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RESEARCH

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"Not a cookie cutter situation": how neurodivergent students experience group work in their STEM courses

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Abstract

Background Although group work is increasingly used in STEM courses and may lead to improved academic outcomes, there is evidence that some implementations of group work may lead to unintended barriers for certain students' learning. Despite the growing number of neurodivergent undergraduate students, there is limited research on neurodivergent students' experiences with group work in STEM courses. To address this knowledge gap, the current research investigated the experiences of 22 neurodivergent undergraduate students with group work in STEM courses at a range of institution types and in a variety of STEM disciplines. Participants shared experiences with in-class and out-of-class group work assignments for lecture and laboratory courses.

Results Through inductive thematic coding of semi-structured interview transcripts, we identified seven themes impacting participants' experiences. Three themes were individual level: personal characteristics that participants associated with their neurodivergence; strategies for academic success (with subthemes of organization/time management, adaptive communication, and self-advocacy); and beliefs on group work's value. Four themes were group level/classroom level: group dynamics; role in group (including leadership roles); the competitive culture within STEM; and recommendations for instructors. Through a social-relational perspective on disability, we proposed a model showcasing how group and classroom factors serve as supports or barriers to neurodivergent students' full participation in group work, as well as to their sense of belonging. Using the seven themes we articulated, we outlined a set of practices for designing group work assignments. In addition, we propose how pairing inclusive assignment design with instructor reflection and articulating anti-ableist values can support neurodivergent student belonging by disrupting discourses of normalcy in STEM.

Conclusions As one of the first studies exploring the impact that group work in STEM courses has on neurodivergent undergraduates, this work may inform reimaginations of group work practices to better address the needs of neurodivergent STEM students and support a more inclusive culture in STEM classrooms. In addition, our conceptual model may serve as the basis for future research regarding interactions between individual-level and group-level factors associated with neurodivergent students' learning through group work and other active learning practices.

Keywords Neurodivergent students, Undergraduate STEM courses, Group work, Active learning, Students with ADHD, Autistic students, Students with learning disabilities, Students with mental health disabilities, Disabled students, Neurodiversity

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Introduction

Over the last two decades, STEM reformers have increasingly advocated for incorporating group work and collaborative learning opportunities into STEM classrooms and curricula (AAAS, 2009; Felder et al., 2000; Kober, 2015). This emphasis on group work stems in part from a desire for students to develop their critical thinking and teamwork skills through working in groups (Goldsmith et al., 2024; Springer et al., 1999). In response, the guidelines for many STEM program accreditation agencies include developing teamwork skills as an explicit learning outcome for undergraduate programs. For example, among ABET's criteria for accrediting baccalaureate engineering programs is a student outcome that calls for "an ability to function effectively on a team," and the American Chemical Society's student proficiencies state that accredited programs "must incorporate team experiences into classroom and laboratory components of the chemistry curriculum" (ABET, 2022; ACS, n.d.).

For the general population of students, a well-established body of research literature shows the academic benefits from formalized models of group learning, including increased academic motivation (Costley & Lange, 2018; Hernandez et al., 2013; Van Blankenstein et al., 2019), self-efficacy (Aikens & Kulacki, 2023; Hutchison et al., 2006), and concept understanding (Parappilly et al., 2015; Slavin, 2014; Webb, 2008). Research on the impact of group work covers a range of formal instructional approaches and informal group work formats (Hodges, 2018), as well as project-based team learning through introductory and capstone design projects (Dunlap, 2005; Marshall et al., 2016; Moffat et al., 2023; Schibelius et al., 2023) and lab courses (Holmes et al., 2022; Reynders et al., 2019). At the same time, research also demonstrates that group work, and other active learning practices that involve peer interaction, may adversely affect some students due to increased anxiety, imbalanced group dynamics, and the challenges of navigating a majoritarian social space for students from marginalized groups (Chang & Brickman, 2018; Chatman et al., 2008; Cooper & Brownell, 2016; Cooper et al., 2018; Downing et al., 2020; Eddy et al., 2015; England et al., 2017; Freeman et al., 2017; Hodges, 2018; Meadows & Sekaquaptewa, 2013; Shekhar et al., 2020; Theobald et al., 2017; Wiggins et al., 2017). In addition, faculty implementing group work assignments express their apprehension about managing group conflict and assessing individual students' contributions to group assignments (Davies, 2009; Pundak & Rozner, 2008).

For the current study, we consider the experiences of neurodivergent students with both in-class and out-of-class group work. Although the nature of these two categories of group work can be quite different, prior research on both categories highlights many similar benefits and challenges, particularly as they relate to group dynamics. For example, students and faculty report challenges with group conflict, communication between group members, differences in group member priorities, and uneven distribution of workload between group members for both in-class and out-of-class group work (Bacon et al., 1999; Burdett, 2003; Davies, 2009; Feichtner & Davis, 1984; Hall & Buzwell, 2013; Kreijns et al., 2003; Premo et al., 2022; Theobald et al., 2017; Tucker & Abbasi, 2016; Wilson et al., 2018). Because we emphasize the interpersonal dynamics and group management approaches between group members for this study, we include experiences of neurodivergent students with both in-class and out-of-class group work assignments.

In addition, in certain cases, both categories of group work have been shown to impact students from marginalized group in sometimes negative ways (Batty & Reilly, 2023; Busch et al., 2023; Cooper & Brownell, 2016; Eddy et al., 2015; Fowler & Su, 2018; Gin et al., 2020; Meadows & Sekaquaptewa, 2013; Theobald et al., 2017). Studies show that group work can be associated with increased experiences of stereotype threat effects [i.e., "activation of negative stereotypes [that] impair the performance of stigmatized individuals" (Schmader et al., 2008, p. 336)] (Neal-Jackson, 2020; Sekaquaptewa & Thompson, 2002), particularly for women working in project teams (Cohen & Swim, 1995; Niler et al., 2020; Sekaquaptewa & Thompson, 2003). In addition, some forms of in-class group work are more likely to incite students' fear of negative evaluation by their peers and instructor for first-generation students, LGBTQ+students, and disabled students (Busch et al., 2023). Despite limited research on neurodivergent undergraduate STEM students, the research that exists on neurodivergent students' experiences with group work in STEM courses (including active learning practices that involve peer interaction) suggests that these practices may also pose unique challenges for some students as well (Gin et al., 2020; Guerrero et al., 2020; McGrath & Hughes, 2018; Pfeifer et al., 2021, 2023). Through this prior research, some neurodivergent STEM students described benefitting from group work by connecting with peers and accessing course material in different ways (James et al., 2020; Pfeifer et al., 2023). Conversely, some students also described challenges with the pacing of group work, increased performance anxiety, and decreased sense of belonging (James et al., 2020; Nieminen & Pesonen, 2022; Pfeifer et al., 2023). However, all of these previous reports were from studies on neurodivergent students' experiences with in-class active learning in general, with minimal treatments of the impacts from group work. The current research addresses this gap in knowledge through a qualitative

study on the experiences of neurodivergent undergraduates with group work for their STEM courses.

Neurodivergent students in higher education

For this study, we focused on neurodivergent students (as opposed to focusing on a single neurotype). The origin of the term "neurodivergent" is attributed to neurodivergent and autistic activist Kassiane Asasumasu, and the term draws on sociologist Judy Singer's conceptualization of "neurodiversity" based on her work on the Autistic Self-Advocacy Movement (Singer, 1999; Walker & Raymaker, 2021). Now, "neurodivergent" is increasingly used as an umbrella term to describe individuals who think or learn differently than what has been socially constructed as "neurotypical." The term "neurotypical" describes individuals "whose selective neurocognitive functions fall within prevalent societal norms" (Shah et al., 2022). While there is not one single definition of who falls within the neurodivergent umbrella, for the purposes of our study we include individuals with neurodevelopmental and/or mental health disabilities (Asasumasu, 2015). This includes, but is not limited to, autistic people and people with ADHD, specific learning disabilities (such as dyslexia, dysgraphia, and dyscalculia), dyspraxia, bipolar depression, generalized anxiety, and/or OCD.

The concept of neurodiversity celebrates the range of human neurocognitive functioning and shifts the notion of neurodivergence away from pathologizing individual ways of thinking, learning, and behaving. The concept of neurodiversity affirms that there is no "normal" way to think, and that instead neurodivergent individuals approach some situations differently than what is socially constructed as neurotypical (Reindal, 2008; Thomas, 2004c). In accordance with a neurodiversity perspective, in the current study, we do not emphasize a single neurodivergent neurotype. This is consistent with previous literature on cognitive, psychosocial, and cultural factors that cut across many neurodivergent neurotypes, including challenges with executive function (EF) and adaptive strategies for managing EFs (Johnson & Reid, 2011; Levinson & Ohler, 1998; O'Hearn et al., 2008; Rasmussen et al., 2009; Snyder et al., 2015; Warren et al., 2021); experiences of discrimination and exclusion, particularly in academic settings (Clark, 1997; Georgiou et al., 2002; Shea et al., 2019; Tollefson & Chen, 1988; Tournaki, 2003; Woodcock & Vialle, 2011); and a dominant culture that medicalizes neurodivergence (Baglieri & Knopf, 2004; Choi et al., 2022; Edyburn et al., 2021; Kirby, 2017; Woods & Thomas, 2003). In addition, multiple diagnoses, misdiagnosis, and shifting diagnosis criteria are common for neurodivergent people (Akinhanmi et al., 2018; Ennis-Cole et al., 2013; Fadus et al., 2020; Fitzgerald, 2002; Frances et al., 2022; Grimm & Schulz, 2014; Lai & Baron-Cohen, 2015; Shifrer et al., 2011; Wood-Downie et al., 2021). For example, over 40% of children diagnosed with autism are also diagnosed with ADHD (Gadow et al., 2004, 2005; Hours et al., 2022; Leitner, 2014; Rong et al., 2021). It is also common for individuals with ADHD, autism, and dyspraxia to be diagnosed with specific learning disabilities and/or anxiety or another mental health disability (Baldwin & Costley, 2016; Cantwell & Baker, 1991; Ibrahim, 2020; Kashani et al., 1982; McGee et al., 1986; Piek et al., 1999; Stewart et al., 2006; Tuchman & Rapin, 2002; Visser, 2003; Willcutt & Pennington, 2000; Willcutt et al., 2007). Focusing on a broad definition of "neurodivergent" for our current study is also consistent with the multiple neurotypes and shared experiences of our participants, which we discuss further in the Results section below.

Despite the growing number of neurodivergent students pursuing a college degree (Cortiella & Horowitz, 2014; Newman et al., 2011), only a small percentage request formal accommodations with their campus disability service offices (DSOs) or disability resource centers (DRCs) (Dowrick et al., 2005; Marshak et al., 2010; West, 1993). For students who request accommodations, these accommodations tend to focus on generalized modifications to assessment timing, assessment and learning environments, and course material accessibility, and are less frequently applied to group work or active learning assignments (Gin et al., 2020). With the increased use of these practices in STEM courses, additional opportunities and challenges for neurodivergent students may arise (Guerrero et al., 2020; James et al., 2020; McGrath & Hughes, 2018; Pfeifer et al., 2023).

In addition, faculty attitudes towards neurodivergent students may also play an important role in neurodivergent students' experiences with group work in their courses. Previous research has found that university faculty feel ill-equipped to support their neurodivergent students (Goodwin et al., 2024; Hansen et al., 2017; Sniatecki et al., 2015). Studies on the experiences of disabled undergraduate STEM students reported an overall unwelcoming environment, with many disabled students (including neurodivergent students) counseled away from majoring in STEM and denied requested accommodations (Alston & Hampton, 2000; Dunn et al., 2012; Lee, 2011; Murray et al., 2008; Sniatecki et al., 2015). In all, prior studies do hint at the potentially nuanced experiences of neurodivergent students with group work, as well as point to the need for more specific research on group work, which we address through our current study.

Social-relational model of disability as a framework for understanding barriers and supports to neurodivergent students' learning during group work

In order to understand the experiences of neurodivergent students with group work in their STEM courses, we must first articulate how we conceptualize of the ways in which their neurodivergences/neurodivergent identities might relate to their experiences as learners. Disability researchers and community leaders have used several models to describe different viewpoints on disability. Recent work in discipline-based education research has also illustrated the value of disability models to understanding the experiences of disabled students in STEM (Chini et al., 2024; Oleynik et al., 2023; Tedeschi & Limeri, 2024). The most commonly described models of disability are the "medical model," which locates disability in the individual, and the "social model," which locates disability in environmental circumstances and social exclusion (Marks, 1997; Oliver, 2013). A "medical model" viewpoint on disability medicalizes difference and focuses on how a disabled individuals' personal characteristics or "disorders" are the primary source of their disabling experiences (Johnstone, 2012). Conversely, a "social model" viewpoint focuses on how disabling sociostructural barriers are the source of disability (Marks, 1997), and distinguishes "disability" (as "social exclusion") from "impairment" (as "physical [or mental] limitation") (Shakespeare, 2013, p. 215). Both models have been critiqued for not accounting for complexity in the lived experiences of individual disabled people, although for different reasons (Barnes, 2012; Haegele & Hodge, 2016; Shakespeare & Watson, 2001).

An alternative model, the social-relational model of disability, shares the social model's focus on structural barriers in society for disabled individuals, but centers the disabled person's lived experience by focusing on how disability arises from the interaction of a disabled individual with these structural barriers (Thomas, 2004a, 2004b). Cologon and Thomas (2014) and other researchers delineate three components to the social-relational model, which are illustrated in Fig. 1 (Cologon, 2016; Mackenzie et al., 2016; Sang et al., 2022). These components are:

- Barriers to doing = "socially imposed restrictions that prevent [or limit] participation in certain activities" (Mackenzie et al., 2016);
- Barriers to being = "words or behaviours that negatively impact on one's sense of self and who they feel they can be" (Mackenzie et al., 2016);
- Impairment effects = "the direct and unavoidable impacts that 'impairments' (physical, sensory, intellectual, emotional) have on individuals' embodied functioning in the social world" (Thomas, 2010, p. 37) that "cannot be remediated by social change" (James et al., 2020, p. 2). These effects "are always bio-social and culturally constructed in character" (Thomas, 2010, p. 37).

