Exploratory Research to Expand Opportunities in Computer Science for Students With Learning Differences

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The computer science (CS) education field is engaging in unprecedented efforts to expand learning opportunities in K–12 CS education, however, one group of students is often overlooked: those with specific learning disabilities and related attention deficit disorders. As CS education initiatives grow, K–12 teachers need research-informed guidance to make computing more accessible for students who learn differently.

Computer science (CS) educators are engaging in unprecedented efforts to expand opportunities in K–12 computer science education. Spurred in great part by the US National Science Foundation's (NSF's) CS education investments, the White House Computer Science for All initiative has added to this momentum. Still, while the benefits of propelling K–12 CS forward are great, barriers for students traditionally underrepresented in CS remain. "Computer Science for All" remains elusive.

Although education leaders and teachers are working hard to provide access to CS education, they face a formidable instructional challenge: accounting for their diverse school classroom populations. This includes students with specific learning disabilities (for example, in reading, written expression, math, and language) and related attention deficit disorders (such as attention deficit hyperactivity disorder, more commonly known as ADHD). We refer to these learners as students with learning differences (or students who learn differently). Students with learning differences have historically been overlooked in CS

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expansion efforts, and there are few evidence-based strategies to make CS education more accessible to them. They've been a "hidden" underrepresented group in computing.

This is a concern for two key reasons. First, it's an issue of educational equity; students who learn differently must be afforded the same economic and social mobility opportunities as their peers. Second, overlooking these students means the computing field misses out on their creativity and talent. Because they learn differently, these students often generate novel approaches to tackling complex problems. However, the chance to benefit from their views is lost because they can't fully participate in many CS opportunities as they're currently presented. This loss isn't restricted to only a few learners: the National Center for Learning Disabilities suggests children with learning differences (specific learning disabilities and attention deficit disorders combined) comprise anywhere from 6 to 7 million school-age students in the US, with almost 2 million of those students diagnosed with both of these differences.[1] Thus as CS opportunities become more available to—or in some cases, become required for high school students—teachers will need specific guidance about how to make CS more accessible for these learners to successfully participate alongside their peers.

This article describes the first phase of an NSF-supported exploratory research study to address this problem. We present our initial findings as well as a description of our research–practice partnership and collaborative process that together have been critical to advancing our work to create more equitable learning in CS.

Understanding IDEA and Learning Differences

Although broadening participation in CS has become a priority for the field, expanding opportunities for students with learning disabilities and attention deficit disorders has received very little scholarly attention. The Individuals with Disabilities Education Act (http://idea-b.ed.gov/explore/home.html) calls for equitable opportunities for students with learning differences.

Individuals with Disabilities Education Act and General Terminology

IDEA is a federal law that ensures all children with disabilities have access to a "free appropriate public education." It emphasizes special education and related services to meet students' specific educational needs and prepare them for further education, employment, and independent living. IDEA highlights the need for students who receive special education services to learn in the "least restrictive environment" (LRE), meaning they should spend as much time as possible in a general education classroom with students who don't receive special education services. Sixty-six percent of students with learning disabilities spend 80 percent of their school day in general education settings.[1,2]

Approximately 5.7 million children in the US are served under IDEA and 42 percent of them have a learning disability.[1] IDEA defines "specific learning disability" as

> a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoke or written, [in] which [the] disorder may manifest itself in the imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations.

The term "learning disability" isn't the same as other disorders such as autism spectrum disorders, emotional disturbance, or intellectual disabilities, although students in these disorder and other disability categories can also have learning disabilities (https://ldaamerica.org/support/new-to-ld).[3] Students who have been diagnosed with a learning disability demonstrate average to superior intelligence, yet experience unexpected underachievement in basic academic skills as a result of psychological processing deficits.[1,3,4] These deficits are caused by neurological differences in brain structure and function, which affect an individual's ability to receive, store, process, retrieve, or communicate information.[1]

Related attention deficit disorders, like ADHD, aren't classified as specific learning disabilities under IDEA but are covered under another category called "other health impairment." As with learning disabilities, attention deficit disorders are brain-based and linked to brain structure and function. This disorder results in significant difficulties with attention, hyperactivity, distractibility, or a combination. According to data from the Center for Disease Control and Prevention, about 6.4 million children in the US have received an ADHD diagnosis.[1]

Students formally diagnosed with a learning disability or attention deficit disorder are predominantly male, making up two-thirds of these students.[1] There are also differences across racial/ethnic groups. More specifically, trends indicate that Hispanic/Latino and Black/African-American students are both overrepresented and underrepresented in various special education categories for several possible reasons, including linguistic and cultural differences among classroom environments, teacher perceptions, assessment tools, inconsistencies in government requirements and reporting procedures, and the historical roots of inequality in the public school system.[1,5,6] Thus, in some cases, students receive services that they don't need or are denied services required for success.

