

Neurodiverse Education and Chatbots as Personalized Learning Tools: Opening the Research Agenda

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ABSTRACT

Approximately 15-20% of the global population is neurodiverse, including individuals with autism, Attention-Deficit/Hyperactivity Disorder, and dyslexia, who often face challenges in communication, social interaction, and sensory processing, leading to educational disengagement. Technology, particularly chatbots, offers potential solutions by providing personalized learning tailored to neurodiverse needs. However, research exploring this potential remains limited. The author examines how chatbots can provide personalized learning experiences tailored to the unique needs of neurodiverse students. This multidisciplinary review, grounded in Self-Determination Theory, explores how chatbots can enhance competency, autonomy, and relatedness for neurodiverse learners. Drawing on existing research and the lead author's lived experience with over 100 neurodiverse individuals and as a parent of an autistic adolescent, the study proposes a framework for integrating chatbots into education. It provides actionable recommendations for educators, researchers, and policymakers to improve engagement and empowerment for neurodiverse students. By aligning with the UN's Sustainable Development Goal 4, this research supports inclusive, equitable education and lifelong learning opportunities for neurodiverse individuals.

Keywords: Neurodiversity, inclusivity, technology, artificial intelligence, chatbots, education, personalised learning, autism, Attention-Deficit/Hyperactivity Disorder, dyslexia, UN-SDG.

1. Introduction

By 2030, a global population of 8.5 billion (United Nations, 2022) will include an estimated 1.2 to 1.7 billion neurodiverse individuals (15–20% of total population; Doyle, 2020). Neurodiversity refers to the natural variations in human brain and cognitive functioning, encompassing a range of neurological conditions (Baumer, 2021) such as Autism, Attention-Deficit/Hyperactivity Disorder, learning disabilities, and Tourette's syndrome. Neurodiverse individuals often face educational challenges, including difficulties with focus, sensory sensitivities, and barriers to processing verbal or written information (Doyle, 2020). Traditional teaching methods frequently fail to accommodate the alternative learning styles required by neurodiverse students, leading to challenges with comprehension, retention, and participation (Shayda Shevidi et al., 2024). Additionally, lack of personalized support, rigid classroom structures, and social anxieties further hinder their academic success (Mackiewicz et al., 2024). Technological advancements, particularly chatbots, hold promise for fostering a more inclusive educational environment by providing personalized, adaptable learning experiences. This study integrates the lead researcher's experiences with a comprehensive review of literature on neurodiversity, education, and technology to examine how chatbots can address challenges faced by neurodiverse students in educational settings. This approach aims to foster an engaging and empowering learning environment.

Meeting neurodiverse individuals' unique needs requires a shift toward an inclusive, strengths-based approach that values cognitive diversity and emphasizes students' abilities over their deficits (Hamilton & Petty, 2023). Such a shift could improve educational experiences and build a more innovative, diverse workforce (Chrysochoou et al., 2022). Academics are increasingly

exploring technological solutions to cater more effectively to neurodiverse learners, though more research is needed to understand these tools' applications.

Recent advances in AI and machine learning enable chatbots to interact with students in natural language, offering real-time, tailored responses (Dolianiti et al., 2020). For example, Singla et al. (2024) developed CAMI, a chatbot providing trusted resources on neurodevelopmental disorders (NDDs) through a knowledge graph. Gamification, such as goal setting, has also shown promise in enhancing engagement, though customization and rewards have had mixed feedback from parents of children with NDDs (Bui et al., 2022). In another study, Li et al. (2022) developed a deep-learning-based chatbot for conversational interventions for children with Autism Spectrum Disorder, underscoring the importance of user-centered design for effective chatbot tools for neurodiverse populations. Despite the potential of chatbots in neurodiverse education, few studies specifically explore their application for neurodiverse learners (Neha et al., 2024). By synthesizing current literature and highlighting key research gaps, this study aims to guide future research toward this critical, yet underexplored, area. A stronger research foundation in this domain will support educators and policymakers in implementing effective, technology-driven strategies that address the unique needs of neurodiverse students, thereby fostering more inclusive and responsive educational systems.

This paper employs Self-Determination Theory (SDT) (Deci & Ryan, 2015) to explain how chatbots can effectively support neurodiverse students by fostering motivation and engagement. SDT provides a framework for understanding the psychological needs that drive personality and social behavior, linking these needs to well-being, psychological growth, and quality of life. For neurodiverse students, personalized chatbots align with SDT's core components: enhancing autonomy through individualized learning paths, strengthening competence by addressing unique needs, and fostering relatedness through supportive interaction. Chatbots designed with SDT principles can thus help create a more engaging and supportive learning environment.

This study aims to address this gap by providing insights and recommendations for implementing chatbot technology in neurodiverse education, thus advancing inclusive educational practices and expanding this field. Additionally, this study supports the United Nations Sustainable Development Goal (UN SDG) 4 (United Nations, 2016), which advocates for inclusive, equitable quality education and lifelong learning opportunities, particularly for neurodiverse students.

2. Methodology

To address the research questions, the author combines personal lived experiences with a multidisciplinary narrative literature review. As a father of an autistic adolescent, a researcher in neurodiversity, an educator, and a member of a neurodiverse community, the first author has gained insights into the needs, challenges, and behaviors of neurodiverse individuals. This unique lived experience significantly enriches the study's findings and recommendations (Reid et al., 2021). The integration of lived experiences throughout research, from discovery to application, has a longstanding, respected tradition, enhancing the validity of the study's observations (Gupta et al., 2023).