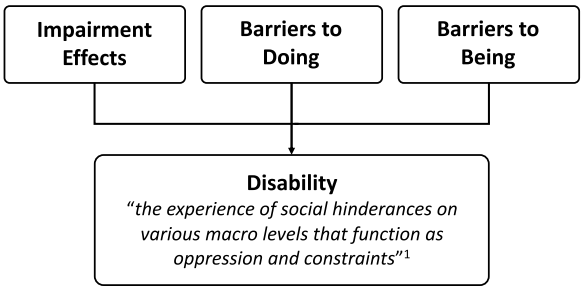

Fig. 1 Diagram of the three categories of factors contributing to disabling experiences of disabled people according to Cologon and Thomas's (2014) conceptualization of the social-relational model of disability. [1](Reindal, 2008). Alt text in Supplementary Table 6

Although "impairments" are physiological in origin, from a social-relational perspective, impairments are "socially understood" (James et al., 2020, p. 2). Therefore, it is necessary to both clearly differentiate between "impairment effects" and "barriers," as well as understand their connection to one another. A social-relational framework might posit that an individual neurodivergent student could experience group work differently from neurotypical students because of a combination of: (1) differences in neurocognition that lead to them thinking, communicating, and processing information in non-normative ways (i.e., "impairment effects"); (2) structural and social characteristics of group assignments and team work processes that they experience in a different way in relation to their neurotype (i.e., potential "barriers to doing"); and (3) norms and values associated with group work and the discipline that value/devalue and do/do not make space for the contributions of students that think or communicate differently (i.e., potential "barriers to being"). This conceptualization of "barriers to being" within the social-relational model has parallels in the literature on cultural and environmental factors that impact students' sense of belonging in STEM (Carlone & Johnson, 2007; Miller & Downey, 2020; Ong et al., 2011; Rainey et al., 2018). With our analysis for the current study, we both draw distinctions between the characteristics our participants associate with their neurodivergence and the barriers that they identify in their STEM learning environments, as well as explore the relationships between the two.

In our analysis, we rely on James and et al.'s (2020) extension of the social-relational model that they used

to identify barriers to learning for undergraduate physics students with ADHD. In their work, they recast "impairment effects" as "diagnosis characteristics" by incorporating an "affirmative perspective" on disability into their theoretical framework. Here, we adopt the use of the term "characteristics," but choose to move away from diagnosis language to describe neurodivergence. Instead, we use the term "characteristics that participants associate with their neurodivergence." We make this choice not to minimize the value of diagnoses and not as a critique for using the term, but instead to acknowledge that neurodivergence exists outside of diagnosis, and that diagnostic criteria might not fully capture the characteristics that our participants themselves associate with their own neurodivergence.

By incorporating an affirmative perspective on "impairment effects" into the social-relational model, we do not intend to critique the model. The social and social-relational models' focus on barriers is a response to deep and pervasive inequality and discrimination for disabled people across societies (Degener, 2016; Linton, 1998; Shakespeare, 2013). However, for our particular study, framing "impairment effects" as "characteristics" allows us to: (1) recognize the strengths and differences that our participants identified, along with the challenges and hinderances and (2) illustrate that removing barriers to access is only one step towards building inclusive STEM classrooms for neurodivergent students—supports that build on students' strengths and differences (including strengths that students associate with their neurodivergence) must also be identified and incorporated into learning environments.

Adaptive learning strategies

The affirmative perspective of the social-relational model also provides a framework for understanding how neurodivergent students' adaptive strategies for learning interact with barriers in their environment. Neurodivergent students often develop adaptive and compensatory strategies to support their learning or to operate in normative/"neurotypical" academic spaces (Pino & Mortari, 2014; Ramakrishnan et al., 2022; Reis et al., 2000; Schaffer et al., 2021; Sedgwick et al., 2019; Sherman et al., 2006; Silverman, 2009; Taylor & Vestergaard, 2022). For example, many neurodivergent students develop adaptive organizational and time management strategies to manage challenges associated with variations in executive functioning (Carter & Sellman, 2013; Goffer et al., 2022; Griffin & Pollak, 2009; Jensen et al., 1997; MacCullagh et al., 2017; Pollak, 2005). In addition, some neurodivergent students develop strategies for communicating with others or engaging within social environments in ways that align with normative expectations of social behavior or that help them decrease their anxiety (Alaghband-Rad et al., 2023; Cook et al., 2021; Livingston et al., 2019). While students' adaptive strategies may support their learning in groups, group work can also pose challenges to students using these strategies, as well as create new circumstances requiring strategy adaption or novel strategy development. In the current study, we investigated the strategies our participants use to support their success while working in groups, as well as instances of misalignment between participants' strategies and those of their group members.

Purpose and approach of current study

Despite an abundance of literature promoting the inclusion of group work in undergraduate STEM courses, there remains limited formal research regarding how these practices benefit and/or challenge neurodivergent students. To inform instructional development efforts that are inclusive of all students in STEM, we investigated the experiences of neurodivergent students with group work in their STEM courses through thematic coding of semi-structured interview data. Our participants' experiences with group work included in-class assignments for lecture and laboratory courses, as well as out-of-class work for short-term and long-term group projects and other group assignments. Our work was guided by the following two research questions:

1. *How do neurodivergent students experience group work in undergraduate STEM courses?*
2. *Based on student experiences and recommendations, what steps can STEM faculty take to support neurodivergent students when using group work in their courses?*

Methods

This study was approved by the Thomas Jefferson University Institutional Review Board (IRB) with exempt status (Study Control #21E.118). All participants consented to participate and publish through an online survey prior to completing a study intake survey. In addition, prior to beginning an interview, the interviewer recorded verbal consent from each participant through a formal verbal consenting process that was approved by the Jefferson IRB.

Participant recruitment

Participants were recruited through an initial intake survey, which included questions on the types of experiences participants had with group work in their undergraduate STEM lecture and laboratory courses; participants' overall feelings towards group work in their STEM courses; participants' academic major/

intended major; and participants' self-reported identifications as neurodivergent and/or as a person with ADHD, autism, a learning disability, and/or mental health disability. Intake survey questions are reported in Supplementary Table 1. Participants who had taken two or more undergraduate STEM courses with a significant group work component were interviewed for the study. Participants were recruited through emails and flyers shared through disability service offices (DSOs)/disability resource centers (DRCs) at seven institutions (three R1 universities, two R2 universities, a liberal arts college, and a community college, including two minority-serving institutions). All institutions were located in the U.S. (in the Northeast, Midwest, and Southwest). Because participants were recruited through DSOs/DRCs and not through specific courses, our participants had experiences with a variety of implementations of group work in different types of courses (lecture, lab, capstone/design); at different academic levels (introductory, intermediate, advanced); in different fields (biology, chemistry, computer science, engineering, math/statistics, physics); and with different faculty at different institution types. After sufficient intake surveys were collected, the first round of sampling with nine participants was conducted to ensure a range of disability identities/neurotypes and backgrounds with group work in STEM courses in the initial round of data. Subsequent rounds of interviews (for a total of 22 interviewed participants from 51 eligible respondents) were conducted to reach a preliminary saturation level by testing themes from our initial data and identifying potentially disconfirming cases to test or expand our emerging theoretical frameworks (Drauker et al., 2007). Demographic data were collected from participants through a survey following each interview. Pseudonyms of participants along with other characteristics are listed in Table 1. Through the intake survey, participants were asked to select their own pseudonyms, and prior to each interview, the interviewer ensured that no one would associate the pseudonym each participant selected with them. In Table 1, in addition to neurotype(s)/disability type(s), we also included disability terminology that participants used to describe their own personal identity as a neurodivergent person or person with a disability. Participants' disability terminology was collected during interviews. Participants' neurotype(s)/disability type(s) were collected in the post-interview survey through a predetermined list with an open-ended option. Supplementary Table 2 lists overall participant demographic information. In Supplementary Table 2, some participants identified with more than one neurotype/disability type or more than one race/ethnicity, and therefore their total values sum to more than 22 (more than 100%).

Interview protocol development

To explore our research questions, prior to participant recruitment, the research team received feedback on the interview protocol from researchers with expertise on the classroom experiences of neurodivergent undergraduate students. Following edits based on this feedback, we piloted the protocol with and received feedback from two neurodivergent undergraduate students. The protocol included questions that addressed participants' experiences with interacting with group members, experiences with different types of group assignments, perspectives on the value of group work, recommendations to instructors about group assignments, and the impacts their neurodivergence had on their STEM learning and experiences with group work. Consistent with the social-relational model, interview questions were designed to probe individual lived experiences from both behavioral and affective perspectives, as well as probe the environmental and social context within which those experiences played out. Interviews also included questions related to participants disclosing their neurodivergence to group members and STEM instructors; our analysis of these disclosure questions will be published separately. Interview questions for this study are listed in Supplementary Table 3. Following the first wave of nine interviews and drafting our initial codebook, we added three additional questions to our interview protocol. These three questions addressed strategies participants used to feel comfortable or learn best in groups for their STEM courses or addressed the roles participants typically took on while working in groups for their STEM courses. We added these questions to probe details on significant and clear patterns we observed in our first wave of data. We used a semi-structured interview protocol, where the interviewer asked follow-up questions to probe for more detail on participants' responses to protocol questions and clarify participants' responses.

Data collection

One interviewer conducted all of the interviews for this study. After a roughly 60-min interview, participants completed a 5–10 min survey with questions on demographic information and academic history. We conducted interviews in spring 2022 through spring 2023. Audio recordings of each interview were transcribed, and then two researchers checked the transcripts for accuracy.

Data analysis

Three researchers analyzed the study data. At least two researchers analyzed each transcript. At least one of

Table 1 Participant characteristics and terminology they use to describe their neurotype(s)/neurodivergent identity ($n = 22$)

Pseudonym	Major discipline	Institution type	Year in college	Overall feelings about group work	Neurotype/disability type	Disability terminology
Aidan	Biological or Life Sciences	Private Research University	Third	Lean Negative	SLD; ADHD	"have ADHD"; "have dyslexia"
Apple	Engineering	Public Research University	Second	Positive	ADHD; Mental Health Disability	"have symptoms of ADHD"
Bridget	Biological or Life Sciences	Private Research University	Second	Mixed	Mental Health Disability	"neurodivergent"; "epileptic"
Elizabeth	Biological or Life Sciences	Private Research University	First	Positive	ADHD	"have ADHD"
Hannah	Biological or Life Sciences	Private Research University	Fourth	Neutral	ADHD	"have ADHD"; "neurodivergent"
Jacque	Mathematics or Math-Related Field	Public Research University (Community College Transfer)	Third	Neutral to Positive	SLD	"take in information differently"; "I never talk about it"
Keira	Biological or Life Sciences	Public Research University (Community College Transfer)	Third	Neutral	ADHD; Mental Health Disability	"have ADHD"; "person with ADHD"
King	Undecided Major	Liberal Arts College	Second	Completely Positive	SLD	"neurodivergent"
Lisa	Biological or Life Sciences	Private Research University	First	Neutral	Mental Health Disability	"somebody with OCD"
Lucy	Biological or Life Sciences & Environmental Sciences & Physical Sciences	Public Research University (Research University Transfer)	Third/Fourth	Generally Negative	ADHD	"have ADHD"
Maeve	Biological or Life Sciences & Environmental Sciences	Liberal Arts College (Research University Transfer)	Second/Third	Mostly Positive	ADHD; Physical Disability	"neurodivergent"; "have a physical disability"
Noah	Engineering & Physical Sciences	Public Research University	Fourth	Mostly Negative	Mental Health Disability	"neurodivergent"; "disability"; "mental disability"
Nora	Health Sciences	Public Research University	Third	Overall Positive	Mental Health Disability; Speech Impairment	"person with anxiety"
Orchid	Engineering	Public Research University	Third	Lean Negative	ADHD; Autism; Mental Health Disability	"autistic"
Patchy	Computer Science or Technology	Community College (Research University Transfer)	Second	Overall Negative	ADHD	"have ADHD"; "neurodivergent"
Penelope	Health Sciences	Private Research University	Third	Mostly Positive	ADHD	"have ADHD"
Ralph	Computer Science or Technology	Public Research University (Community College Transfer)	Fourth	Neutral	ADHD; Autism; Mental Health Disability; Physical Disability	"have a disability"; "have a mental disorder"
Richard	Biological or Life Sciences	Public Research University	Second	Positive	Autism; Mental Health Disability	"person with autism"
Samson	Mathematics or Math-Related Field	Public Research University	Second	Neutral	SLD	"dyslexic"
Shiloh	Undecided STEM Major	Liberal Arts College (Liberal Arts College Returning/Community College Transfer)	Third	Negative	SLD; ADHD; Mental Health Disability	"person with ADHD"; "dysgraphic"; "learning disability"; "learning differences"
Terrance	Computer Science or Technology	Liberal Arts College (Community College Transfer)	Fourth/Fifth	Neutral	ADHD; Autism	"neurodivergent"; "learning difference"
Yhara	Biological or Life Sciences & Psychology or Neuroscience	Public Research University	Second	Neutral	Autism	"autistic person"

the researchers was neurodivergent, at least one of the researchers was in a STEM field, and at least one of the researchers was an undergraduate student. At least one of the researchers was a STEM faculty member with experience using in-class and out-of-class group work and active learning in lecture, laboratory, and project-based courses. One researcher (who conducted interviews) had formal training in qualitative research methods, research interviewing, and human relations facilitation. The other two researchers were trained on thematic coding through directed readings and training exercises. All researchers engaged in reflective writing and conversations on their positionality and preconceptions in relation to the research questions and data.