A hallmark of the school experience for all students with learning differences is the struggle they experience in mainstream classrooms that lack proper instructional strategies, accommodations, or modifications to address their learning needs. For students with learning disabilities and attention deficit disorders, this struggle isn't because of an intellectual disability (a common misconception) or decreased intellectual capacity.[7] They can be successful if provided with appropriate instruction and support. It's critical that as we work for broader participation in CS, this large percentage of the US student population with these disabilities receive the same opportunities to participate in and contribute to computing as other students.

Students Who Learn Differently and Computer Science

Much of the current K–12 research focused on increasing accessibility for students with learning disabilities is specific to the life sciences and mathematics.[8–11] Research suggests that with appropriate adaptations and accommodations, K–12 students who learn differently can achieve success with a mainstream curriculum.[12]

An example of successful adjustments for university-level CS learning can be seen in two studies in England[13,14] that examined computer programming with students with dyslexia. These studies found that students with dyslexia (a reading disorder) could be supported through the use of sequential assessments, multimodal approaches to learning, and assistive technologies. Moreover, they found that the students brought keen visualization and problem-solving skills to programming. Norman Powell and colleagues[14] found that not only did students with dyslexia respond positively to instructional adjustments, but that their dyslexia appeared to have beneficial consequences—programming seemed to be an area where these students could exploit their strengths and circumvent their weaknesses. And in CS at the elementary level, researchers are just now beginning to explore the types of supports that are helpful for students with a range of disabilities in learning computational thinking.[15,16]

Notwithstanding emerging work, there's little scholarly work targeting learners with disabilities in K–12 CS settings. Our exploratory research will contribute to filling this gap by focusing on a critical element of the push for CS: the new AP Computer Science Principles (CSP) course. This study is generating findings about helping high school students who learn differently engage in CS that will also, we suspect, make CSP more accessible for a diverse range of students without formally identified learning disabilities or attention deficit disorders.

Research Study

Our interdisciplinary team's work aims to make the CSP course more accessible for students who learn differently. Over two years (through Fall 2017), our team is applying a rigorous research approach to identify teaching and learning challenges specific to learning differences in two sets of CSP instructional materials (Beauty and Joy of Computing and Code.org's CS Principles), propose adjustments to the instructional materials to address these challenges, and test the adjusted materials with students who have learning differences at Wolcott School (a high school for students with learning differences) in the AP CSP course, 2016–2017. A key intention of our work is to share what works and why with CSP curriculum developers and CS teachers, equipping them with research-derived strategies to address student needs specific to learning differences.

This article describes two related aspects of this study: our research–practice partnership (RPP) process and approach, and our initial steps toward addressing two research questions: the first relates to the learning and teaching concerns in making high school CS education in general and CSP in particular accessible to students with learning differences, and the second asks what types of lesson adjustments are required to make CSP courses accessible to students with learning differences.

The Study Collaboration

Our study is an RPP—that is, a collaboration between expert practitioners and education researchers working together to explore a practical question: How do we make CSP more accessible for students with learning differences? RPPs are characterized by long-term collaborations between practitioners and researchers that are focused on problems relevant to practice; a commitment to mutualism; the use of intentional strategies to organize work together; and the production of original data analyses to answer research questions posed by practitioners.[17,18] Study team members include individuals with expertise in education research; special education, psychology and learning strategies ("learning specialists"); teaching and curriculum development; and high school CS content, including CSP.

We believe that student voices are essential in educational improvement efforts, so our team also includes students who have learning differences. Wolcott has a course offered through all four years of high school called Learning Strategies during which students consider their learning differences, their learning needs, and ways to advocate for themselves as learners. Thus, students play dual roles in this research: they're student learners and research collaborators, documenting and describing their experiences with the lessons and recommending changes through the lens of their Learning Strategies course training.