In addition to lived experience, this paper includes a narrative review of research published in SCOPUS listed journals in areas of neurodiversity, education, psychology, and technology to identify relevant literature on the intersection of technology—particularly chatbots—and neurodiverse education. A narrative literature review is a qualitative summary of existing research (Sukhera, 2022). Unlike systematic reviews, which follow strict protocols, a narrative review synthesizes findings from various studies to provide a broad understanding (Baumeister & Leary, 1997). This approach identifies key themes, highlights gaps, and critically analyzes the existing literature (Cissey Usman et al., 2025).

For the current paper, the narrative literature review is a suitable choice, enabling a broad and flexible exploration of the topic. Given the wide range of studies from fields like neurodiversity, education, technology, and psychology, the narrative approach allows critical assessment and integration of various findings. This methodology supports the paper's goal of synthesizing knowledge and identifying areas for further research, contributing to a more comprehensive understanding of the subject.

3. Literature Review

The literature review is divided into two key sections: “Understanding Neurodiverse Education” and “Exploring Chatbots in Education”. The first section addresses essential topics, including defining neurodiversity, neurodiverse learning styles and cognitive profiles, challenges faced by neurodiverse students in traditional educational settings, the need for personalized learning, and the role of technology in supporting these learners.

The second section provides an overview of chatbot technology, focusing on its applications within educational environments. This structure lays a foundation that connects neurodiversity concepts with the potential of chatbots to enhance learning experiences for neurodiverse students.

3.1. Understanding Neurodiverse Education

3.1.1. Defining Neurodiversity

Neurotypical individuals exhibit a relatively uniform cognitive profile, while neurodiverse, neuroatypical, or neurominority individuals demonstrate significant variability across cognitive domains (Doyle, 2020). Neurodiversity, the concept that neurological differences are natural variations within the human genome, encompasses a range of cognitive functioning and enriches human experiences. Coined by Judy Singer in 1999, the term captures innate cognitive diversity, promoting inclusivity for neuro-minorities—those whose cognitive functioning deviates from societal norms (Chapman, 2020). Neurodiversity posits that all individuals, including "neurotypical" ones, are essential to society's diverse fabric (Baumer, 2021).

Neurodivergent individuals feature "spiky profiles," with disparities in cognitive skills, contrasting with "neurotypical" individuals whose abilities align within standard expectations across cognitive areas, whether average, above-average, or below-average (Doyle et al., 2022). Neurodivergent individuals, often classified at the bell curve's edges, include those with (O'Dwyer, 2022):

- **Specific Learning Disabilities (SpLDs):** Dyslexia, dysgraphia, dyscalculia, and dyspraxia impact learning and cognitive functioning. For instance, dyslexia complicates reading tasks such as interpreting instructions and filling out forms, often leading to frustration. Dysgraphia impedes written expression, affecting note-taking, paperwork, and communication (Gruendemann, 2023). Dyscalculia hinders numerical processing, making tasks like managing finances challenging, while dyspraxia affects motor skills, complicating activities such as cooking and driving (Kaufmann & Von Aster, 2012).
- **Developmental Disorders:** Autism Spectrum Condition (ASC), Attention-Deficit/Hyperactivity Disorder (ADHD), and Tourette's syndrome pose challenges in communication, sensory processing, and attention regulation. For example, individuals with autism may experience difficulties with social interactions, and sensory sensitivities, making public spaces or social gatherings stressful. ADHD affects time management and impulse control, complicating schedules and routines (Turk, 2021). Tourette Syndrome's involuntary tics can lead to social stigma, adding stress to interactions (Tsaur & Ku, 2019).

3.1.2 Understanding Neurodiverse Learning Styles and Cognitive Profiles

Neurodiverse learners benefit significantly from flexible, tailored educational approaches (Azuka et al., 2024) that respect and adapt to their unique cognitive profiles. Unlike traditional learners, who often develop effective learning strategies independently, neurodiverse students frequently require structured support to build individualized learning pathways (Clouder et al., 2020). These personalized methods empower neurodiverse learners to engage more deeply in the learning process, fostering awareness of their cognitive strengths and learning preferences (Puccini et al., 2013). By understanding their optimal learning paths, neurodiverse students become better equipped to tackle academic challenges and cultivate lifelong learning strategies.

Adaptive educational technologies play a crucial role in creating a safe and supportive environment, enabling neurodiverse students to learn without fear of judgment, thereby enhancing resilience and self-esteem. These tools allow students to explore diverse learning methods, helping them to identify techniques that resonate with their strengths and cognitive preferences (Halkiopoulous & Gkintoni, 2024). With a clearer understanding of their learning styles, neurodiverse learners can develop the self-direction and independence necessary for both academic and personal success.

A deeper comprehension of cognitive diversity is essential to fostering this inclusive, neurodiverse perspective. As classrooms increasingly embrace cognitive variability (Ashman & Conway, 2017), the demand for evidence-based frameworks has grown. These frameworks enable educators to adopt a "neurodiverse lens," which acknowledges the distinct learning needs and strengths of each student. Recognizing that neurodiverse students often process information, solve problems, and engage with content differently enriches the learning environment with unique perspectives (Eckel, 2019). For instance, frameworks like Norris (2023) Learning Ladder provide educators with tools to understand the nuanced learning mechanisms in neurodiverse individuals, especially those with autism. Norris identifies critical distinctions in memory systems, noting that individuals with autism spectrum disorder may show weaker episodic memory (memory of personal experiences) but often demonstrate strong semantic (factual) and perceptual memory (sensory processing). Recognizing these differences allows educators to tailor instructional strategies and implement assistive technologies that align with each student's unique memory strengths, thereby enhancing learning retention and engagement.