Supplementary Figure 1 illustrates our data analysis process, which we further describe below. We used NVivo (version R1) qualitative data analysis software for coding and memoing. We analyzed interview transcripts through inductive thematic coding using the constant comparative method to identify patterns of meaning across participants' responses (Fram, 2013). Each step of our analysis was an iterative process, and we utilized reflective memo writing (Boychuk Duchscher & Morgan, 2004; Charmaz, 2000). Through successive readings, two researchers first independently coded three transcripts using descriptive codes (initial codes) that indexed segments of the data that addressed students' experiences and beliefs, often with language similar to that used by participants (Gibbs, 2007). After this initial wave of analysis on three transcripts selected based on their range of experiences and beliefs that addressed the research questions, the team compared their initial codes for conceptual agreement. Because of the specific, contextual nature of these initial codes and the broad nature of our research questions, researchers generated over 200 codes in this first phase of analysis. Two researchers independently analyzed six additional transcripts (for a total of nine). The nine transcripts for the first wave of analysis were selected to ensure a range of neurotypes and types of group work (in-class or out-of-class for lecture or lab courses), as well as feelings towards group work based on intake survey and interview responses (three each positive, negative, and neutral/mixed). Through discussion and consensus building between two researchers, we condensed the initial codes from all nine transcripts into overarching focused codes that represented the generalized premise of each set of initial codes. At this point, one researcher drafted an initial codebook with proposed definitions and examples. In drafting the codebook, we drew on existing theory and concepts that aligned with our emergent codes to draft their definitions, including self-advocacy, adaptive strategies, and specific characteristics of neurodivergent people reported in the literature.

To strengthen the trustworthiness of our codebook development process, a third researcher generated initial codes on five of the nine transcripts from the first wave of data collection. All three researchers discussed these initial codes and collaboratively compared the third researcher's initial codes to the focused codes in the draft codebook. Through this process, we edited the codebook—re-wording code titles and definitions, as well as condensing and creating a small number of focused codes through constant comparison. After a second wave of interviews, all three researchers independently coded two transcripts using the draft codebook, and then compared their codes for agreement. After clarifying code definitions and creating and merging subcodes, all three researchers independently coded one more transcript. After one final modification, all three researchers independently coded two more transcripts using the codebook. At this point, we reached a Cohen's kappa coefficient of 0.80 or higher between each pair of researchers for every top-level code. At least two researchers coded all remaining transcripts using the codebook. In analyzing transcripts from the second wave of data collection, we edited 8 subcodes within the existing top-level codes without changing top-level codes. From analyzing a third wave of interview transcripts, no new subcodes were identified, and we finalized our codebook. We identified no new themes (top-level codes) after analyzing 12 transcripts, and after analyzing 18 transcripts, we identified no new dimensions of our themes' meanings (no new subcodes). We coded the remaining transcripts and recoded previous transcripts, using the finalized codebook. Where we disagreed on coding, we came to consensus through discussion.

For our holistic analysis, we compared top-level codes to outline seven themes. Each theme was related to one of seven top-level codes. The remaining five top-level codes were used as follows. We maintained top-level codes of "group work in labs," "group work online," "positive experiences with group work," and "negative experiences with group work" to sort specific types of group work experiences. Often data coded within these four top-level codes were double coded within another top-level code. We used data coded with a top-level code of "finding group members" in our discussion of implications for practice. The codebook for this study is shown in Supplementary Table 4. All top-level codes related to themes were used on data from at least half of our participants (in most cases nearly all participants). All subcodes (i.e., subthemes) were used on data from at least four participants (frequently more). Finally, through comparing themes and subthemes associated with individual-level factors to those associated with group/classroom/cultural factors,

we identified barriers/supports to doing and to being consistent with a social-relational model of disability.

Results

Through our analysis, we found evidence that, in some way, all of our participants experienced environmental barriers to learning or fully participating in group work for their STEM courses (i.e., "barriers to doing"). For 16 of our participants, we also found direct evidence that these barriers were related to the personal characteristics that each of them associated with their neurodivergence. Relatedly, many of our participants experienced barriers to feeling included as neurodivergent students based on experiences that they had working in groups (i.e., "barriers to being"). All of our participants recommended instructional practices that either supported or could have supported their learning and sense of belonging while working in groups for their STEM courses.

Through thematic coding, we identified seven themes which encompass the most common factors contributing to our participants' experiences with group work. The seven themes and their subthemes are summarized in Fig. 2. Three of these themes were individual-level factors (personal characteristics that participants associated with their neurodivergence, strategies participants used to support their learning, and beliefs on the value of group work). The remaining four themes were associated with social/environmental factors that hindered or supported our participants' learning and/or sense of belonging while working in groups (group dynamics, role in group, competitiveness in STEM, and recommendations for instructional support).

Although we separated individual level from environmental/social factors, it is important to note that from a social-relational perspective, these factors are intertwined and dynamically interacting with each other. We found relationships across themes, not only by comparing multiple segments of coded data from the same individual (as illustrated through examples shown in Fig. 3), but also within the raw data, when participants explicitly described cross-theme relationships. As one of a number of examples, Apple described a relationship between

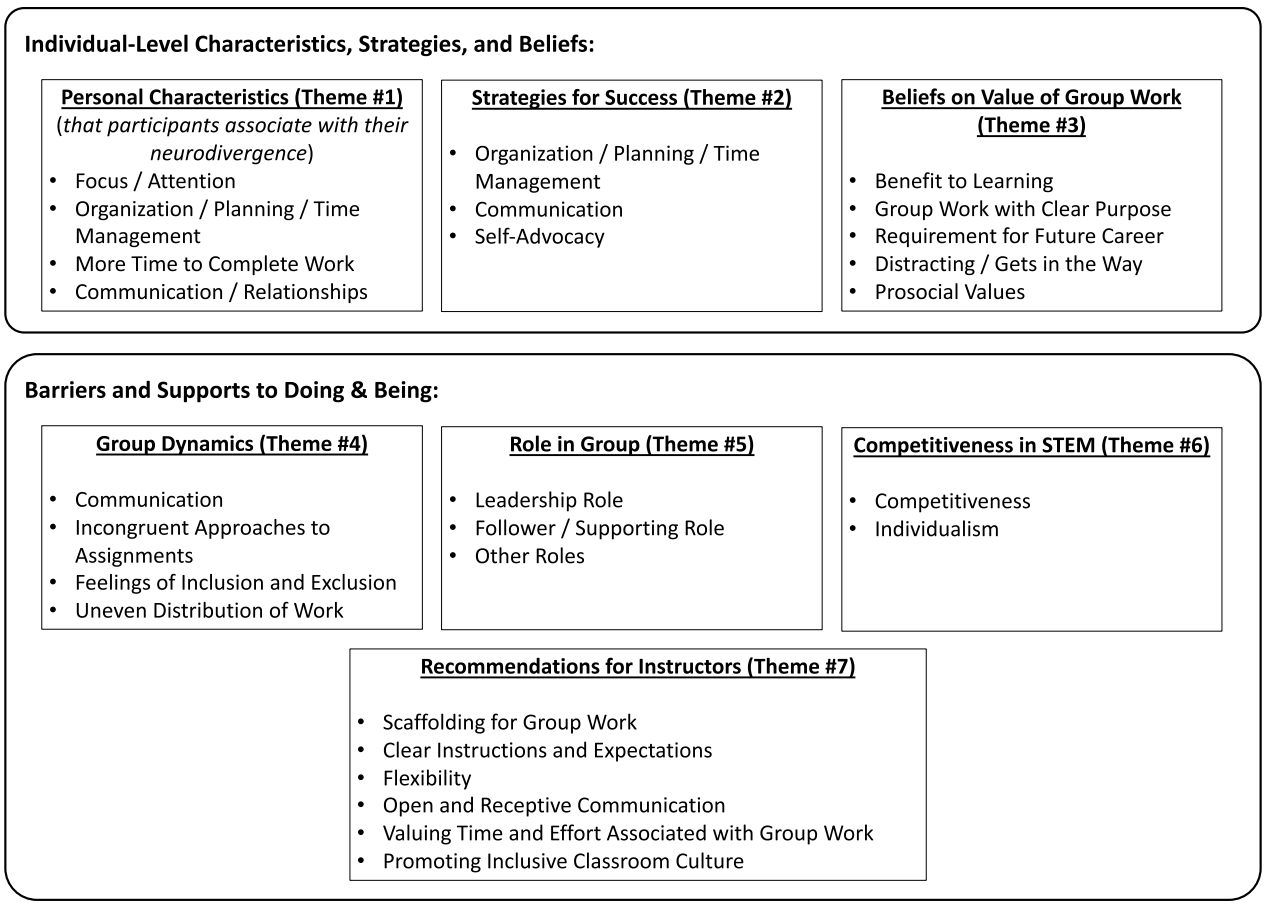

Fig. 2 Themes and subthemes of factors impacting participants' experiences with group work in their STEM courses. A text-based version of this figure is presented in Supplementary Table 7

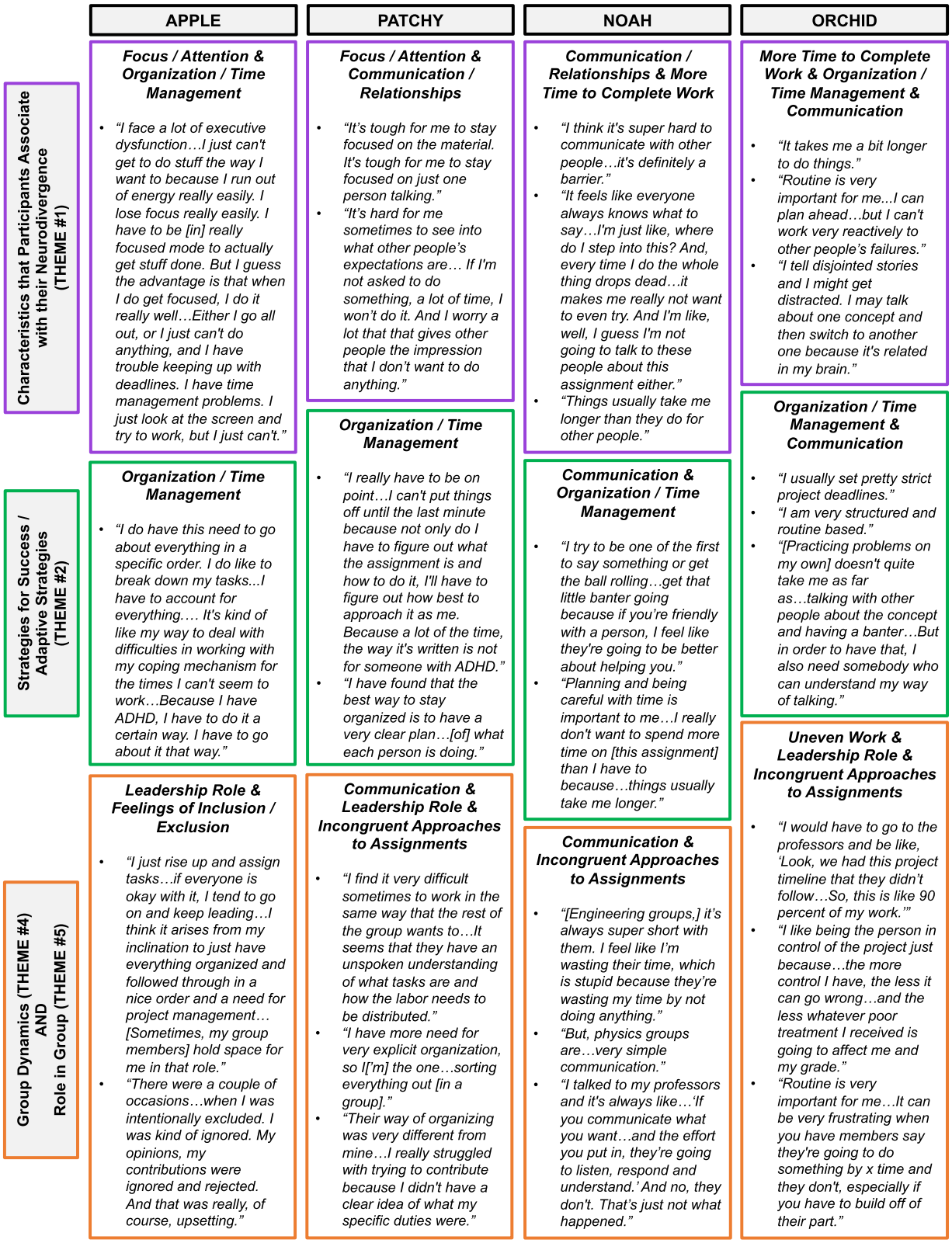

Fig. 3 Data illustrating patterns between themes for four participants. At the top of each box, the subthemes associated with the data presented for the theme for that participant are listed. In order to highlight the patterns between themes, in some quotes, we include data that references connections between the themes (i.e., the theme under which the quote is classified and another theme in the figure). A text version of this figure is presented in Supplementary Table 8

needing to complete tasks in a specific way and having ADHD:

> *"I do have this need to go about everything in a specific order [and] to break down my tasks…Because I have ADHD, I have to do it a certain way."*

And then separately, Apple described a relationship between taking a leadership role in their engineering course groups and needing to complete tasks in a specific way:

> *"I just rise up and assign tasks…and keep leading…I think it arises from my inclination to just have everything organized and followed through in a nice order."*

In addition, 17 participants directly connected their recommendations for STEM instructors using group work in their courses (Theme #7) to characteristics that they associate with their neurodivergence (Theme #1) and/or personal strategies that support their learning (Theme #2). For example, Aidan linked her recommendation for offering "*check point*" progress meetings on multi-week group assignments to supporting her self-regulation and time management:

> *"Meeting with the students…and having them explain what they submitted so far…Because I think that would hold accountability, and I know that's something I personally can struggle with is self-disciplined and making sure I'm doing things on time and managing my time."*

Aidan not only described how additional structure to group work assignments would support her learning (i.e., "doing") but also affirm her "being"/belonging through more direct engagement from her instructor:

> *"If I were to see [a] professor as going out of their way almost to make sure I'm not falling behind, just because when I get overwhelmed, I can avoid certain tasks and just put them off because they might be really stressful. So, that kind of engagement…would make me feel included."*

In our Results section, we focus on the themes that we identified separately from one another. Then, we further describe the inter-relationship between themes through a social-relational lens in our Discussion section. Because "Recommendations for Instructors" (Theme #7) is directly tied to the implications of our findings for instruction, we describe this theme in our Discussion section. In our Discussion section, we also highlight that although some of the group- and classroom-level challenges and supports that our participants described are consistent with those articulated through prior research on the general population of students (Bacon et al., 1999; Burdett, 2003; Davies, 2009; Feichtner & Davis, 1984; Kreijns et al., 2003; Premo et al., 2022; Theobald et al., 2017; Tucker & Abbasi, 2016), even these more common challenges/supports had some unique impacts for our participants because of the relationships between their group work experiences and the characteristics that our participants associated with their neurodivergence.