Our team embodies the key RPP principles in many ways. For example, we share a commitment to solving a practical problem: the underrepresentation of students with learning differences in CS. Second, we planned and developed the study research questions, process, and timeline together. Third, we agreed that leadership needed to be shared (as co-PIs) to collaborate and contribute expertise equally. Fourth, we committed to and maintained a rigorous collaboration schedule to build rapport and mutual respect, and to facilitate learning across areas of expertise. And fifth, we agreed on the importance of and benefits to maintaining our partnership for future research to further advance efforts to include students with learning differences in computing. We committed to working together on the problem, not on the proposal only.

The Study Setting

Wolcott School is a private, nonprofit independent college-preparatory high school with a public purpose for students with learning differences. The Wolcott student body (N = 87 in the 2015–2016 school year; 43 percent female; 57 percent male) represents learning, ethnic/racial, socioeconomic, and geographic diversity. In the 2015–2016 school year, learning differences represented at Wolcott included learning disabilities (33 percent), learning disabilities/ADHD (48 percent), ADHD only (14 percent), ADHD/speech and language disorders (SL) (4 percent), and other (1 percent). Sixty-two percent of the students identified as White, 18 percent as African American/Black, 15 percent as Hispanic or Latino, and 5 percent with more than two racial categories. Wolcott offers several CS courses, taught by one teacher. Two sections of the same CS course were the setting for the Year 1 study pilot activities (N = 14 total students), described below. The pilot entailed using adjusted Beauty and Joy of Computing lessons in one section (composed of students who were freshman and sophomores) and using adjusted CS Principles lessons in the other (sophomores and juniors).

Exploring Ways to Make CS More Accessible for Students Who Learn Differently

An early step in our study was to specifically discuss the range of learning differences that exist and the adjustments commonly made for them in any discipline. In our study, we define lesson *adaptations* as adjustments to lessons that will benefit the whole class, particularly those with specific learning differences. Those versed in Universal Design for Learning (UDL) will see some overlap in our whole-class adaptations and elements of UDL, as many of our adjustments are focused on similar principles (www.cast.org/our-work/about-udl.html#.V8Rta5grK71). Different, however, is our particular focus on students' needs specific to their learning and attention-based disorders. Lesson *accommodations*, on the other hand, are adjustment suggestions for teachers that target needs of learner subgroups and are offered on an individual basis. Each lesson adjustment whether adaptation or accommodation falls into one of five categories: presentation, response, timing, setting, and social interactions (see Table 1). It's essential to be clear that adaptations and accommodations don't change the content or rigor of a CSP lesson, nor do they simplify materials or change grading and testing measures. Rather, they're recommendations for lesson adjustments that provide students with a range of ways to access content, enabling them to demonstrate understanding in different ways.

Even among students with the same diagnosed specific disorder or subdisorder, the characteristics of the disorder vary and present in different ways. Therefore, we needed to consider more than the diagnosed learning disorder—we also needed to consider the basic, psychological processes underlying the disorders and subdisorders. Because students with learning differences experience interferences with these underlying processes in different ways, even those with the same diagnosed learning disorder experience different challenges that can make

Table 1. Lesson adjustment categories.

Adjustment category	Provides students with…
Presentation	• access to instructional materials, presented in multiple ways (such as directions presented both orally and in writing; color coding of information presented on a screen, board, or activity sheet)
Response	• options for solving or organizing work in alternate ways (such as typing or handwriting a response; providing a sentence stem for use when writing a response) • options for demonstrating understanding and sharing work in multiple ways (such as delivering a presentation to the teacher individually versus in front of the whole class; marking test responses directly on a booklet versus using a Scantron/bubble sheet)
Timing	• additional time for assignments, projects, and tests • changes to the organization of class instructional time (such as teacher adjustments to sequence of lesson activities, or timing for activities to accommodate for student needs)
Setting	• adjustments to physical setting for learning (such as access to instruction in quiet space; calming music to increase focus or productivity)
Social interactions	• positive social interactions with other students (such as placing students in groupings where possible student conflicts/disruptions are minimized, such as grouping students challenged with social skills with those not intimidated by this difference)

activities or tasks that are part of CS classes (or any classes) difficult at times.