Working memory, a cognitive function often critical for learning and retaining information, also varies significantly among neurodiverse individuals. While neurotypical learners can typically retain up to seven items in working memory, dyslexic learners, for example, may retain only three (Puccini et al., 2013). This limitation underscores the importance of customized instructional methods that accommodate specific working memory capacities, allowing neurodiverse students to access, process, and retain information more effectively. Such tailored strategies ensure that students' cognitive limitations do not impede their ability to achieve academic success.

3.1.3. Challenges in Traditional Educational Systems for Neurodiverse Learners

Neurodiverse individuals encounter a variety of challenges that can influence their education and learning processes. Traditional school settings often fail to adequately support their learning due to a lack of understanding of neurological differences and sensory processing challenges (Leinfuss & O'Hara, 2024). Each neurodiverse condition affects specific aspects of learning and information processing, which shapes how neurodivergent students interact within academic contexts. Dyslexia, for example, impacts reading and comprehension, making it challenging for students to keep up with reading-based curricula (Shaywitz & Shaywitz, 2003). Dysgraphia limits students' abilities to clearly express ideas on paper, while dyscalculia impairs mathematical reasoning, creating significant barriers in numerically

intensive subjects (Gruendemann, 2023). Dyspraxia, associated with motor coordination difficulties, complicates tasks involving physical activity, such as taking notes or completing hands-on projects (Gibbs et al., 2007). Autism, similarly, often presents challenges in social communication, sensory processing, and adaptability, all crucial skills for success in traditional classroom environments (Frizell et al., 2024). Students with ADHD face persistent struggles with attention, impulse control, and organization, making it difficult to focus during lectures, manage time, and complete assignments (Meyers & Bagnall, 2015). Tourette Syndrome, characterized by involuntary vocal and motor tics, can further complicate classroom participation and peer relationships due to social stigma and anxiety (Leckman, 2002).

Neurodiverse learners also encounter significant societal stigma and prejudice, driven by insufficient accommodations and understanding within educational environments (Patton, 2019). This lack of support profoundly impacts these students' academic success. Research has shown that deficits in communication and peer interaction are key predictors of bullying, particularly for students with autism, who report heightened rates of victimization. Studies indicate that between 40% and 60% of children with autism and ADHD experience bullying, domestically and internationally, highlighting the pervasive nature of these challenges (Webb et al., 2024). Furthermore, data from the U.S. National Survey of Children's Health (2016–2020) reveals that stigmatization and marginalization by peers and educators contribute to mental health challenges, including anxiety and depression, among neurodiverse students (Accardo et al., 2024).

In addition to bullying, traditional educational environments often misinterpret neurodiverse traits, viewing them as deficits rather than valuable differences. This gap, compounded by fears of stigmatization, often prevents students from fully utilizing support services and adaptive technologies (Clouder et al., 2020). Additionally, discrimination in professional environments mirrors the stigmatization experienced in academic settings, perpetuating a cycle that can impede personal and professional growth.

Higher education institutions in particular face challenges in providing adequate support, with a disconnect between available resources and the actual needs of neurodiverse students. This experience and inadequate support contribute to higher dropout rates among neurodiverse students. For instance, students with autism are more likely to have lower graduation rates and higher dropout rates compared to their neurotypical peers, underscoring the absence of effective support structures (Clouder et al., 2020). Global statistics on dropout rates specific to neurodiverse students are limited, posing challenges to comprehensive efforts aimed at addressing these issues. However, based on the author's observations, dropout rates among neurodiverse students exceed 80% in higher education and 30% in primary education.. Furthermore, the perception of neurodiversity as a “disability” rather than a potential asset often restricts students' participation in specialized fields, such as engineering, where neurodiverse traits could offer unique value (Chrysochoou et al., 2022).

Interestingly, in higher education, while neurodiverse students may face obstacles in courses like business communication, these settings also offer opportunities to develop essential soft skills. In engineering education, the perception of neurodiversity as a disability rather than a potential asset limits the participation of neurodiverse students, which is a challenge that could be mirrored in other educational disciplines (Chrysochoou et al., 2022).

By offering appropriate accommodations, such as personalized learning, educational institutions can play a crucial role in enhancing neurodiverse students' success and well-being, aligning with global efforts to create inclusive and supportive learning environments.

3.1.4. Importance of Personalized Learning for Neurodiversity

Personalized learning, as defined by Shemshack & Spector (2020), is a customized educational approach that enables individuals to enhance their understanding, abilities, perspectives, and knowledge through tailored instruction. Unlike traditional models, personalized learning is designed to accommodate each learner's specific needs, goals, and skill levels, allowing students to progress at their own pace and work towards individualized objectives (Shemshack & Spector, 2020).

For neurodivergent individuals, personalized learning may be particularly essential as it provides flexible, adaptive educational methods that acknowledge and support their distinct cognitive and behavioral profiles. The variability among neurodiverse learners necessitates approaches that are adaptable to their unique learning styles, processing abilities, and socio-emotional needs. By adjusting educational content and methods, personalized learning facilitates better engagement and achievement for neurodivergent students, who may otherwise struggle in traditional, standardized classrooms (Azuka et al., 2024).

Instructors crafting personalized learning experiences for neurodiverse students often focus on specific learner characteristics and targeted outcomes, adapting their approach based on the individual's sensory-motor, cognitive, and socio-emotional profiles, which are critical for educational success (Bernacki et al., 2021). This is especially significant for learners with neurodevelopmental disorders and specific learning disabilities, as these conditions impact various functions—sensory processing, motor coordination, and social interaction—that are foundational to effective learning. Personalized learning, by addressing these specific functional areas, enhances the educational experience and fosters the holistic development of neurodiverse individuals, supporting their long-term growth and success (Ramos Saes et al., 2024). However, implementing personalized learning requires significant resources, including personnel and materials. Integrating advanced technology, however, may help to reduce the costs associated with these resource demands, making personalized learning more accessible and sustainable.