Neurodiversity focus of analysis

Although each participant referenced their neurotypes or diagnoses several times and there was a slight (but by no means complete) emphasis on challenges with interpersonal communication for autistic participants and challenges with focus/attention for participants with ADHD, themes that cut across participants of all neurotypes overwhelmingly outweighed differences. This is consistent with previous literature on cognitive, psychosocial, and cultural factors that cut across many neurodivergent neurotypes, as we discussed in our Introduction. For our participants, 10 out of 22 disclosed multiple disability types.

Theme #1: cognitive, behavioral, and other personal characteristics that participants associated with their neurodivergence

In order to study whether and in what ways our participants' neurodivergence could be related to barriers and supports of their learning while working in groups, we coded our data for the personal characteristics that our participants associated with their neurodivergence. To different extents, every participant referenced these characteristics in relation to their experiences with group work or with STEM learning more generally.

We identified four subthemes of characteristics, each of which at least 7 participants described: (1) focus/attention; (2) organization/planning/time management; (3) taking more time to complete work; and (4) communication/interpersonal relationships. Table 2 shows examples of the different types of characteristics participants described for each subtheme. These findings are consistent with cognitive and behavioral characteristics held by neurodivergent people that are reported in previous literature (references to prior literature describing these characteristics are provided in Table 2). Many of the characteristics we identified cut across neurotype, both for our participants and as previously reported. For example, mind-wandering is a common cognitive process for autistic people and people with ADHD, depression, OCD, and schizophrenia (Lanier et al., 2021; Marchetti et al., 2016; Seli et al., 2015, 2017; Shin et al., 2015; Simpraga et al., 2021). Hyper-focusing is common for autistic

Table 2 Cognitive, behavioral, or other personal characteristics that participants associated with their neurodivergence

Subtheme (*Participants*)	Type of characteristic	Examples	References
Focus/Attention (*Aidan, Apple, Bridget, Elizabeth, Keira, King, Lucy, Maeve, Noah, Nora, Patchy, Ralph, Richard, Shiloh, Terrance*)	Cognitive Inhibition (of external stimuli)	"*Public places [are] not great for me because I tune in and out from multiple different conversations going on around me.*" —Elizabeth "*I just get so distracted so easily.*" —Shiloh	(Forslund et al., 2016; Wang et al., 2012)
	Cognitive Switching (between foci)	"*I have difficulty regulating my attention between certain stuff.*"—Keira	(Keinhans et al., 2005; Oades & Christiansen, 2016)
	Mind-Wandering	"*My mind goes a million different ways.*" –King "*I find myself zoning out just because I have a bunch of different topics in my head.*" —*Terrance*	(Seli et al., 2017; Simpraga et al., 2021)
	Hyper-focusing	"*Once I'm in the zone doing my work, I will forget to eat.*" –Lucy "*I have to be [in] really focused mode to actually get stuff done.*" –Apple	(Ashinoff & Abu-Akel, 2021; Hupfeld et al., 2019)
Organization/Planning/Time Management (*Apple, Elizabeth, Keira, Maeve, Penelope, Richard, Shiloh*)	–	"*I have trouble keeping up with deadlines. I have time management problems.*" —Apple	(Cai & Richdale, 2016; James et al., 2020)
Taking More Time to Complete Work (*Aidan, Bridget, Hannah, Jacque, Keira, Lisa, Lucy, Noah, Orchid, Patchy, Ralph, Samson, Shiloh, Yhara*)	–	"*I have to interact with the material in a specific way, and I need a lot of time and a lot of input.*" –Jacque "*I need the time to sit there and soak in.*" —Shiloh	(Accardo et al., 2019; Gin et al., 2020; Green & Rabiner, 2012)
Communication/Interpersonal Relationships (*Bridget, Keira, Noah, Orchid, Patchy, Richard, Shiloh, Terrance, Yhara*)	Tone/Intonation	"*I sound pretty deadpan and rather serious…even if I'm kind of questioning what I'm saying.*" —Orchid	(Hubbard & Trauner, 2007)
	Communicating Thoughts & Non-Linear Communication	"*I may talk about one concept and then switch to another one because it's related in my brain.*" –Orchid "*It does like make it more difficult to work with others and to convey my ideas.*" –Keira	(Carruthers et al., 2022; Ying Sng et al., 2018)
	Social Cues and Norms	"*I socialize differently than the norm.*" —Terrance "*I have difficulty telling what people are thinking in the assumptions that they make.*" –Richard	(Rifai et al., 2022; Schafer & Kraneburg, 2015; Sheppard et al., 2016)

people and people with ADHD, depression, OCD, and generalized anxiety (Ashinoff & Abu-Akel, 2021; Bacow et al., 2010; Dupuis et al., 2022; Hupfeld et al., 2019).

We observed some overlap in participants who described characteristics coded as "focus/attention" and "organization/planning/time management," as well as overlap in "focus/attention" and "taking more time to complete work." Although a subset of participants connected challenges with maintaining focus or directing attention with their difficulty in planning or taking more time to complete their work, another subset did not directly relate these personal characteristics to focus/attention. Therefore, we kept these subthemes separate from one another, and only coded data if a participant explicitly referenced a subtheme.

It is important to note that although some of our participants framed their characteristics as challenges or deficits, other participants emphasized these characteristics as either strengths or differences in comparison with other students. For example, Hannah associated her neurodivergence with holding multiple thoughts at once and rapid cognitive switching between ideas. When working with others, Hannah described "*acting, but also reciprocating*" which allowed her to "*change anything at the same time*" when working or problem-solving in groups. Hannah shared how these abilities served as a strength in her STEM courses by allowing her "*to be creative… and think of things that [other] people aren't because I'm thinking about the problem in like three or four different ways.*"

King, Elizabeth, and others described characteristics that they identified as "*different*" from those of other students. King discussed how he was a strong hands-on learner and learned best when he physically "*move[d] around*" because of his neurodivergence. King shared, "*I learn better in different ways…I really don't see it as a disability.*" Elizabeth stated that through her diagnosis process at the beginning of college, she came to believe that thinking the ways she does is "*not necessarily a bad thing, it's just different.*" Elizabeth also described feeling a sense of belonging when she learned that some other students with ADHD think the ways that she does.

Other participants (Apple, Bridget, Elizabeth, Hannah, Keira, Lucy, Orchid, Richard) explained how the same exact type of characteristic could afford both strengths and challenges. For example, Richard described his need for routines as "*another one of those two-sided things*" that helped him with organization and planning, but made cognitive switching between tasks and managing unexpected changes more challenging. Apple described how strong variations in their ability to focus lead them to "*either go all out, or just [not] do anything*" (see Fig. 3). Bridget provided another example, when describing how sometimes they had a more limited ability to focus on processing information or completing a task, and at other times, her ability to focus was extra heightened and became an asset, when she was hyper-focusing or hyperactive:

> *"Other people…[might] be ten steps ahead of where I might be. And, so, there's sometimes an inferiority complex that goes along with that. But then, of course, with bipolar…there are other times when I'm very hyper and then I can absorb all the information, and I'm already finished the project before other people can understand it."*

Similarly, Keira discussed how her ability to focus can be both an asset and lead to challenges:

> *"What needs to be understood about ADHD…[is that] it means my attention span diverts into stuff that are super random, and I have difficulty regulating my attention to certain stuff. But the thing is, when I'm very, very, very interested in something, I'm only concentrating on that."*

Keira went on to describe that because she was interested in science and math as a child, her ability to hyperfocus while studying new material in these subjects was "*very beneficial*" for her. Keira also discussed how her tendency towards mind-wandering made her strong at generating ideas and conducting exploratory research, but that she found memorizing concepts and sequential planning difficult for the same reason.

The clear ways in which some of our participants described both strengths and challenges that they associated with the same personal characteristics highlight the importance of distinguishing between these characteristics and structures/norms that may serve as barriers or supports. As we discuss further below, several participants described how the structures of group assignments and expectations of group members or instructors during group work exacerbated the challenges they experienced in relation to the characteristics that we described in this section, rather than draw on strengths.

Theme #2: strategies for success

Strategies for success can be described as the skills participants learned or developed to support their learning and goal-oriented behavior. For this study, when our participants described an adaptive or compensatory strategy/skill that facilitated their success in courses (outside of requesting formal academic accommodations), we identified the strategy/skill as "strategies for success." For many participants, these strategies helped in managing challenges that arose from learning or operating within a restrictive academic setting, as we discuss below. In addition, for several participants, these strategies built on strengths associated with their neurodivergence.

One set of commonly reported strategies for success centered on organizational skills, planning, and time management, such as creating stepwise tasks or chunking larger assignments into a set of smaller tasks (Landin, 2019; Schuessler, 2017). For example, Penelope described color coding and breaking an assignment down stepwise into related sets of tasks. Apple described how chunking helped them when they had trouble completing their work. Apple discussed how chunking and highly specified task management was both a "*coping mechanism*" for and an "*intrinsic*" aspect of their personal academic experience as a person with ADHD. Apple used chunking and other forms of task and time management not only to manage their individual work, but also as a key component of project management during group assignments for their engineering courses (see Fig. 3 under "Apple" for further related quotes). Richard also described the importance of breaking down tasks and planning ahead to his success in STEM courses. Richard relayed how his planning strategies helped him feel comfortable and confident in his learning by providing a structured routine, because he *"function[ed] best when there's no surprises."*

A second subtheme of "Strategies for Success" is communication-related strategies. Strategies in this subtheme included a range of techniques focused on either: (1) developing rapport/building interpersonal relationships; (2) directing attention towards important information relayed by others in a conversation;

(3) supporting clear communication of ideas; or (4) managing comfort level/anxiety during conversations. Noah, who stated that "*it's super hard to communicate with other people,*" described developing the strategy of starting off in a new group with "*just try[ing] to talk to people normally first.*" Jacque described: "*repeat[ing] what people say in [his] head as they're saying it*" which helped him "*process it better.*" Keira discussed how it is more comfortable for her to focus on communicating with one person when working in a larger group because "*group work can get very distracting*:"

> *"I'm feeling much more comfortable talking with one person, because I concentrate on their face. I can see kind of what they are saying, and I can communicate with them better. So, I often divert myself from the group itself and glom only to one person, communicating with them. And then during the group work,…people hear what we are talking about, and then it gets into a group conversation. But I don't need to handle hearing multiple people working together."*

Elizabeth, Hannah, and Shiloh discussed interrupting group members or calling out as a strategy to manage communicating the rapid-fire ideas that "*pop*" into their head in the midst of conversations with group members. As Elizabeth explained, *"If I have a thought, I have to say it because I'll forget about it or…I can't continue to learn without this question being answered."*

Finally, a majority of participants identified self-advocacy as a helpful tool for them when working in groups. Self-advocacy is the "ability to assertively state wants, needs, and rights [and] determine and pursue needed supports" (Izzo & Lamb, 2002, p. 6). The reasonings behind our participants' beliefs on self-advocating during group work included ease of communication and setting realistic expectations between group members, as well as ensuring that their individual learning needs were being met. Jacque described how self-advocacy "*lets people know what to expect from you*" and "*ease[s] communication.*" Nora talked about how self-advocacy is important to her learning in groups, but also discussed how it can sometimes be challenging to self-advocate, depending on the dynamic between fellow group members. If Nora felt like she was "*bothering*" her group members, then she would not advocate for herself, so that she was not "*an annoyance.*" However, if she felt that there was "*a mutual understanding,*" then she would self-advocate for her needs.

The impact of group dynamics and fellow group members' communication and work habits were themes that came up more broadly in our analysis. We discuss this theme further in Theme #4 (Group Dynamics).

