ikiugu et al. (2019) emphasized the importance of combining models of practice in a systematic manner by adopting an eclectic framework to address clients' needs. The EDP has the potential to be used flexibly along with the CO-OP as a complementary tool to facilitate peer-mediated problem solving. Designing such interventions will allow occupational therapists to help autistic adolescents develop the coping skills that are required in the classroom and in nonacademic spaces. Students can learn from their peers and try leading peer-mediated teaching processes if they desire (Bond et al., 2016; Bustamante et al., 2018; Martin et al., 2020). While working together, team members' individual strengths can be creatively incorporated to solve a problem (Ehsan & Cardella, 2020; Householder & Hailey, 2012).

Occupational therapy practitioners integrate the domain-general process of the Goal–Plan–Do–Check cognitive strategy that is part of the CO-OP to mediate the problem-solving procedure by offering guidance and solution interpretations in an effort to promote learning generalization

Figure 1. The Engineering Design Process cycle.



Note. From "Promoting Science, Technology, and Engineering Self-Efficacy and Knowledge for All With an Autism Inclusion Maker Program," by W. B. Martin, J. Yu, X. Wei, R. Vidiksis, K. K. Patten, and A. Ricco, 2020, *Frontiers in Education, 5*(75), paragraph 2 (https://doi.org/10.3389/feduc.2020.00075). *Note.* Reprinted from the original under the terms of the Creative Commons Attribution 4.0 Generic License (https://creativecommons.org/licenses/by/4.0). Retrieved from https://www.frontiersin.org/articles/10.3389/feduc.2020.00075/full#F1. Used with permission of Sara Camnasio.

(Missiuna et al., 2001; Polatajko, 2017). For example, in a study conducted by Rodger and Vishram (2010), therapists co-set goals chosen by children, including completing homework and managing anger on the playground. These goals were then addressed using the Goal–Plan–Do–Check strategy, and specific skill deficits were addressed through skill acquisition. Although the CO-OP can be used with a group by adopting an adapted strategy, a therapist must guide the problem-solving process (Chui et al., 2020; Polatajko, 2017). In contrast, the EDP primarily uses a collaborative peer-mediated problem-based learning approach in which the strengths of individual autistic students can be harnessed to solve problems collaboratively (Bustamante et al., 2018; Martin et al., 2020).

Along with this emphasis on peer-mediated problem solving, the EDP can be amalgamated with the CO-OP because of its adaptive and flexible structure. Bidirectional mobility between the seven steps facilitates failing and mistake-making by allowing students to improve their solutions through each iterative attempt (Lottero-Perdue & Parry, 2017). In this way, students can move among the seven steps of the EDP without completing a full iteration to determine whether their solution is effective. Thus, they can potentially correct errors they make during the problem-solving process and improvise their solutions (Cunningham & Lachapelle, 2016). In addition, incorporating individual students' inner curiosity, interests, and motivation provides them with the agency and persistence to solve their problems using their natural environments and resources. Students also learn to creatively use existing resources in novel ways, similar to how engineers solve complex real-life problems (Bustamante et al., 2018). As a flexible and peer-mediated problem-solving strategy, the EDP has other crucial advantages that make it well suited to be included in the occupational therapy tool kit for use with autistic adolescents in the school setting (Cahill & Bazyk, 2020).

Elements of Engineering Design Process That Enhance Peer-Mediated Problem Solving

The elements of the EDP that make it well suited for peer-mediated problem solving are systems thinking (ST), collaboration, communication, and creativity (Ehsan & Cardella, 2020; Greene & Papalambros, 2016; Householder & Hailey, 2012; Khandhani, 2005). In addition, the EDP highlights students' strengths and propels them to adapt and solve the situation presented to them with their resources. The impact of each component on EDP and problem solving is summarized in Table 1.