Evaluating the impact of personalized learning on neuroatypical students' educational experiences and academic performance remains challenging, as the definition of personalized learning can differ across various settings (Bernacki et al., 2021) and is still inconclusive even for neurotypicals.

3.1.5. Technology in Neurodiverse Education

The integration of technology into neurodiverse education can prove transformative. Information and Communication Technologies (ICTs) play a critical role by offering structured environments that foster learning and skill development. Tortosa & Ingavélez-Guerra (2021) highlights how ICTs create predictable, controllable environments with visual, multisensory stimulation that support autonomous work, reinforce self-control, and encourage active engagement. These technologies help students maintain focus, reduce frustration, and provide constructive feedback, thus lowering the anxiety associated with mistakes.

ICTs can also support strengths-based approaches in neurodiverse education. Sewell & Park (2021) describe how technology can reframe “intense interests” associated with autism as a constructive trait, allowing students to channel focused attention productively. Social clubs based on these interests can enhance peer inclusion and promote a sense of belonging, which is crucial for neurodiverse students' social development.

Technological interventions, such as virtual reality applications, telehealth systems, social robots, and specialized software, have been particularly successful in improving communication, social learning, and imitation skills. These technologies allow neurodiverse individuals to practice social and communication skills in low-stress

environments, helping bridge the gap between isolation and interaction. However, many of these tools are generic, often lacking the customization necessary to meet individual users' needs.

While virtual reality, telehealth, and social robots enhance vocabulary and communication abilities, current tools often treat autism learners as a monolithic group (Tortosa & Ingavélez-Guerra, 2021). Shifting toward more personalized tools, such as chatbots that use artificial intelligence, can better address each neurodiverse learner's unique strengths and challenges, thereby improving educational outcomes.

3.2. Chatbots in Educational Technology

3.2.1. Overview of Chatbot Technology

The term “chatbot,” derived from “chat” and “robot,” was introduced by Michael Loren Mauldin, describing software applications capable of text- or voice-based interaction (Dharani et al., 2020). Chatbots are automated systems designed to facilitate two-way communication with users, utilizing artificial intelligence (AI) and machine learning to simulate conversation (Szőke & Lakosy, 2024). Artificial intelligence is the field of computer science dedicated to creating systems capable of performing tasks that typically require human intelligence, such as understanding language, recognizing patterns, and making decisions (Simon, 1995). Machine learning is a subset of AI focused on developing algorithms that enable systems to learn from data, improving their performance on specific tasks over time without being explicitly programmed for each outcome (Sarker, 2021). In chatbots, Artificial Intelligence provides the overall framework for simulating human-like interactions (Tyagi & Chahal, 1 C.E.), while Machine Learning enables the chatbot to improve its responses over time by learning from user input and behavior patterns (Sarker, 2021).

A core component of chatbot functionality is Natural Language Processing, which enables chatbots to process and generate human-like responses (Wong, 2022). NLP is composed of Natural Language Generation and Natural Language Understanding, two key techniques that allow chatbots to interpret, analyze, and respond to users' text or audio input, simulating human intelligence across various devices. Through Natural Language Processing, chatbots can classify words, understand context, and provide meaningful feedback, creating an intuitive interface between computers and humans (Wong, 2022).

Chatbots, through their programmed capabilities, can recognize the intent behind a user's query and provide appropriate responses (Szőke & Lakosy, 2024). Once a chatbot identifies the user's intent, it can further personalize responses based on user preferences, learning styles, and interaction history (Dharani et al., 2020). For instance, a chatbot might recommend learning materials tailored to a student's interests and previous interactions.

In business, chatbots operate as virtual assistants, enhancing customer support by managing multiple interactions simultaneously, thus reducing service costs and mediating data access (Silva et al., 2023). Leveraging AI, they can analyze extensive datasets to identify patterns and preferences, delivering valuable insights to businesses (Simon, 1995). Recent bibliometric analyses reveal a growing body of research on chatbots in business domains such as customer service, marketing, human resources, and financial management (Ramya & Alur, 2023). The use of chatbots is rapidly expanding in educational settings (Ramya & Alur, 2023).

3.2.2. Chatbots in Educational Settings

In educational settings, chatbots provide a cost-effective means of supporting and supplementing formal instruction (Hobert, 2019). They deliver a wide range of pedagogical content, assess student progress, and offer multimedia resources, adapting dynamically to diverse subjects and learning levels (Hobert, 2019). Furthermore, chatbots

facilitate collaborative learning by organizing and managing smaller learning groups, responding to individual needs, and even recognizing learners' emotional states to offer personalized support (Hwang & Chang, 2023). These capabilities position chatbots as transformative tools in personalized education, contributing to increased engagement and improved learning outcomes (Hwang & Chang, 2023).