Theme #3: beliefs on the value of group work

To explain their overall feelings towards group work in STEM courses (listed for each participant in Table 1), nearly all of our participants shared beliefs that they held about the value of group work. Out of the 22 participants that we interviewed, seven had an overall positive feeling towards group work in STEM courses, and six had an overall negative feeling towards group work in STEM courses. Nine participants had a neutral or mixed feeling towards group work in their STEM courses, depending on the type of group work, the way in which group work was organized and facilitated by instructors, the social dynamics within the group, and/or the way in which responsibilities were shared and communicated among group members. Some participants, including those with neutral and negative feelings towards group work, shared that they saw a general value to working in groups, but that in practice, they themselves did not learn well in groups or had negative experiences while working in groups in the past. For example, Bridget shared that they learned better when working on math problems "*independently*" and that group work can be a "*complete hindrance*" to some people's learning. At the same time, Bridget also stated that learning to collaborate with others is *"a very useful skill that you can't really work around in most settings,"* but that instructors should "*fully consider*" how group work impacts individual students' learning. Bridget emphasized that using group work as an instructional practice should not be a "*cookie cutter kind of situation.*"

We identified five dominant subthemes to when and why our participants did or did not believe group work was valuable for their STEM courses: (1) working with others benefited their learning; (2) group work had a clear purpose/function for completing the assignment; (3) the expectation that group work would be a required part of their future career; (4) group work was distracting or got in the way of learning; and (5) group work aligned with their prosocial values (i.e., beliefs "that promote concern and care for the welfare of others" (Carlo & Sandman, 2012, p. 2709)). We briefly report on these subthemes to highlight ways that our participants believed that group work was or could have been supportive of their learning. Descriptions and supporting data for the subthemes are presented in Supplementary Table 5.

Overall, our participants' beliefs on the value of group work were neither uniformly positive or negative, and were often nuanced. The five subthemes that summarize our participants' beliefs were consistent with those reported for students in the general population (Chang & Brickman, 2018; Downing et al., 2020; Nokes-Malach et al., 2015; Pfeifer et al., 2023). However, as we describe through the following three group level/environmental

themes below, their experiences were often shaped by the ways in which environmental factors interacted with the characteristics and adaptive strategies that they associate with their neurodivergence.

Theme #4: group dynamics

The first of four themes associated with social/environmental factors impacting our participants' experiences with group work in their STEM courses was the interpersonal dynamics among their group members. These group dynamics included how group members interacted with one another and communicated expectations. Our participants described specific experiences during which individual group members had differing expectations or did not communicate their expectations to one another. Conversely, our participants also described experiences during which group members clearly communicated their expectations and accommodated each other's needs. In both cases, participants discussed how these group dynamics impacted their feelings about the work that they did in the group. Our participants' experiences with group dynamics were grouped into one of four subthemes that we discuss below: (1) communication, (2) incongruent approaches to assignments, (3) feelings of inclusion and exclusion, and (4) uneven distribution of work.

Six participants (Aidan, Noah, Orchid, Patchy, Shiloh, and Terrance) highlighted how communication between them and their group members made certain group assignments difficult for them. Patchy described a situation for a group project where her group members did not communicate their expectations. Patchy's group members "*just kind of stopped talking*" to her. On the last day of the project, her group members sent their results to her, which she had already completed on her own after not hearing from them. Patchy felt "*pretty upset*" because her group members "*were mad at [her]…when they didn't just communicate clearly what their expectations were.*" Patchy discussed how this breakdown in communication along with a mismatch in organizational style (which she described elsewhere, see Fig. 3) led to an upsetting situation that got in the way of her learning. As we discuss later, this and other similar situations also impacted Patchy's sense of belonging, serving as a "barrier to being." For Noah, when checking in on group progress for projects in his engineering courses, he found communication between his group members to "*always [be] super short.*" Noah contrasted his experiences with group work for his engineering courses to experiences with groups for his physics courses, where he had "*very simple communication*" with group members that were "*more conscious*" about being respectful of each other.

Notably, Patchy, Noah, and other participants (Hannah, Jacque, Lucy, Nora, Orchid, Shiloh) cited incongruent approaches to an assignment between them and their group members, specifically regarding project organization, time management, and task delegation. For group assignments outside of class, Hannah discussed how the incongruent approaches to time management between her and her group members challenged her way of balancing obligations for all of her courses. When working in groups, she expressed being "*fixated*" on making things the "*most time effective*" because she tended to "*want to finish [work] so [she doesn't] have procrastination.*" Elsewhere, Hannah discussed difficulties when working with group members that were not as focused as she was on completing work on a set schedule or working together in a time-efficient way. In these cases, Hannah described the challenge of changing her well laid out plans for managing the time commitments of group assignments with other academic and extracurricular obligations, given she often needs to "*spend more time*" and be "*cognizant*" of the time she takes to complete assignments. Similar to Hannah's experiences, Noah described how having his group members "*goofing off*" during meetings got in the way of spending time on other assignments that "*take [him] longer than they do for other people.*" Patchy described how her group members' "*way of organizing was very different*" from hers, because she needed clear divisions of labor, while her group members preferred to work in parallel at the same location and to individually claim responsibilities on the fly. Orchid, who described "*routine*" as being important to them, discussed situations where they had "*some problems with time management and [with them] doing things on time and then other people not.*" Lucy discussed that her university accommodations provided her with "*flex time*" for assignments, which she typically tried to plan ahead to use, and then organized her time based on a modified schedule. Lucy described a situation where her fellow group members did not want to create a group timeline and then left work for an end-of-semester project to the last day of the semester, leaving Lucy with no opportunity to use her accommodations. Jacque spoke about time management with a group for one of his STEM courses, stating that the group had *"time constraints, we weren't on the same page about times to meet and stuff like that."* These disagreements led to Jacque being unable to fully participate with his group because he needed "*a lot of time and a lot of input*" from instructors or peers when learning new material. Lastly, one of Nora's groups did not share her strategy of using organization and planning to manage her time when she had trouble focusing or when her anxiety

was heightened. However, Nora described how, rather than leading to conflict, her group members came to appreciate the planning she did, when they noticed how much work their group got done compared to other groups who were "*not really as organized.*"

While group dynamics played a large role in our participants' negative experiences with group work, other participants (like Nora) shared the benefits of positive group dynamics. Maeve discussed how attending a small liberal arts college where she had "*a personal connection to just about everybody in the course*" led to group members being "*respectful*" and "*us[ing] each other's time carefully.*" Similar to the "*sense of community*" expressed by Maeve, feelings of inclusion and exclusion within groups was another subtheme that the majority of participants touched upon. Richard described experiences of feeling included within his group for an intermediate-level biology course, where he "*didn't overpower people, but…also wasn't lost.*" Similarly, Jacque described feeling included when his lab partners would explain course material to him and when he formed personal connections with lab group members to the point where "*it felt more cordial.*" Bridget stated how they "*gravitate towards generally positive individuals*" so that their group experiences are not in a "*judgmental setting.*" Conversely, Apple discussed instances when they were "*intentionally excluded*" by other group members and their "*contributions were ignored*" for project-based group assignments in engineering courses.

For a few participants, although certainly not for all participants, one contributing factor to their feelings of exclusion or discomfort when working in groups on problem-solving was their or others' perceptions that they were working more slowly than the rest of their group. As Hannah put it, "*I think that when it's left to the easiest way, and the fastest to get it done is just split it up and get it done, people are going to be left out.*" Bridget described their "*self-efficacy feel[ing] at an all-time low*" when working in groups on computations because computations "*always just take me longer.*" Samson shared instances in his introductory physics courses when he was "*uncomfortable*" because he "*felt like [he] was slowing them down.*" Samson stated that these types of situations caused him "*unnecessary pressure.*"

Finally, for our last subtheme, eight participants (Lisa, Lucy, Noah, Orchid, Patchy, Ralph, Richard, and Shiloh) discussed multiple experiences of doing a larger share of work for out-of-class group assignments than their fellow group members. These experiences were primarily, although not exclusively, negative. Orchid shared experiences approaching professors and graduate teaching assistants about completing the bulk of the work for group assignments in introductory lab courses. Orchid summarized her instructors' responses:

> *"In those classes, the professors are like, 'Well, we don't care. The whole point of the early classes is learning how to work as a group, so we're not going to reassign you any groups, you've got to stick with who you are the rest of the entire semester.'"*

Lucy shared: "*I feel like I have to do a lot of the work for it to be up to the standard I'd like it to be.*" Although Lucy expressed frustration at having to do more than her share of work for out-of-class group assignments, she described how taking on the work was "*almost like a relief at that point*" because she knew "*what I'm handing in is something to the quality I'd like it to be.*" At the same time, the extra work was leading to Lucy *"staying up super late and putting a lot of extra time into*" the assignments. Similarly, Lisa described how taking on more work for group assignments made her feel more comfortable when working in groups because it allowed her to have more control over what her group turned in. Importantly, Orchid, Lucy, and Lisa all shared that, while sometimes frustrating or tiring, taking on extra work decreased their stress over group assignments and allowed them to lower the impact of misalignments between their and their group members' approaches to completing or managing time for assignments.

Overall, group dynamics had a significant impact on the experiences of our participants. Through our analysis, we identified a relationship between group dynamics as potential barriers/supports to neurodivergent students' learning and belonging, the characteristics our participants associated with their neurodivergence (Theme #1), and our participants' strategies for success (Theme #2), which we further discuss in the Discussion section. In addition, we highlight ways that instructors can support students when they are experiencing challenging group dynamics and can promote a culture where students feel empowered to express their needs.

Theme #5: role in group

A fifth theme that we identified was the role that participants typically took on when working in groups. The most frequently identified role was group leader, however, a few participants stated that they prefer not to take on a leadership role in groups. Other roles that individual participants identified with were organizer, mediator, secondary/deputy leader, mentor, supporting role, passive role, observer, person to tie individual ideas/products together, and no role at all.

Most participants who acted as a group leader did so when they faced or anticipated challenges with group dynamics. Some participants (including Apple, Lisa,

Orchid) described how taking on a leadership role made them feel more comfortable and/or decreased stress or anxiety about the group work process. As mentioned above, our participants described challenges with group dynamics due to different approaches to organization, time management, and task delegation. Out of the participants that identified these types of differences, a majority of them took on a leadership role to manage these differences. For example, Orchid discussed how taking on a leadership role put them in control over managing project tasks. Orchid described their functional considerations for taking on a leadership role (related to anticipated "barriers to doing"), and also how taking on the role buffered the potential impact of negative treatment by others (related to "barriers to being"). Orchid stated that leading made it less likely things "*can go wrong…and the poor treatment I received [was] going to affect me and my grade.*"

Although some participants did not state that they typically were group leaders, the role they described shared some of the same functions as the leader role that other participants discussed. Lucy described a "mentor" role that focused on supporting group members, including pointing out deadlines and soliciting whether group members needed support with their work for the project. Nora and Patchy described their role in groups as an "organizer." Nora stated that she "*help[ed] make sure that everyone is on task.*" For Patchy, an organizer role that involved some task delegation met her need for defining clear group roles and tasks (see data presented under "Patchy" in Fig. 3). In addition to the organizer role, Patchy stated that she sometimes took on "*no role at all,*" when group members excluded her. Patchy attributed being excluded in part to her difficulty with predicting other people's expectations of her without being explicitly told.

Other participants stated that they typically take on a "follower" or supporting role. Samson shared how a follower role best suited him because he worked best when given explicit instructions. Yhara described taking on a supporting role during group work by "*check[ing] over people's work if they had any questions,*" which "*helps [her] learn it a little more*" and not "*have to talk that much.*" For Yhara, taking on a supporting role provided her with time to "*prepare what I'm going to say.*" Another participant, Keira, described not taking on the role of a leader and instead a supporting role, because *"it takes [her] time to form an opinion about something*" and she *"feel[s] more comfortable observing others."* Keira contrasted her approach to group work in her college STEM courses with her approach to group work in high school, when she would rush to be the first to complete her work during in-class group assignments. Keira attributed her prior approach to working with others as being related to a "*regulation of impulsivity,*" but she now takes a different approach because she "*saw how it's done to [her]*" by other people.

In summary, for many of our participants, the role that they took on when working in groups supported their learning within the group. For some participants, their roles allowed them to better manage group dynamics and align overall group strategies to their individual learning/work strategies. For others, their roles allowed them to focus on their learning while others managed overall group functioning. In the Discussion section, based on these results, we will explore the implications of our participants taking on leadership roles from a social-relational perspective on disability.

Theme #6: competitiveness in STEM

Most participants identified the competitive environment within STEM as a factor in their experiences with group work. Participants shared their perspectives on and experiences with a mentality among their peers in STEM that promoted competition rather than collaboration. Hannah described her belief that this competitiveness was pervasive in STEM professions, saying: *"I think that's just the type of profession that you're going to feed into, so people pick up those mannerisms."* Orchid described the college environment in STEM fields as "*hostile*" toward neurodivergent students and the environment in engineering fields as "*toxic*" in general. Orchid discussed having "*so many bad experiences with professors…being very competitive and creating kind of toxic class cultures because engineering can be a very competitive space.*" Nora partially attributed the competitive environment within large-enrollment introductory STEM courses to the belief that these courses are meant to "*weed out*" students. Therefore, Nora expressed how the general culture in STEM incentivizes faculty not to *"care as much*" about individual students compared to other academic disciplines. Another participant, Lisa, shared her own experience with this competitive mindset, describing it as unfortunate but a common perspective among STEM students.

An individualistic attitude was noted by a number of participants as contributing to an uncomfortable or negative group work experience, as well as contributing to issues with group dynamics, as described by Aidan:

> *"I don't know if it's like a competitive element, but I think working in groups, a lot of students think, 'Oh, I did most of it; I'm not going to help anymore' or 'I want to do all of it so it's right.' Or, they just don't want to contribute and lean back and let everybody else do it."*

In addition, some participants noted that the prevalence of competition in STEM extended to their instructors as well as their peers. Jacque shared his belief that "*it's much more likely that a STEM professor would care less about whatever issue you're having and understand it less*" compared to faculty in other disciplines. Orchid shared experiences with how this competitive environment and messaging from professors and graduate teaching assistants (GTAs) made them feel about their place as a neurodivergent student in engineering. Addressing STEM faculty's and GTAs' expectations of how students ask questions and interact with them, Orchid shared that, based on their experience, these expectations "*leave very little space for people who don't naturally think of it that way.*"

Discussion

Our results provide insights into how group work in undergraduate STEM courses may impact neurodivergent students. Through our analysis, we not only identified patterns in the experiences of different participants, but also patterns across the themes of individual participants. As an example, we identified a relationship between the following themes in Patchy's experiences (see Fig. 3 for data): (1) personal characteristics (it being "*tough [for her to] stay focused*" and hard "*to see into what other people's expectations are*"); (2) adaptive strategies (formulating a "*very clear plan*" and identifying how to best "*approach [an assignment]…when the way it's written is not for someone with ADHD*"); and (3) group dynamics that served as barriers to her participation in groups, along with roles in groups that were supportive of her participation (misalignment between "*way[s] of organizing*" and taking on a role as an "*organizer*").