ST skills expose learners to competencies and routines that equip them to see emerging patterns and relationships (Greene & Papalambros, 2016; Householder & Hailey, 2012). The EDP enhances ST (or an engineering frame of mind) by promoting critical analysis, flexible thinking, and pattern recognition so a specific problem can be imagined in a grander systemic context (Householder & Hailey, 2012; National Academy of Engineering & National Research Council, 2009; Sneider, 2011, 2012). In a comparative study conducted by Kapur (2008, 2011, cited in Householder & Hailey, 2012), students engaged in deeper learning when using ST to solve ill-structured, challenging, complex problems with multiple solutions while being exposed to failure. Here, failing at complex tasks resulted in more profound subject matter expertise among these students. Students tried different ways to solve the problem and pushed themselves to undertake more challenges in class and nonacademic spaces. In addition, developing ST skills can improve problem solving because learners can then consider additional possibilities for solving the challenges by considering solutions from different angles and possibilities. Also, ST skills enable students to view the problem holistically or to view parts of the problem.

Collaboration is a critical skill that is built into the core of the EDP (Householder & Hailey, 2012; National Academy of Engineering & National Research Council, 2009). Students can engage, coordinate, organize, and adapt through open negotiations, shared understandings, and dialogue (Khandhani, 2005; Scardamalia & Bereiter, 2003). When solving problems collaboratively, students seek advice, support, and critical feedback on their ideas about shared work without judgment or criticism from therapists, teachers, and peers (Bustamante et al., 2018; Householder & Hailey, 2012). As students engage in activities of high interest, they are motivated to persist through frustration and regulate each other as members of a group, thus building crucial self-regulatory skills, such as frustration management, that increase willingness and openness to constructive criticism (DiDonato, 2013; Householder & Hailey, 2012). These skills align with typical response-to-intervention goals at Tier 1 and Tier 2 levels of support, often addressing group social skills enhancement (Cahill & Bazyk, 2020).

Householder and Hailey (2012) discussed how collaboration also improves ST as a whole-classroom strategy. They provided an example of a project in which student groups work to build individual parts of a sustainable energy source and then collaborate to combine these individual components into a holistic project. Each team's success depends on other teams; hence, there is built-in accountability to brainstorm practical solutions. Leveraging intentional grouping that combines complementary strengths can help teams develop the skills to brainstorm effectively (Householder & Hailey, 2012). In a study conducted by Martin et al. (2020), autistic students' capacity to problem-solve with peers increased as they participated in the EDP process. This intentional grouping, based on organic interests rather than forming groups on the basis of deficits, can augment social skill building in an authentic and strengths-based manner (Kaboski et al., 2015; Martin et al., 2020)

Communication is another component ingrained in the EDP (Householder & Hailey, 2012; Khandhani, 2005). The *Occupational Therapy Practice Framework: Domain and Process* (4th ed.; AOTA, 2020) emphasizes the role of communication as crucial; through communication a therapist can create collaborative partnerships with their clients or students. When students' voices are heard and respected, a power shift occurs, giving them agency in their intervention process (AOTA, 2020). As Cahill and Bazyk (2020) asserted, social skills interventions in the school context must center around autistic adolescents' formation of peer relations alongside increased agency to participate in their social roles.

Moreover, the EDP can accommodate various conventional and nonconventional communication practices (Householder & Hailey, 2012; Khandhani, 2005). Autistic students experiencing challenges with verbal and written expression can incorporate various meta-representational approaches, such as graphic organizers (e.g., storyboards), visual tools (e.g., videos, graphs, tabs, charts, lists), and symbols (Householder & Hailey, 2012). Using the EDP in combination with different channels (e.g., writing, text-to-speech, texting, graphs, symbols) can encourage autistic students to communicate in whatever manner is most effective for them, thus customizing this process to their unique needs (Householder & Hailey, 2012). Emphasis should be placed on exchanging ideas rather than language, diction, grammar, or syntax. In addition, groups should be assembled with the intent of minimizing power hierarchies among members to ensure that each member has equitable participation and that every member has an opportunity to ensure their voice is heard (Householder & Hailey, 2012).