Research shows that chatbots bring notable benefits across various learning contexts, positively influencing students' attitudes, engagement (Torrado et al., 2023), and academic performance (Hobert, 2019). Studies indicate that chatbots enhance enjoyment, sociability, and trust, encouraging students to interact more readily with these systems (Hwang & Chang, 2023). Their 24/7 availability is particularly valued by students, as it provides flexibility that accommodates diverse study schedules and learning preferences (Hwang & Chang, 2023). By offering a consistent, on-demand presence, chatbots ease transitions through challenging tasks, reduce cognitive load, and foster focus and motivation in learning activities (Carayannopoulos, 2018). Beyond engagement, chatbots play a pivotal role in boosting academic outcomes by enhancing self-efficacy, critical thinking, and performance across various subjects (Chang et al., 2022). Platforms like ChatbotSQL and e-tutor provide specialized feedback, supporting skill development in fields such as SQL and Python programming (Pereira et al., 2023). In experiential learning environments, chatbots like MERLIN effectively promote autonomous learning, resulting in high student satisfaction, with over 90% of participants reporting a sense of competence and achievement (Shim et al., 2023). Additionally, systems like E-tutor have demonstrated significant improvements in academic performance and passing rates among students using chatbots for self-directed learning (Castillo Valdivieso & Aguilar-Luzón, 2021). Chatbots can be categorized into two main types based on their educational purpose: service-oriented and teaching-oriented chatbots (Pérez et al., 2020). Service-oriented chatbots focus on administrative support by addressing frequently asked questions (FAQs) and reducing the workload on institution staff. For instance, Dina (Agus Santoso et al., 2018), Lola (Pérez et al., 2020), and the FAQs Chatbot (De Lacerda & Aguiar, 2019) help answer a high volume of repetitive inquiries about admission, enrollment, and general academic procedures, improving administrative efficiency and student satisfaction. Specific applications, such as the UC3M Library bot, show enhanced usability and accessibility on mobile devices, receiving positive evaluations from users (Pérez et al., 2020). LiSA (Dibitonto et al., 2018), FITEBot (Hien et al., 2018), and similar service-oriented bots provide consistent, satisfactory responses, optimizing university services and reducing errors, as seen in the 77% reduction achieved by a university enrollment chatbot (Pérez et al., 2020). Jill Watson, a chatbot used at Georgia Tech, serves as an assistant teacher by answering class-related FAQs and has been met with positive feedback for its utility in enhancing course support (Cremonesi et al., 2023).

In contrast, teaching-oriented chatbots aim to facilitate and enhance the learning process by acting as virtual tutors in both formal and informal education settings. Autotutor, for example, uses dialog exchanges to promote learning and has been evaluated for both its interactive quality and pedagogical effectiveness (Wolfe et al., 2013). ScratchThAI employs gamification to teach programming to children while fostering computational thinking (Tatnall, 2022), whereas CALM System supports self-assessment and reflection, yielding positive outcomes (Sagrilo et al., 2002). Other teaching-oriented chatbots, such as NDL tutor and Virtual Patient, assist students in skill development and practical applications, like improving nursing communication skills. Chatbots like Duolingo and Clive leverage language practice and gamified exercises, maintaining high student engagement through interactive sessions (Pérez et al., 2020). In addition, specialized bots like Xbot target specific educational goals, such as boosting skills in mathematics and programming, showcasing the potential of chatbots to support personalized, goal-oriented learning (Garcia-Perez et al., 2015).

While there is no universal metric for assessing the educational impact of chatbots, most studies rely on self-perceived learning gains among users compared to non-users. Across studies, chatbots have consistently shown positive effects on learning outcomes (Hien et al., 2018), with students valuing the autonomy, self-organization, and motivation these tools provide. Whether through administrative support or direct educational engagement, chatbots in educational settings represent a valuable resource for enhancing both the learning process and overall student experience.

4. Developing the theoretical framework

The potential for chatbots to enhance the educational experience of neurodiverse students finds a solid theoretical foundation in Self-Determination Theory (SDT), which underscores the importance of fostering competency, autonomy, and relatedness. Competency embodies an individual's need to feel effective, capable, and successful, promoting a sense of mastery and accomplishment (Deci & Ryan, 2015). Autonomy reflects the desire to exercise control over one's actions and make self-directed choices aligned with personal goals and values (Deci et al., 2017). Relatedness, meanwhile, represents the need for connection, support, and a sense of belonging within a social context. Together, these core needs create a robust framework for understanding human motivation, engagement, and well-being across diverse environments.

For neurodiverse students, each of these elements addresses pressing challenges they frequently encounter in traditional educational settings, such as difficulties in mastering academic skills, limited independence, and social isolation. Chatbots, utilizing advancements in natural language processing and machine learning, can provide interactive, personalized support that fosters a more inclusive learning environment. By creating adaptive and reliable systems responsive to individual needs, chatbots hold the potential to enhance engagement, self-efficacy, and well-being for neurodiverse students. This section develops a theoretical framework (refer figure 1) suggesting how service-oriented and teaching-oriented chatbots can address these challenges in educational contexts, specifically tailoring their functionality to enhance competency, autonomy, and relatedness for neurodiverse learners.

Competency

For neurodiverse students, achieving competency in traditional educational settings can be challenging due to limited access to personalized feedback (Baysan & Naeem, 2023), information retention issues, and reliance on single-modality instruction (Beaux et al., 2024). Sensory sensitivities often complicate learning (Shayda Shevidi et al., 2024) further, as students may struggle with content presented through non-preferred modalities, affecting their ability to absorb and retain information effectively (Clouder et al., 2020). Additionally, working memory weaknesses—which are essential for tasks such as reading comprehension and following complex instructions—are common among neurodiverse learners (Smith-Spark & Fisk, 2007).

Neurodiverse learners may require flexibility in their learning approaches to understand their individual process, as traditional methods do not necessarily support this need for self-awareness. Effective educational technology, including service-oriented chatbots like UC3M Library bot and CourseQ, can enhance competency by providing immediate access to information and resources, allowing students to address academic queries independently (Pérez et al., 2020). By automating responses related to academic processes and resources, these chatbots can reduce cognitive load, enabling students to access and retain relevant information on demand. This approach may support students in navigating educational resources, thus reinforcing confidence and competency in managing academic tasks.