Figure 4 provides a phenomenological description of the relationships between the factors that contributed to whether group work was supportive of or challenging to our participants' learning in their STEM courses. Although other factors may affect the experiences of neurodivergent undergraduates with group work, the model in Fig. 4 focuses on the major themes described by our participants. We took a tiered approach to modeling the social-relational nature of our participants' experiences with group work within the ecological system in which these experiences took place. Ecological models have been used in the past to understand classroom learning experiences in STEM (Basham et al., 2010; Bronfenbrenner, 1994; Burgess & Patterson Williams, 2022; Del Toro & Wang, 2023; Morton & Parsons, 2018). Ecological models have also been paired with social models of disability to map factors that serve as barriers to disabled people's participation in society (Barnes, 1998; Devereux et al., 2015; Hollomotz, 2009). Using an ecological model provides a framework for understanding how practices and culture at the classroom and department/college levels may impact students differently based on the nature of group- and individual-level factors. Conversely, distinguishing salient group- and individual-level factors may provide a better understanding regarding how experiences of individual students and groups may vary, even

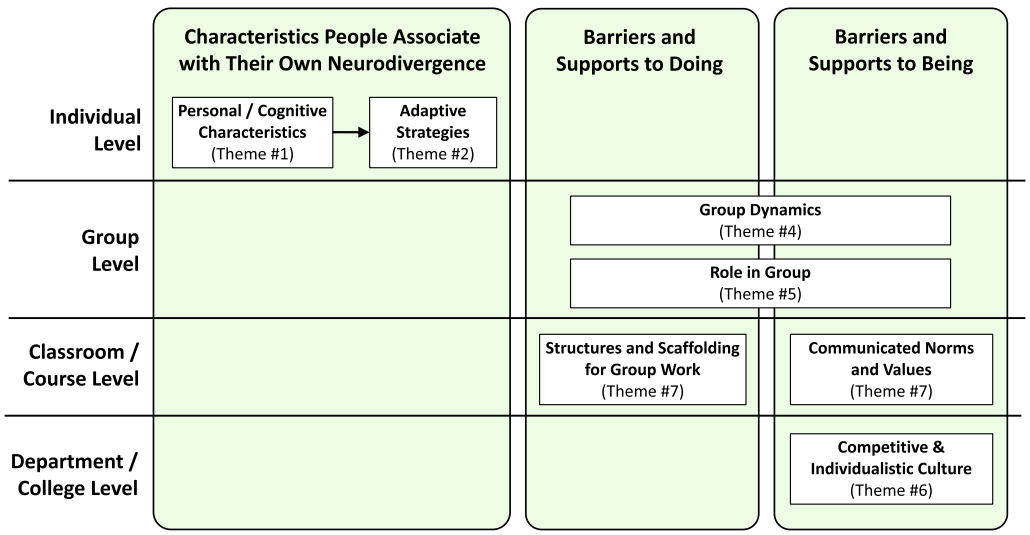

Fig. 4 Conceptual model of individual-, group-, classroom-, and department-level factors associate with group work in STEM courses that serve as barriers or supports to students' learning within a modified social-relational model of disability. The arrow indicates a direct relationship between personal characteristics and adaptive strategies observed in our study and cited elsewhere (Pino & Mortari, 2014; Ramakrishnan et al., 2022; Reis et al., 2000; Schaffer et al., 2021; Sedgwick et al., 2019; Sherman et al., 2006; Silverman, 2009; Taylor & Vestergaard, 2022). Boxes indicate factors identified based on our analysis of participants' experiences. Alt text in Supplementary Table 6

when the same classroom- and department/college-level practices are deployed. In Fig. 4, we adapt the description of the social-relational model presented in Fig. 1 to include an "affirmative perspective" that aligns with our findings. Our adaptations included replacing impairment effects with "characteristics people associate with their neurodivergence" and adding "supports" to barriers to doing and being.

Turning to the individual-level components of the model, nearly all participants who discussed their (often adaptive) strategies for learning and communicating connected these approaches to cognitive, behavioral, or other personal characteristics (e.g., needing structure or predictability to support focus). For example, as we discussed under "Strategies for Success" (Theme #2), Apple described their adaptive task management strategies (i.e., ordering and breaking down tasks) as coping mechanisms for occasions when they had difficulty focusing on work. Richard connected planning tasks in order to avoid "*surprises*" to his propensity for routines (the maintenance of routines is a practice held by many autistic people (Ribu, 2018)). Therefore, in our model, we connected characteristics (Theme #1) to adaptive strategies (Theme #2). For a subset of participants (Hannah, Jacque, Maeve, Noah, Orchid, Patchy, Penelope, and Shiloh), their organizational strategies were misaligned with those of group members. In addition, for some participants (Elizabeth, Hannah, King, Noah, Nora, Orchid, Patchy, and Shiloh), taking on a leadership role served as a form of self-advocacy, particularly as a way to anticipate and head off potential conflicts in organizational and time management strategies among the group. In the next subsection, we further discuss our participants' experiences with this misalignment through a social-relational framing, as well as how these misalignments connect individual-level factors (the characteristics discussed under Theme #1 and the adaptive strategies discussed under Theme #2) to group-level factors (Theme #4: "Group Dynamics" and Theme #5: "Role in Group"). Finally, classroom-level practices, resources, and culture impacted how individual- and group-level processes played out for our participants.

Barriers and supports to doing

Many of our participants experienced what may be common challenges during group work, including scheduling conflicts, group members not setting or keeping to a schedule, miscommunications, uneven distributions of work, groups not articulating a clear division of labor, and unresponsive group members (Bacon et al., 1999; Burdett, 2003; Wilson et al., 2018). However, their occurrence put a particularly high burden on many of our participants, because these occurrences interacted with characteristics associated with their neurodivergence and personal strategies that supported their learning or communicating. When faced with these barriers, several participants took on extra work, either by completing a larger portion of the assignment or taking on a leadership or organizer role. Other participants, as well as some of the same participants at other times, took on a "passive" or "follower" role. This included being excluded by group members or being unable to contribute how they typically would under different circumstances. A few participants described instances where their contributions were discounted or left out of the groups' overall efforts or final products.

A medical or individualistic model of disability would minimize the socially constructed conditions that led to disabling or otherwise challenging circumstances for our participants. Instead, an individualistic approach would focus on how, for example, a participant's divergent ways of directing their attention or communicating with others "led them to" experiencing a barrier, and perhaps seek to address how the student could change themself to lessen the barrier. This individualistic/medical model is still the dominant view in the U.S. education system across all levels (Kim & Aquino, 2017; Mole, 2013; Sandoval Gomez & McKee, 2020; Triano, 2000), and shares characteristics with the individualistic and competitive culture in STEM described by our participants (Imad et al., 2023; Ong et al., 2018).

Alternatively, within a social-relational frame, barriers to neurodivergent students' full and affirming participation in group work originate from social/environmental conditions that limit their functioning based on individual, neurodiverse characteristics. Likewise, supporting factors can serve a similar role by providing conditions for students to use or develop adaptive strategies that align with and affirm their ways of thinking and learning. To illustrate how a social-relational perspective provides insights regarding which structures and scaffolding for group work might hinder or support student learning, we will use one participant (Noah) as an example. However, the experiences of several participants that we described earlier would also serve as fitting illustrations.

According to data in Fig. 3, Noah had specific needs for setting clear timelines and expectations based on personal characteristics which he associated with his neurodivergence. Because of the dynamics within his engineering course groups and how his group members responded to Noah's requests for clear timelines and progress updates, Noah found it difficult to manage the time he spent on group projects. He also emphasized that "*now [he] ha[d] to stress about*" managing the unpredictable nature of when and how his group members would respond and whether he would get stuck with completing

an outsized portion of work at the last minute. In addition, the limited structural supports provided by Noah's instructors for setting expectations amongst group members and resolving group conflicts also served as barriers for Noah. Conversely, Noah described positive experiences with his physics groups due to "*simple communication*" and better alignment between members on setting clear timelines. Because Noah sometimes found it challenging to communicate with others, the responsiveness of his physics group members and the alignment between their ways of planning supported his participation. While Noah recognized that different groups of people will have varying social dynamics and ways of working together, he described how improvements to assignment structure and scaffolding would have better supported him in navigating challenging group dynamics and misalignments in work habits. Noah attempted to consult with his first-year engineering instructors, and was told, "*If you communicate what you want out of this class…they're going to listen, respond, and understand.*" Noah described feeling "*brush[ed] off*":

> *"Great, what was the point of even bringing this up? Or, why would you have a survey in class about group work, if you don't care about it at all? It was so discouraging…It made me really doubt engineering…Is this what it's all going to be like?"*

Not only did Noah describe barriers and supports for "doing," through his descriptions of this set of experiences, we also identified ways in which the dynamics in his groups and his instructors' responses led to barriers to "being"/belonging. We discuss "barriers to being" in detail in the following subsection.

Although we cannot say whether the approaches of our participants' group members aligned with their own personal needs and strategies, we can say that group dynamics led to barriers for our participants. We highlight these misalignments and points of conflict, not as a call to alleviate sources of difference or disagreement within groups, but instead to make visible the often hidden circumstances surrounding group work, particularly as they relate to how students experience their neurodivergence and their neurodivergent identity. Thus, our findings compel faculty to: (1) normalize that people work differently and have varying needs that group members should work together to support; (2) recognize the time and effort needed to work through these misalignments and the heightened burden that it might place on some neurodivergent students; (3) believe and support students when they seek assistance with managing group dynamics or advocating for their needs while working in groups, without minimizing the challenges they face or presuming that the benefits of working in groups outweigh the impact of those challenges; (4) reflect on their underlying presumptions of what makes a "good" learner and group member, how structures and scaffolding for group work in their courses might be built on these presumptions, and how these presumptions might disproportionately impact neurodivergent students; and (5) implement instructional practices to increase the inclusivity of group work assignments and experiences.

We return to these ways of making group work more inclusive of neurodivergent students below. In addition, based on our analysis of our participants' recommendations for instructors (Theme #7), we outline implications for instructional practice. But first, related to the third and fourth points above, we discuss how the "barriers to doing" outlined in this section also threatened our participants' sense of belonging in their groups or in STEM, specifically as they relate to students' conceptions of themselves as neurodivergent STEM students.

Barriers and supports to being

In Theme #4 (Group Dynamics) and Theme #6 (Competitiveness in STEM), we presented several instances of our participants feeling excluded or included by their groups or by the broader culture within their STEM classrooms. These experiences served as barriers or supports to our participants "being" neurodivergent people in STEM by impacting their views of themselves and their place in STEM and by (intentionally or unintentionally) targeting their neurodivergent identity. Our findings are consistent with the growing literature on disability microaggressions and ableism in academia (Dolmage, 2017; Lett et al., 2020; Olkin et al., 2019). This literature cites "subtle remarks or insults" and attitudes or expectations that stigmatize disability by "positively valu[ing]" attributes associated with nondisabled people, making these attributes "compulsory" (Dolmage, 2017, p. 7; Heung et al., 2022, p. 1).

Several participants (Aidan, Apple, Bridget, Elizabeth, Jacque, Keira, King, Lisa, Lucy, Noah, Orchid, Patchy, Richard, Shiloh) expressed how group work experiences impacted their sense of belonging or sense of self. Many of these participants expressed or hinted at a concern over their peers or instructors viewing them in a negative way, which is consistent with recent research on fear of negative evaluation's contribution to student anxiety during active learning in STEM courses (Busch et al., 2023; Hood et al., 2021). For example, Bridget stated that they developed an "*inferiority complex*" from taking more time than their peers when doing in-class group work in STEM courses. However, as described earlier, we also identified a prominent concern by this set of participants that others would misinterpret their intentions or behaviors, and *therefore* negatively evaluate them,

be frustrated by them, or treat them poorly. As a result, Orchid described feeling ignored and devalued as a student through their experiences interacting with group members and faculty:

> *"…how many more people like me are at the beginning [of their careers as STEM students] and get ignored and then just give up. Because I didn't know if I was going to come back to college after I withdrew. I could have given up and easily been a part of the 60 percent of autistic people who never get a degree."*

Returning to Noah, not only did the challenging group dynamics that he faced create barriers to him using his adaptive organizational and time management strategies, the responses he received from faculty directly targeted characteristics associates with his neurodivergence:

> *"It was always on me…'Talk about your expectations' and stuff. And I'm like, 'Why is it only on me?' If this is a group assignment, shouldn't this other person be involved as well? It's so frustrating, especially as a person who struggles communicating with others, to have it pushed all on me."*

As we previously presented, Noah questioned his place in engineering because of these experiences. Although any student can face challenges with group communication, when a neurodivergent student who struggles with communicating is told that they just need to communicate expectations with their group members more effectively, that recommendation can come across differently because it directly relates to their neurodivergence. This is all the more true when recommendations do not align with the reality of how group members interact with one another. For a different group that was functioning well but had limited communication, Noah described questioning if he was doing something wrong. Although Noah felt the group's limited communication was productive, he compared his reality to the norm articulated by his professors that group members would become "*best of friends*."