Table 1. Elements of the EDP That Enhance EFs and Problem-Solving Skills

Element of EDP	Step of EDP Cycle	EF Skill That Can Be Developed	Problem-Solving Skill That Can Be Developed	How Do Users of EDP Learn These Skills?
Systems Thinking	Problem-scoping and problem-defining stage (first stage of EDP)	Cognitive flexibility and working memory	Problem identification (Browne et al., 2021)	Students can learn about the problem deeply and from different angles to find information about its nature, complexities, and challenges to solve the problem and understand the availability of resources (Khandani, 2005).
Collaboration	Problem identification and scoping; identifying possible solutions; building, refining, and evaluating the prototype	Self-regulation and co-regulation	Self-regulation	Students can be motivated to persist through frustrations and regulate each other as members of a group, thus building crucial self-regulatory skills (DiDonato, 2013).
Communication	Identifying possible solutions; building, refining, and evaluating the prototype; dissemination	Cognitive flexibility, working memory	Reflection, critical analysis, brainstorming	Students learn to ensure that a proposed solution is feasible, accurate, appropriate, easy to use, and appealing and to develop expressivity skills (Khandhani, 2005).
Creativity	Identifying the problem; finding possible solutions; creating, refining, and testing prototypes	Cognitive flexibility, working memory	Organization, planning, sequencing, and correcting errors to achieve a final creative thought or a novel product (Diamond, 2013; Householder & Hailey, 2012)	Diamond (2013) underscored that engaging in activities that foster creative thinking can boost the capacity to visualize connections between apparently unconnected ideas by disassembling and recombining ideological elements in new ways.

Note. EDP = Engineering Design Process; EFs = executive functions.

The EDP can foster *creativity* and innovation in school contexts by incorporating iterative ST, collaboration, and effective communication (Dym et al., 2005). Creativity is expanded through iterative loops of *convergent thinking* (when analytical skills are used to reach a confirmable answer) and *divergent thinking* (when a variety of strategies and possible solutions are considered before a response is confirmed; Householder & Hailey, 2012), and this can help autistic adolescents convert their ideas into tangible solutions with real-world implications. Occupational therapy practitioners can use this to their advantage by incorporating the EDP into interventions in which autistic adolescents are tasked with solving problems in real-world scenarios, applying convergent and divergent thinking, and using the feedback from these situations to develop and enhance their skills in academic and nonacademic situations. Occupational therapy practitioners can also help them participate and engage in their student roles in the classroom and outside.

Case Study: Using the Engineering Design Process to Solve Tricky Challenges Involving Robot Creation

The IDEAS (Inventing, Designing, Engineering for All Students) club is an inclusive after-school program that was developed to teach engineering, tinkering, designing, and technical skills to middle school students across three public schools in a large urban city (Chen et al., 2022; Martin et al., 2020). Both autistic and nonautistic students interested in engineering and tinkering, and their classroom teachers, were invited to participate in this club every year. Two teachers run the club, and students act as "maker experts." The EDP is integrated into the 12-part core curriculum as a peer-mediated problem-solving approach every year.

Let us learn from Sandy's and Katerina's (pseudonyms) experiences running the IDEAS club with their middle-school students in an inclusive setting. The students are working on motors as the week's activity. To begin, Sandy and

Katerina introduce them to the conceptual idea of motors, and the students, along with their teachers, build their knowledge by discovering how motors work, how they get energy, and which objects have motors. Students are then introduced to the different types and parts of motors they can use to build their robots or other creations. Some parts include insulated wires, AA batteries, paper plates, cups, and sticks. The whole club then brainstorms together using ST and collaborative communication to develop creative ideas to make small motorized machines or robots. The challenge is to make these machines or robots move so the students can have robot wars with their peers or complete a challenge to develop a new design.

Once this step has been completed, the students and teachers start working on their individual prototypes, discussing their ideas, correcting their errors, and thinking realistically about the resources available to them. Students then match their prototype with expected outcomes and start iterating their designs while fixing errors and making changes. Finally, students present their finished products to their peers and teachers while disseminating information about their finished products. Sandy and Katerina participate as peers throughout this cycle, refraining from taking the role of an expert or providing instructive feedback while the students work on their motor-controlled robots.

When Ross, an autistic student interested in robotics, approaches the teachers to take on the role of an expert, they create a leadership position for him, and he guides his peers through the process of robot making while answering their questions. As Ross becomes the maker expert for the day, he helps his peers to problem-solve through collaborative brainstorming to meet their design goals. When one student, Jamie, is stuck in the prototype revision phase, Ross helps by teaching him how to affix his motor to the robot, secure it, and then test-run it. Once all the students have built their robots, they spar with each other, or fight them against each other, to find the best robot in the club.