Teaching-oriented chatbots can also play a critical role in developing competency by adapting content to the unique cognitive needs of neurodiverse

learners. Through NLP and machine learning, chatbots like AutoTutor and ScratchThAI assess students' performance and adjust responses based on preferred learning modalities, such as visual, auditory, or kinesthetic (Pérez et al., 2020). This multimodal approach is essential, as it allows students to engage with content across various sensory channels (Pereira et al., 2023), which has been shown to improve comprehension and retention. Additionally, by providing a low-stakes, judgment-free environment for practicing academic tasks, these chatbots (Hwang & Chang, 2023) may help neurodiverse students build self-confidence and mastery over time, allowing them to make mistakes, rebuild self-esteem, and gain valuable insights into their unique learning styles. Such tools foster competency by supporting students' self-awareness, ultimately may help them become lifelong learners with robust, independent learning strategies.

Autonomy

Inflexible educational structures often limit the autonomy of neurodiverse students (Aresti-Bartolome & Garcia-Zapirain, 2014), as they may require assistance in managing academic routines, thereby reducing opportunities to develop independent learning strategies. Autonomy may be particularly important for neurodiverse students, who must have the flexibility to pursue learning at their own pace and in their preferred modality.

Service-oriented chatbots encourage autonomy by providing real-time support for university services and routine academic tasks, that may enable neurodiverse students to handle scheduling, enrollment, and administrative inquiries independently. Chatbots like LISA and Lola, for instance, offer guidance on essential university processes (Pérez et al., 2020), promoting self-sufficiency in managing educational requirements. By reducing the reliance on administrative staff for routine tasks, these chatbots may empower neurodiverse students to navigate the academic environment independently.

Teaching-oriented chatbots may further enhance autonomy by enabling self-paced, individualized learning experiences. Language-learning bots such as Duolingo and NDLtutor adjust lesson plans and assessments according to each learner's specific preferences and pace (Q. Wang, 2024), thereby fostering autonomy and allowing students to exercise control over their learning journey. This flexibility may encourage neurodiverse students to manage their academic responsibilities independently, reinforcing self-efficacy and independence. Moreover, multimodal learning pathways enable students to choose their preferred modality, enhancing engagement and reducing dependency on rigid instructional structures (Puccini et al., 2013). This autonomy aligns with frameworks like Norris's (2023) "Learning Ladder," a tool to help educators understand the mechanisms of learning for neurodiverse students, particularly those with autism. Such frameworks support educators in viewing neurodiversity as a strength and in creating environments that facilitate self-directed learning.

Relatedness

Social interactions can be challenging for neurodiverse students (Doyle, 2020), often leading to feelings of isolation and limited engagement with peers and instructors (Chapman, 2020). Social anxieties in neurodiverse students may further hinder classroom participation, inhibiting their ability to build meaningful connections and social skills (Chapman, 2021).

Service-oriented chatbots like Differ and LibBot help foster a sense of relatedness by connecting students to campus resources and learning communities (Pérez et al., 2020). For example, "Differ" groups students based on shared academic interests, facilitating peer connections and encouraging collaborative learning (Abbas et al., 2022). LibBot helps students navigate library resources, making them feel more integrated into the academic community by providing support that meets their educational needs (Rodriguez & Mune, 2022).

Teaching-oriented chatbots contribute to relatedness by offering neurodiverse students a non-judgmental, structured environment to practice social skills and interact with academic content. Tools such as Nao and ChatGPT serve as conversational partners, enabling students to develop communication skills and receive feedback in a safe, anxiety-free setting (Boyer & El-Chidiac, 2023). These chatbots, equipped with AI and NLP capabilities, provide structured interactions that reduce the unpredictability and perceived judgment that can occur in human interactions (Pérez et al., 2020). By offering an environment where neurodiverse students can freely express ideas and practice social skills, teaching-oriented chatbots may alleviate social pressures and enhance students' sense of belonging. The importance of viewing neurodiverse perspectives as assets in the classroom has been emphasized by (Sharma, 2020), further supporting the role of inclusive, supportive tools in promoting emotional well-being and academic engagement among neurodiverse learners.

Overall, chatbots tailored to enhance competency, autonomy, and relatedness represent a transformative resource in neurodiverse education. Service-oriented chatbots streamline administrative support, fostering independence and resource accessibility, while teaching-oriented chatbots adapt to individual learning needs, addressing issues with retention, self-efficacy, and social integration. By thoughtfully designing and implementing these tools with the specific needs of neurodiverse students in mind, educators can create a more inclusive educational experience that supports holistic growth, self-confidence, and lifelong learning. This proposed framework aligns with the need for educators to adopt a "neurodiverse lens" (Halder et al., 2023), viewing diverse cognitive profiles as a strength and supporting the success of neurodiverse learners in both academic and social realms.