Other participants compared their personal characteristics associated with their neurodivergence to what they felt were viewed by others as "normal" ways of thinking, communicating, or behaving. Orchid described communicating in a non-linear fashion by connecting topics that are "*related in [their] brain*," but may not seem related to some other people. Hannah described "*seeming dumber*" to other people because she asked questions and sometimes interrupted people as ideas came into her mind, so that she expressed those ideas before she lost focus through continued mind-wandering. Patchy described "*worry[ing] a lot*" that "*other people [have] the impression that I don't want to do anything*," when her groups do not organize themselves in a way that explicitly delegates tasks to individual members. Keira described her non-linear thinking, which she identified as a strength, but one that could lead to difficulties "*fitting standards of [the] norm*" when people expected "*very logical and organized thinking*" in STEM.

Although any student may experience a loss of focus, trouble with group dynamics, or a difference in approach to communication, when messaging and behavior from instructors and group members (and broader STEM culture) directly relate to the personal characteristics that neurodivergent students associate with their neurodivergence, these experiences have additional implications for neurodivergent students' sense of belonging and self. This type of messaging may activate feelings of stereotype threat and reinforce disability stigma (Akin & Huang, 2019; Foy, 2018; May & Stone, 2014; Trammell, 2009). Other common messaging used by instructors when discussing teamwork skills can also become a barrier for some neurodivergent students, including when flexibility is pitted against a need for organization and routines or when leadership skills based on interpersonal relationships are favored over task-focused approaches to leadership.

When conceptualizing of the barriers we describe and their relationship to characteristics of our neurodivergent participants, it is important that we do not think of a barrier as exclusively existing for the neurodivergent student experiencing the barrier. Instead, as expressed through the recommendations and frustrations of our participants, for neurotypical instructors and peers, a barrier also exists to them "empathizing" with their neurodivergent student or peer. However, the social and functional ramifications of this empathy barrier still primarily fall on the neurodivergent student (Milton, 2012). One well developed conceptualization of this empathy barrier is the "double empathy problem," which is frequently discussed in the autistic community (Finke & Dunn, 2023; Milton et al., 2022). The double empathy problem refers to "a disjuncture in the reciprocity between two differently disposed social actors, which becomes more marked the wider the disjuncture in dispositional perceptions of the lifeworld" (Milton, 2012, p. 884). For neurotypical people, the disjuncture in perspective is often "perceived as a breach in the 'natural attitude' of what constitutes 'social reality,'" but for autistic people the disjuncture is "an everyday and often traumatic experience" (Milton, 2012, p. 884). Researchers and neurodivergent community leaders have extended the "double empathy problem" concept to the experiences of people with other neurodivergent neurotypes (Gerlach, 2023; Hamilton & Petty, 2023; Schuck & Fung, 2024). The "double empathy

problem" serves as a useful point of consideration within the instructor self-reflection and learning we suggest in Figs. 5 and 6. In the next subsection, we discuss how STEM instructors may reflect on and adapt *both* their practices and their messaging to better include and make space for neurodivergent students, when using group assignments in their courses.

Implications for practice/recommendations for instruction

All of our participants shared recommendations for STEM instructors interested in making group work more inclusive of their neurodivergent students (Theme #7). Based on Themes #1–6 above and our analysis of participant recommendations, we identified a set of six implications for practice listed below (these categories are also summarized in Fig. 6). In addition, based on our analysis of barriers and supports to doing and being, in Fig. 5, we outline how the recommendations from participants (that we outline in more detail in Fig. 6) can be integrated into a broader plan for instructors interested in making space for their neurodivergent students through group work.

Before describing these implications, we want to emphasize how these implications can benefit all students (neurodivergent and neurotypical), as well as address "barriers to doing" and "barriers to being" for neurodivergent students, in particular. For any student, the personal characteristics outlined in Theme #1 (focus/attention, organization/time management, communication, and taking more time to complete work) could either be supported or hindered by group dynamics and instructional choices during group work. Any student can lose focus, have trouble managing time or planning tasks, have difficulty communicating with group members, or take more time than average to complete work. For both neurotypical and neurodivergent people, these characteristics can also be exacerbated by lack of sleep (Randazzo et al., 1998; Schneider et al., 2016; Telzer et al., 2013) or personal trauma (DePrince et al., 2009; Nyvold et al., 2022; Op den Kelder et al., 2018; Welsh et al., 2017). However, and importantly, for many neurodivergent people, some or all of these characteristics are particularly heightened (as described by our participants and elsewhere (APA, 2013)), leading to increased barriers to doing when characteristics and strategies for learning are

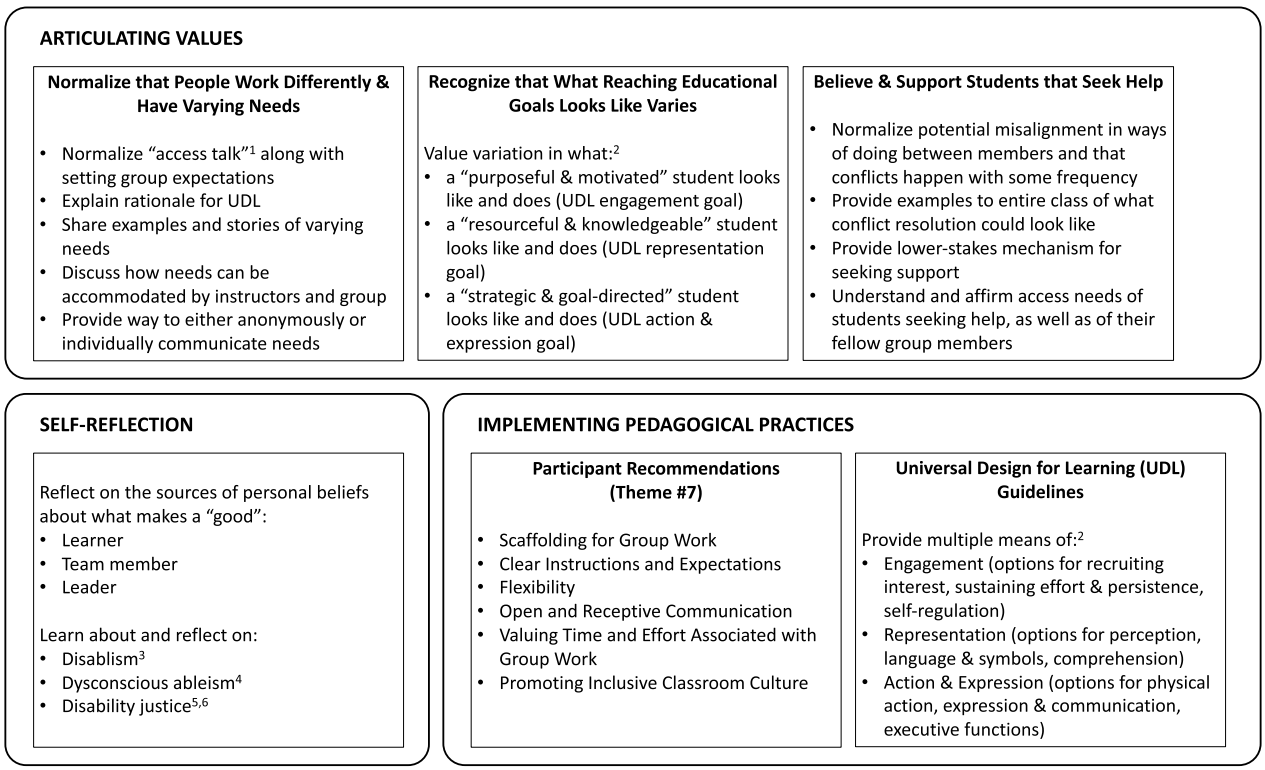

Fig. 5 Recommendations to instructors for facilitating inclusive spaces for their neurodivergent students through group work and for working towards dismantling ableism in their group work assignments, see Fig. 6 for details and supporting data on participant recommendations for pedagogical practices. A text version of this figure is presented in Supplementary Table 9. *Notes.* [1](Reinholz & Ridgway, 2021); [2](CAST, 2018); [3](Campbell, 2009); [4](Broderick & Lalvani, 2017); [5](Sins Invalid, 2017); [6](Berne et al., 2018)

Fig. 6 Recommendations for designing and implementing group work assignments that are supportive of neurodivergent students. Examples of supporting data are shown below each recommendation. These recommendations are a subset of the practices presented in Fig. 5 under "Implementing Pedagogical Practices." A text version of this figure is presented in Supplementary Table 10

misaligned with the environment. Just as importantly, as we outlined earlier, the explicit and implicit messaging associated with group work assignment design and instructor expectation setting, as well as obstacles to learning that students experience during group work, can serve as barriers to being. Therefore, we highlight both the shared benefits from our recommendations to all students, as well as unique ways to support neurodivergent students.

The broad outlines of our implications align with the universal design for learning (UDL) guidelines of providing multiple means of engagement, representation, and action (CAST, 2018). UDL is an instructional philosophy based around the principle that teaching practices and learning environments should be accessible to all students so that they can fully engage through their individual ways of learning in the classroom (Edyburn, 2010). UDL posits that designing for those who may engage with practices or environments in what are socially considered to be non-normative ways can benefit all students by offering everyone opportunities to

engage in unique and sometimes unexpected ways that benefit their learning (King-Sears et al., 2015).

For neurodivergent students, in particular, providing opportunities for "doing" while working in groups that align with their personal characteristics and adaptive strategies will better support their learning during group work in STEM (Black et al., 2015; Meyer et al., 2014). In addition, with appropriately paired messaging (as described below), instructors can also support their neurodivergent students' sense of belonging. While UDL is often exclusively thought of as a set of practices applicable to every student, a subset of UDL literature argues that its "implementation within an institution cannot be a practical project alone," and instead must "disrupt the discourse of normalcy" to fully benefit disabled students (Fornauf & Erickson, 2020, p. 191). Our findings support the assertion that adopting a UDL framework without reflecting on the unique and diverse experiences of neurodivergent students can risk overlooking expectations, structures, and messages that rely on normative and ableist values, even when utilizing UDL-inspired assignments. In addition, designing a UDL classroom but not messaging it as such is a missed opportunity to promote inclusion for diverse ways of thinking and doing. Frequently, discussions of neurodivergent students' access needs are relegated to ancillary spaces (Reinholz, 2021; Robinson et al., 2023; Smith et al., 2021), rather than creating learning spaces where students expressing their needs is accepted and commonplace. Below and in the accompanying figures, we provide tangible ways of applying and messaging UDL guidelines for group work assignments, while also centering the diversity of the neurodivergent experience.

- **Self-reflection** To confront ableism within the classroom, it is valuable to understand what it is and how it may manifest. Distinguishing between "disablism" and "ableism" is a first step. Disablism is "a set of conscious or unconscious assumptions and practices that foster the different or unequal treatment of people because of their actual or presumed disabilities" (Campbell, 2009, pp. 3–4). Disablism is one potential outgrowth of ableism, which values characteristics associated with nondisabled people over related characteristics of disabled people (Goodley, 2014). The concept of dysconscious ableism draws on the concept of dysconscious racism (Broderick & Lalvani, 2017), where dysconsciousness is the "uncritical habit of mind…that justifies inequality and exploitation by accepting the existing order of things as a given" (King, 1991, p. 135). STEM faculty using group work can use the extensive literature on ableism and disablism to reflect on how ableism (dysconscious as it may be) impacts their personal beliefs about what makes a "good" learner, team member, or leader (Dolmage, 2017; Kattari, 2015; Kattari, 2015; Wolbring, 2017; Woolf & de Bie, 2022). In addition, faculty can reflect on the ways in which potentially ableist traditions within their broader disciplinary culture may impact their students' beliefs and expectations (see Cooper et al. (2021) for an example about considering how traditions of sharing sessions in STEM could be related to the "share" of think-pair-share active learning activities and see Nieminen et al. (2024) for how disabled math students challenge "'normal' ways of being 'mathematically able.'" (p. 1)). This reflection can help faculty when designing more inclusive structures for group work and explicitly articulating their values, as recommended below. Faculty may want to engage in this self-reflection alongside colleagues, particularly as it relates to broader cultural norms at the department/college level. Communities of practice or transformation are models for organizing joint or parallel work on a common theme or goal (Hakkola et al., 2021; Kezar et al., 2018; Tinnell et al., 2019). Department action teams is another model for reflecting on and strengthening the culture and practices within a department (Reinholz et al., 2017). Faculty can enlist other important stakeholders in their process of self-reflection who bring diverse perspectives and expertise, such as center for teaching and learning specialists, DRC/DSO advisors, student support specialists, STEM administrators, and students themselves. These additional stakeholders can support faculty in identifying, designing, and developing resources and lesson plans, as they move to strengthen the inclusivity of their own classrooms or departments.
- **Articulating values** As we advanced earlier, it benefits students when faculty not only implement inclusive group work practices, but also articulate their inclusive values (Binning et al., 2020; Killpack & Melon, 2016; Murrar et al., 2020). The potential positive impact of articulating inclusive values is consistent with recent research on the salience of "non-content instructor talk" that "establish[es] classroom culture" and "explain[s] pedagogical choices" (Ovid et al., 2021, p. 2). In Fig. 5, we propose three emphases that align with our findings when viewed through a social-relational framework, and we provide bulleted lists of suggestions to institute each of these points. Here, we will provide additional detail on normalizing "access talk" as a mechanism to normalize that people have varying needs. We also discuss some examples of how reaching educational goals might look different for some neurodivergent