Although in this example two teachers oversaw this group activity, occupational therapists can easily adapt the process to individual or group settings because the process of problem solving using the EDP is very adaptable. This can also be a curriculum-driven activity in which all students in a classroom can participate. Through this process, occupational therapists can meaningfully integrate crucial age-appropriate occupations and skill development. The EDP has successfully been adapted to different activities, such as planning a taco party, creatively adapting a science class, or helping a student build a simple organizer for their school locker (EiE Spotlight, 2017; KQED Quest, 2017; Teach Engineering, 2018). For all these examples, the skills used by teachers, researchers, and practitioners included collaboration, facilitation, creativity, and the use of ST. Occupational therapy practitioners are already adept at incorporating these skills into their intervention planning and delivery.

Clinical Implications and Assimilation of the Engineering Design Process in Occupational Therapy Interventions

Occupational therapy practitioners' primary focus in schools is to help students obtain an education despite any shortcomings by augmenting their environmental access to participation in a successful manner (Cahill & Bazyk, 2020). Although conventional behavioral therapy interventions, such as applied behavioral analysis, focus on remediating or fixing negative behaviors (Anderson, 2022; Maw & Haga, 2018), they do not develop top-down skills, such as EF and problem solving, that increase autistic adolescents' capacities to participate in age-appropriate occupations (Bustamante et al., 2018; Gardiner & Iarocci, 2018; Patten Koenig, 2020; Urbanowicz et al., 2019). However, occupational therapists can adapt the EDP without using sophisticated engineering activities (Engineering Design Process, n.d.) to develop interest-based, top-down approaches that expose adolescents to generalized learning and adaptive strategies. Moreover, the EDP provides a self-sustaining system in which students can learn and practice ST in real-world, contextually relevant, and interest-driven situations. Moreover, they can make errors a normalized part of problem solving.

The dynamic and continuous nature of the collaborative partnership is ingrained in each step of the EDP. It can transcend home or classroom contexts, after-school activities, and nonacademic spaces, leading to organic friendships. The creative problem solving it entails can effectively increase students' participation in academic and nonacademic occupations in their classrooms by tackling daily challenges in these contexts. In addition, participation in shared occupations can lead to a sense of community among adolescents as they learn to work together on shared interest areas, leading to organic, spontaneous conversations initiated and sustained by autistic adolescents (Chen et al., 2022; Martin et al., 2020). Because such interactions are collaborative, the power of expressing ideas, finding solutions, and voicing concerns is distributed equally among the team members, that is, occupational therapists and students. Goals for school-based group interventions include collaborative and didactic interaction, which can be achieved with the EDP authentically and organically (AOTA, 2020; Householder & Hailey, 2012; National Academy of Engineering & National Research Council, 2009).

The EDP's philosophy is consistent with occupational therapists' multitiered interventions (Cahill,

2019). Whole-classroom strategies, as Cahill (2019) noted, benefit all students. The EDP can be effectively adapted to fit school occupational therapy interventions. It has the potential to reduce challenges associated with traditional pull-out services that increase autistic adolescents' risk of social isolation (Bolton & Plattner, 2020). Teachers and occupational therapists can also develop and strengthen a critical collaborative relationship to ensure that students attain educational goals (Bolton & Plattner, 2020).

Conclusion

EFs are domain-general skills that help autistic adolescents adapt to and solve daily challenges they encounter in school. Improving EFs must be a focus of occupational therapy because they propel participation in academic and nonacademic school occupations and encourage integration in school communities. Problem solving with peers expands students' collaborative and communicative skills. The EDP is structured to include collaborative work and to improve cognitive flexibility, self-regulation, and working memory. Occupational therapists can implement the EDP in a whole classroom or in small groups to solve daily challenges and act as collaborators, solving problems alongside each other, leading to more natural and context-specific social skills. This democratizes and builds authentic partnerships by promoting the inclusion of students with disabilities by providing them with agency in the learning process. The EDP's flexibility encourages the assimilation of students' interests and their curiosity to solve daily challenges. It has the potential to level the playing field for children from marginalized and minority contexts, giving exposure to science and engineering alongside problem-solving skills. Papert (1998 "Education's Nineteenth-Century Thinking in a Twenty-First-Century World," para. 11) observed that "We need to produce people who know how to act when they are faced with situations for which they were not specifically prepared." The EDP has the potential to empower autistic adolescents through the development of fundamental learning, literacy, and life skills that prepare them to face the dynamic competitive and dynamic employment market (Stauffer, 2020).

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