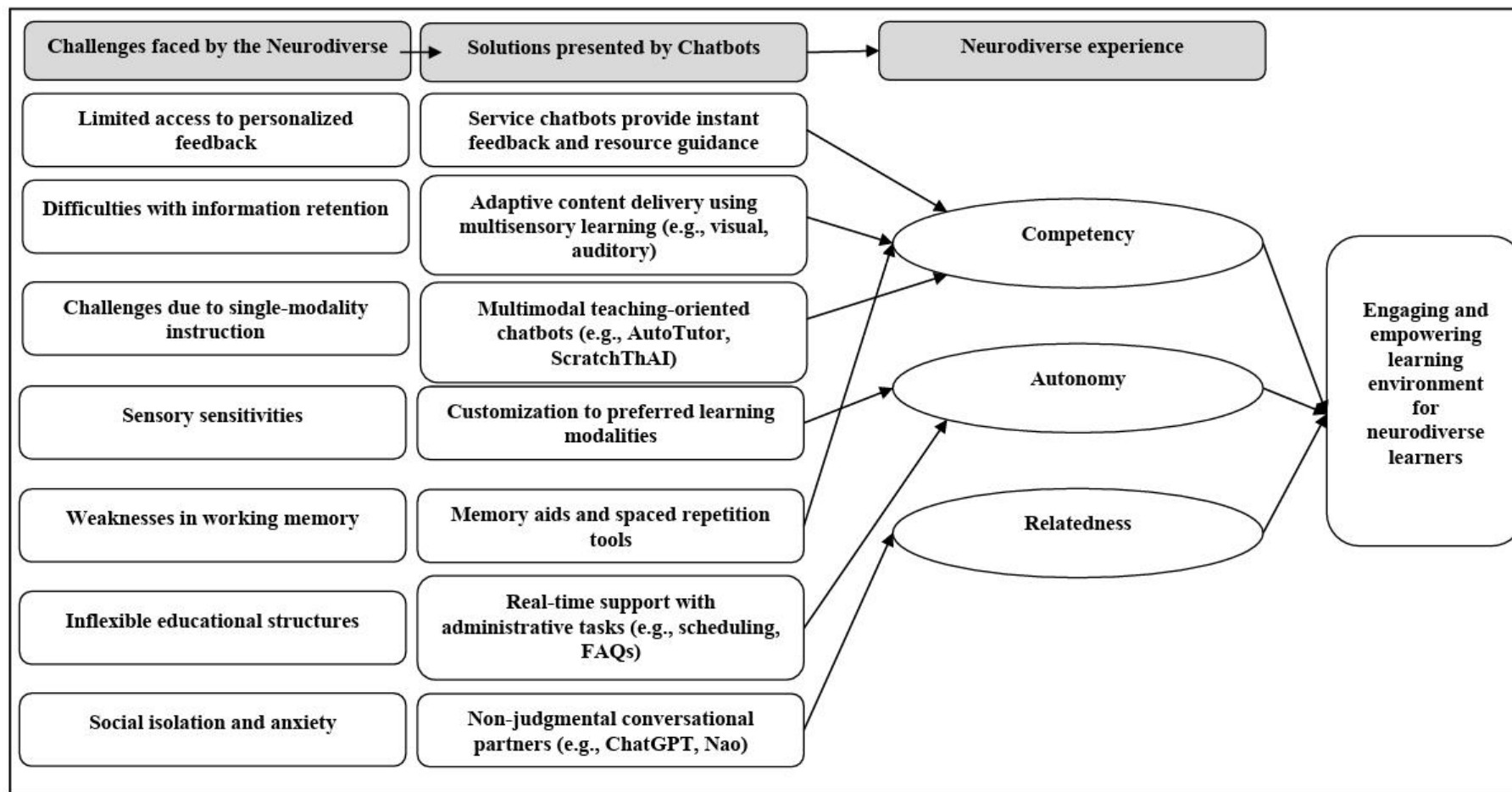


Figure 1: Conceptual Model of how Chatbots address Educational Challenges experienced by Neurodiverse students. Source: Author of the current paper.

5. Future Research Agenda

As educational technology evolves, chatbots are emerging as a powerful tool to support students, offering personalized, adaptive, and on-demand learning experiences. While studies demonstrate chatbots' benefits in general education, limited research specifically addresses their potential impact on neurodiverse students, whose unique learning needs often go unmet by conventional approaches. Addressing this gap, future research should investigate how chatbots can be optimized to enhance educational accessibility, engagement, and skill development for neurodiverse learners. The following research agenda outlines critical areas to explore, focusing on how chatbots can be designed and implemented to better serve neurodiverse students in ways that foster inclusivity, skill-building, and ethical, balanced use of technology in education.

1. Assessing the Holistic Impact of Personalized Learning on Neurodiverse Development

Personalized learning has the potential to support not only academic growth but also social and emotional development (Bernacki et al., 2021), both crucial for neurodiverse students' long-term success. Investigating the effects of personalized learning on these dimensions will clarify how such interventions contribute to overall well-being and achievement. Key areas of focus include the impact on academic performance, retention, and social-emotional outcomes, offering a comprehensive understanding of personalized learning's role in neurodiverse education and supporting data-driven improvements to educational strategies.

2. Exploring Technology's Role in Reducing Resource Demands for Personalized Learning

Implementing personalized learning typically requires substantial resources, including human support and materials, which can limit scalability. Advanced technologies, such as AI and machine learning, have the potential to alleviate these demands by automating personalization processes. Research should examine which technologies most effectively reduce resource strain without compromising educational quality. Findings will provide insights into making personalized learning more accessible and sustainable, supporting wider adoption in resource-constrained environments.

3. Exploring the Impact of Chatbots on Neurodiverse Student Engagement and Learning Outcomes

Current literature suggests chatbots enhance student engagement in general educational settings (Pérez et al., 2020); however, little research examines their specific impact on neurodiverse students. Given the unique communication needs and processing styles of neurodiverse individuals, chatbots designed with personalized, adaptive features could significantly improve engagement by aligning with each learner's preferences.

Investigating the effects of chatbot-assisted learning on the engagement and learning outcomes of neurodiverse students compared to neurotypical peers, focusing on how customized chatbot features influence motivation, participation, and academic performance, will provide foundational knowledge on how chatbot interactions may need to be tailored to meet neurodiverse needs, enabling researchers to refine AI models for a more inclusive approach to educational technology.

4. Inclusive Design Principles for Chatbots in Neurodiverse Education

Despite chatbots' potential to provide personalized learning support, inclusive design principles specific to neurodiverse students are underdeveloped (Singla et al., 2024). For neurodiverse learners, the interface, interaction style, and feedback mechanisms must accommodate cognitive diversity to be effective (Bui et al., 2022). Research in this area would yield practical insights for developing chatbots that enhance usability and accessibility across neurodiverse profiles.