students. "Access talk" is the intentional statement of access needs (Reinholz & Ridgway, 2021). "Access check-ins," like "What do you need to do your best work?" and "What do folks need?" (Reinholz & Ridgway, 2021, p. 6), can welcome others to express their needs. Faculty can explicitly discuss, model, and provide examples of both access talk and access check-ins. Faculty can incorporate access talk and check-ins into group work in a similar way to how they may recommend setting group norms and expectations (Chang & Brickman, 2018). When discussing access talk, it is important for faculty to recognize that many neurodivergent students may not be comfortable articulating their needs or all of the details of their needs because of negative past experiences and their concerns over a dominant ableist culture (Chini & Scanlon, 2022). Therefore, it is important to not single out any students and to provide a way for all students to share their needs anonymously or with faculty directly, in addition to working to change classroom culture through normalizing the practice of expressing needs. Turning to valuing variation in what reaching an educational goal looks like for different students, as referenced through our analysis, some neurodivergent students might not appear to think or behave in ways that align with normative expectations, but still meet or exceed targets set by instructors. For example, if faculty have a specific image of what a "purposeful and motivated" student looks like and does, they might misinterpret some students who are motivated and working purposefully, but not in the ways that their faculty would expect. A neurodivergent student who engages with group work on their own/with only one group member or is mind-wandering or is working towards identifying their duties within a group or is frustrated with their group dynamic may not appear purposeful and motivated, when in fact, it can be quite the opposite, as our participants shared. As another example, a subset of our participants (Elizabeth, Noah, Orchid, and Richard) expressed strong prosocial beliefs on the value of learning with and from others, but also described situations during which their ways of communicating their thoughts or needs were interpreted as antisocial, rude, or falling outside of normative expectations by fellow group members or instructors. It is important for instructors to adopt an inclusive view of what constitutes meeting course expectations, and also explicitly share this view with their students. In addition to communities of practice mentioned earlier, faculty may benefit from partnering with students to identify ways to foster a culture within their classrooms that is inclusive of their neurodivergent students. Pedagogical partnerships and "students as partners" models provide frameworks for developing meaningful and reciprocal partnerships with students on instructional development (Cook-Sather et al., 2014, 2019; Mercer-Mapstone et al., 2017). As a first step, faculty can partner with students through existing structures, when available, such as with course teaching assistants, peer mentors, or learning assistants. Faculty can also consider getting feedback from student campus leaders, academic advisors, and student life advisors to identify the ways in which faculty can align their own discussions of access needs and conflict resolution with the ways in which these topics are handled in other living and learning spaces on their campuses.

- **Implementing pedagogical practices** In addition to the UDL guidelines summarized in Fig. 5, we outline recommendations for pedagogical practices from our participants (Theme #7) in Fig. 6.
- **Provide scaffolding for group work** Several participants recommended that instructors provide scaffolding for time and task management associated with group work assignments, including providing feedback on group progress towards meeting management goals. In addition, the strategies that participants used themselves (described under "Strategies for Success" (Theme #2)), such as chunking, can be translated into instructional strategies. It is important to provide resources that acknowledge diverse ways of thinking, such as examples of both linear and nonlinear notetaking as methods for knowledge management during group planning (Dror et al., 2011; Makany et al., 2009).
- **Clearly communicate instructions and expectations** Some participants (Orchid, Richard, and Samson) specifically described the value of articulating the "why" of an assignment, expectation, or requirement, even when their instructors may have assumed that their reasoning was "obvious." Some neurodivergent students may spend excessive time or get caught in a rut while attempting to identify the reasoning behind an unclear expectation (Ribu, 2018; VanBergeijk et al., 2008).
- **Allow for flexibility and modifications** Most participants expressed the value of picking their own group members. A few participants recommended having the option to opt out of or modify the nature of group work, if possible. When assessing whether to offer students flexibility in how a group assignment is completed, it is valuable for instructors to recognize when group work will support learning for an individual student and when it will get in the way of their learning.

- **Maintain an open and receptive line of communication with students and emphasize teamwork skills are learned and developed** Shiloh, Bridget, and others emphasized the importance of having instructors keep an "*open line of communication*" and serve as a mediator to "*facilitate [resolving] group disagreement*" that could not otherwise be resolved without external support. Earlier, we described several aspects of group dynamics that affected our participants' experiences with group work.
- **Value the effort associated with group work** Several participants described the amount of effort involved in navigating group dynamics and planning with their group. While in some cases, the time that a student commits to engaging in the process of group work may be valuable to their learning and skill-building, the time and cognitive load required to navigate group dynamics and to manage group tasks may be significant, even for short-term assignments or in-class group work. Setting aside an appropriate amount of time for managing these dynamics provides the time that all students need to build valuable team and organizational skills, as well as learn other technical and scientific content associated with these assignments.
- **Promote an inclusive classroom culture** In addition to our previous recommendations in Fig. 5, general techniques for promoting an inclusive classroom culture in undergraduate STEM courses are described in the literature (Dewsbury, 2020; Dewsbury & Brame, 2019; Fortepiani & Marsh, 2023; O'Leary et al., 2020; Sathy & Hogan, 2022). With group work, one mechanism for supporting a more inclusive culture may be promoting prosocial values through on-going, cooperative activities built on positive interdependence between group members (Choi et al., 2011; Johnson & Johnson, 1999; Johnson et al., 2007; Kreijns et al., 2003; Premo et al., 2018a, 2018b, 2018c; Van Ryzin et al., 2020). Jigsaw lessons and reciprocal teaching are two common forms of cooperative learning activities, which can involve resource or task interdependence to complete, with goals or rewards shared among group members (Van Ryzin et al., 2020).

While our participants provided recommendations on the practices of individual instructors in their classrooms, their recommendations have implications for broader departmental practices. To meet STEM program accreditation agency guidelines focused on developing "team skills," STEM departments have opportunities to not only incorporate activities into their curricula that require students to work in teams, but to also incorporate formalized teaching and learning of teamwork skills in an inclusive way (Goldsmith et al., 2024; Oakley et al., 2004, 2007; Reynders et al., 2019; Riebe et al., 2010; Sancho-Thomas et al., 2009; Smith & Imbrie, 2004). Departments and institutions can prioritize providing professional development opportunities for faculty and teaching assistants/learning assistants to strengthen both their pedagogical knowledge on teaching teamwork skills, as well as inclusive teaching. Finally, departments can focus on normalizing access talk and disrupting discourses of normalcy at the department level.

Implications for research

Considerations of neurodivergent students are largely absent from research on group work in STEM and from STEM education research more broadly (McDermott & Mosley, 2023; Pfeifer et al., 2023; Syharat et al., 2023). However, our research and a few other recent studies showed that, while group work may benefit some neurodivergent students, there are several ways in which specific implementations of group work practices may challenge some neurodivergent students' learning (Cullen, 2015; Gin et al., 2020; Hillier et al., 2018; Pfeifer et al., 2023; Shmulsky et al., 2019). This research points to the need for further "second-generation" STEM education research focused on how specific implementations of group work may impact neurodivergent student learning (Eddy & Hogan, 2014).

In particular, we identified group dynamics as one of several key factors that warrants further study. Both fundamental research into the nature of these group dynamics and applied research into practices that support students as they navigate challenging group dynamics are needed. Other researchers also highlighted the importance of group dynamics to student perceptions of group work for some neurodivergent students, students from other marginalized groups in STEM, and STEM students in general (Chang & Brickman, 2018; Cooper & Brownell, 2016; Cooper et al., 2018; Eddy et al., 2015; Hodges, 2018; Meadows & Sekaquaptewa, 2013; Pfeifer et al., 2023; Theobald et al., 2017). Through our research, we found links between group dynamics and neurodivergent students' adaptive strategies and personal characteristics that could serve as the focus of future research from a social/social-relational perspective.

Our current work identified the process of taking on a leadership role for neurodivergent STEM students, as well as how this role assisted in supporting students' adaptive strategies for success. Our findings stand in contrast to prevailing assumptions that neurodivergent people will face challenges as leaders based on their skills (Luria et al., 2014). Recent management and organizational behavior research into neurodivergent (in particular, autistic) leaders has theorized that some

neurodivergent leaders are more likely to value "task-focused" approaches to leadership (including complex problem-solving and novel thinking, organization, group task management, and group "stewardship") over social and interpersonal dimensions of leadership that dominate within fields of management (Roberson et al., 2021). The field of STEM education would benefit from research into how STEM faculty conceptualize and teach leadership, and whether the prevailing views favor a social- or a task-focused approach.

In addition, there is very limited research on how faculty who adopt UDL guidelines conceptualize of ableism and disrupting normalcy, as well as on how UDL impacts undergraduate students' views. Further research is needed on whether, how, and why UDL impacts classroom and departmental culture in STEM higher education. Likewise, further research is warranted on how neurodivergent students experience specific group work pedagogies and practices (such as peer evaluation, group contracts, and role assignments (Chang & Brickman, 2018)).

Finally, in STEM education research more broadly, neurodivergent students most often remain "invisible" to researchers, because no data is collected on neurodivergent identity or neurotype, and neurodivergent voices are not represented or centered in studies. Collecting data on neurodivergent and disability identity as part of education research studies is one step towards making neurodivergent students visible in STEM.

Transferability and study limitations

Overall, our participants were from a range of institutions, institution types, and STEM majors; had a range of neurotypes; and had experiences with group work in STEM courses with a range of subjects, levels, and assignment types. Although our participants' experiences and strategies were individualized and dependent on personal characteristics and the nature of their specific assignments, instructors, and group members; the themes and recommendations that we identified through our analysis were broadly applicable to our participants. Therefore, our findings are likely transferable to other academic contexts in which group work is used in STEM courses. In addition, although our findings are not necessarily representative of a population of neurodivergent students in STEM courses, because of the range of participants in our study and the consistent patterns we identified in our data, which in many cases were supported by existing literature on neurodivergent students, our findings are likely transferable to other neurodivergent STEM undergraduates.

However, it is valuable to note that this study was only conducted with students at U.S. institutions, and therefore some of our findings may not be transferable to institutions in other countries. Although neurodivergent undergraduates around the world may share similar academic experiences, how neurodivergent students view their neurodivergence depends on their sociocultural context (Brown & Leigh, 2018; Oyserman & Markus, 2014; Peterson, 2021; Reinholz & Ridgway, 2021; Rosenberg, 2017). Because the dominant cultural views on disability and neurodivergence, as well as the legal and academic policies protecting neurodivergent students' rights and access to education vary by country (Agrawal et al., 2019; De Bruin, 2019), students' academic experiences could potentially differ in significant ways. In addition, although participants from different STEM majors shared similar beliefs about the culture within their STEM disciplines, we did not investigate differences that may exist between the cultures of individual disciplines. We also did not collect data from instructors or group members, and therefore this study does not provide data on their attitudes and intentions. However, we do provide data on supports and barriers for our participants that existed, whether or not instructors and peers intended them to. Nonetheless, studies comparing student experiences to instructor attitudes, beliefs, and practices would provide valuable insights that could help further refine our recommendations for practice. Finally, although 2 out of 22 participants were not registered with their campus DSO/DRC and were not receiving any academic accommodations, a much larger percentage of neurodivergent students do not receive accommodations as undergraduates (Kranke et al., 2013; Newman & Madus, 2015; Newman et al., 2019; Wagner et al., 2005). These students may have unique experiences with group work that are not fully accounted for in our current study.

Conclusion

The results of this study were consistent with previous research that showed how the specific nature of instructional practices and classroom culture may provide supports or barriers to neurodivergent students' learning (Cullen, 2015; Fuller et al., 2004; Gin et al., 2020; Hart et al., 2010; Levinson & Ohler, 1998; Pfeifer et al., 2023). In addition, our results are consistent with prior findings that neurodivergent students develop adaptive strategies to support their learning within restrictive academic environments (Alaghband-Rad et al., 2023; Goffer et al., 2022; Griffin & Pollak, 2009; Livingston et al., 2019; MacCullagh et al., 2017; Pino & Mortari, 2014; Reis et al., 2000). Through our analysis, we identified time and task management strategies, adaptive communication strategies, and self-advocacy as "strategies for success" that our participants used during group work to support their learning and their

group's functioning. Based on the experiences shared by our participants, through a novel model based on a social-relational framework of disability, we connected these individual-level factors (along with participants' cognitive, behavioral, and other personal characteristics) to group-level factors (i.e., role in group and group dynamics). Through our data analysis of these factors and our participants' recommendations for making group work more inclusive of neurodivergent students, we also discussed implications for classroom-level and department-level practices that would address barriers to doing and to being for our neurodivergent participants. Our findings may serve as the basis for future research that studies the interaction between individual-level and group-level factors associated with neurodivergent students' learning through group work. This work is critical to understanding the unique and varied experiences of neurodivergent students with group work, as the use of cooperative and team-based instructional practices in STEM courses becomes increasingly commonplace and required by institutions and accreditation organizations. Developing best practices and making explicit pedagogical knowledge that support the learning and sense of belonging of neurodivergent students, along with all students in STEM, will contribute to supporting student persistence in STEM and moving towards an academic culture that is more inclusive of neurodivergent students.

Abbreviations

ADHD	Attention deficit hyperactivity disorder
DRC	Disability resource center
DSO	Disability services office
GTA	Graduate teaching assistant
OCD	Obsessive–compulsive disorder
SLD	Specific learning disability
STEM	Science, technology, engineering, and mathematics
UDL	Universal design for learning

Supplementary Information

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Supplementary Material 1.

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SPT collected data. SS, CW, and SPT analyzed data. SS and SPT collaborated on manuscript writing. CW edited the manuscript. All authors read and approved of the final manuscript.

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Availability of data and materials
Data generated and analyzed may be available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The study on which this manuscript is based was approved by the Jefferson Institutional Review Board (IRB) with exempt status (Study Control #21E.118). All participants consented to participate and publish through an online survey prior to completing a study intake survey. In addition, prior to beginning an interview, the interviewer recorded verbal consent from each participant through a formal verbal consenting process that was approved by the Jefferson IRB.

Consent for publication
All participants consented to publish through an online survey prior to completing a study intake survey and a formal verbal consenting process approved by the Jefferson IRB.

Competing interests
The authors declare that they have no competing interests.

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