Developing and testing chatbot design principles that cater to neurodiverse students' specific needs, such as multimodal interaction options, adaptive feedback, and flexibility in pacing, to maximize learning effectiveness and ease of use would allow designers to create chatbots that reduce cognitive load and offer a comfortable, user-centered experience for neurodiverse students, enhancing accessibility and satisfaction.

5. Evaluating Chatbots as a Tool for Developing Soft Skills in Neurodiverse Students

Chatbots have shown potential for facilitating social and communication skill development by offering a safe, low-stakes environment for practicing social interactions (Halabieh et al., 2024). However, little empirical evidence examines how effectively chatbots can support neurodiverse students' soft skill development, such as teamwork, adaptability, and empathy, which are often challenging for neurodiverse individuals.

Assessing the effectiveness of chatbots in improving social and communication skills for neurodiverse students, exploring how chatbots can act as conversational partners to enhance these skills in a structured, anxiety-free setting, could offer valuable strategies for integrating chatbots as supplementary tools in social skills programs, helping educators create safe environments that encourage neurodiverse students to practice and build confidence in social scenarios.

6. Understanding Ethical Concerns in Implementing Chatbots for Neurodiverse Education

As chatbots in neurodiverse education gain traction, ethical issues such as data privacy, algorithmic bias, and potential over-reliance must be addressed. Neurodiverse students, who may be more vulnerable to data misuse and may rely heavily on structured, predictable interactions, are particularly sensitive to these ethical concerns. Addressing these issues is critical to ensuring safe and effective chatbot use.

Investigating the ethical implications of chatbot use in neurodiverse education, focusing on data security, privacy protections, and strategies for reducing algorithmic bias, as well as measures to prevent over-reliance on technology, could inform policies to safeguard neurodiverse students' data privacy and prevent discrimination through algorithmic bias, supporting the development of ethical standards for AI in educational contexts.

7. The Dark Side of technology and chatbots in Neurodiverse education

Zamfir (2018) study indicates that too much exposure to virtual environments at an early age may lead to developmental challenges, showing similarities to the social, communication, and behavioral traits seen in ASD. While chatbots can provide significant support, there is a risk that neurodiverse students may become overly reliant on these technologies for academic tasks, potentially hindering the development of self-reliance and problem-solving skills. Understanding this risk is essential to creating balanced chatbot implementations that support autonomy without fostering dependence.

Examining the potential risk of dependency on chatbot technology among neurodiverse students, investigating how chatbot use influences students' independence, critical thinking, and problem-solving skills in both short- and long-term educational contexts, would help educators develop balanced approaches for integrating chatbot technology, promoting independent learning skills while leveraging chatbot support effectively.

6. Implications for Practice

For Researchers

This multidisciplinary study makes a significant contribution to the literature on neurodiversity, psychology, education, and technology, with a particular emphasis on chatbots and artificial intelligence in educational contexts. It provides a timely

and valuable addition to the field of neurodiverse education, which has garnered increasing attention in recent years, by highlighting the need for focused studies on the interaction between chatbots and neurodiverse students—an area largely uncharted in current research.

By applying Self-Determination Theory (SDT) in this novel context, the study broadens the theory's applicability, demonstrating its versatility and enhancing its generalizability beyond traditional domains. The paper further contributes by developing a theoretical model illustrating how chatbots can be effectively integrated into educational systems to address the unique challenges faced by neurodiverse learners, fostering an engaging and supportive learning environment. This model offers a foundation for future empirical studies aimed at testing and refining chatbot interventions in diverse educational settings, particularly those involving neurodiverse students. In addition, the study encourages researchers to explore how specific chatbot features and designs can be optimized to better serve neurodiverse learners, addressing a critical research gap. By pursuing these avenues, future research can deepen our understanding of how technology can be leveraged to create inclusive, adaptive educational environments that support diverse learning needs. This paper also proposes a comprehensive future research agenda, offering a roadmap for advancing the field and guiding subsequent studies in neurodiverse education and educational technology.

For practitioners

For practitioners, particularly educators and developers of educational technologies, the findings highlight the potential of chatbots to enhance the learning experiences of neurodiverse students. By integrating chatbots into educational settings, practitioners can provide more personalized and accessible learning opportunities, catering to the unique needs of neurodiverse individuals. This could lead to more effective teaching strategies, improved student engagement, and better educational outcomes for neurodiverse populations. Additionally, the insights from this research can guide the development of more inclusive educational tools and resources, encouraging the adoption of technology that supports diverse learning styles.

For Society

The societal contributions of this research are substantial, particularly in promoting inclusive education and providing meaningful support to neurodiverse individuals. By investigating the role of chatbots in neurodiverse education, this study offers promising avenues for enhancing the educational experiences of students with diverse learning needs. This approach aligns closely with the United Nations Sustainable Development Goal (UN SDG) 4: Quality Education, which seeks to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

7. Conclusion

Around 15-20% of the global population is neurodiverse, facing challenges in communication, social interaction, and sensory processing, which can lead to disengagement from formal education. Chatbots hold promise for addressing these educational barriers by fostering competency, autonomy, and relatedness, as framed by Self-Determination Theory (SDT). Teaching-oriented chatbots using NLP and machine learning can adapt to students' preferred modalities, enhancing comprehension and efficacy, while service-oriented chatbots like LISA support independence in tasks like scheduling. Tools such as Differ further promote social connectedness by linking students with shared interests. These chatbots empower neurodiverse students and helps to improve inclusivity and spread of quality education (UN-SDG 4). Future research should explore chatbot designs and interactions to optimize neurodiverse learners' educational experiences further, fostering accessibility and success.

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