For example, *retrieval fluency* is a psychological process. A student with a retrieval fluency processing deficit could have more difficulty retrieving words and information from their own stored knowledge than students without the deficit. This deficit is often associated with a reading disorder, but it might also underlie a completely different disorder in a different student. Yet, in CS, both students, albeit with different diagnosed disorders, might face similar difficulties due to their shared retrieval fluency processing deficit. Here are some underlying psychological process examples, and possible ways they might present in the CS classroom:

- *visual processing*, where a student might interchange a "{" with a "(" in a program and can't identify why the program won't compile/run;
- *social skills*, where a student could have consistent difficulty reading social cues when working in pairs and doesn't recognize when he or she is talking too much, interrupting, or saying abrasive things to others; and
- *executive functioning and attention*, where students receive a completed test and are asked to correct the problems they missed. For several incorrect answers, a student might cite "I guessed" or "I didn't get it" as his or her correction due to his or her frustration with being required to redo the task, requiring review and attention to detail.

Early team discussions that focused on these issues led to the generation of a working document we refer to as the "preliminary guidelines." These guidelines include a list of specific learning and attention deficit disorders and the underlying psychological processes typically associated with them.[19,20] Table 2 gives examples.

The project guidelines serve as the starting point for adjustments specific to CS instruction and curriculum. Our team created a key (using a number and letter system; you'll see these represented in Tables 3 and 4 below) to easily identify each disorder, subdisorder, and underlying psychological process during the pilot lesson adjustment work. We refer to these as preliminary guidelines because the project team adds to and refines the guidelines at each stage of the project, informed by examples from the CS classroom. This process contributes to answering our first research question: What are the learning and teaching concerns in making high school CS education in general and CSP in particular accessible to students with learning differences?

CSP Lesson Review and Adjustment

Using BJC and CS Principles project collaborator recommendations about lesson content and timing, and accounting for the Wolcott weekly CS class schedule (205 instructional minutes/week), a Wolcott CS teacher selected several sequential BJC lessons for one section and several CS Principles lessons for the other with a programming focus.

Table 2. Excerpt from the study's "guidelines."

Learning disabilities and attention deficit disorders	Learning disability and attention deficit subdisorders	Underlying processes associated with some learning and attention deficit disorders*
Reading disorders	Reading decoding Reading fluency Reading comprehension	Phonological awareness Retrieval fluency Processing speed
Written expression disorders	Spelling accuracy Grammar and punctuation accuracy Clarity or organization of written expression	Sustained focus and alertness Organization/planning Oral formulation
Math disorders	Number sense Memorization of arithmetic facts Accurate math reasoning	Visual perceptual reasoning Cognitive flexibility Pattern recognition
Language disorders	Reduced vocabulary Limited sentence structure Social pragmatic communication	Vocabulary and semantics Working memory Listening comprehension
Attention disorders	Combined presentation Predominantly inattentive Predominantly hyperactive/impulsive	Sustained tempo Self-monitoring Activation initiation

*This is not the complete list developed by our study team.

Once the pilot lessons were identified, the Wolcott learning specialists considered the adaptations and accommodations typical in non-CS disciplines for application to CS instruction and curriculum in general and the pilot BJC and CS Principles lessons in particular. The learning specialists then worked in consultation with the team's CS teachers to review lessons for the most critical sections that could potentially pose challenges for students who learn differently (both teacher- and student-facing materials) and then developed adjustment recommendations to address those sections in the CSP lessons.

This process first involved careful review of each pilot lesson to identify components of activities or activity instructions (that is, sections within the materials) likely to be challenging for students because of their learning differences. Using the preliminary guidelines as a key, the learning specialists wrote adjustments (adaptations and accommodations) rooted in evidence-based practices used in other subject areas and identified the learning challenges each adjustment would address.

Concurrent with this process, education researchers systematically documented the recommended lesson adjustments to clearly delineate the specific challenges that each lesson, as written, presents for students with learning differences, the adjustments suggested to the CS teacher for addressing those challenges, and the intended benefits. This documentation created the foundation for collecting data on the adaptation and accommodation adjustments actually enacted during the pilot so the team could systematically analyze the circumstances in which each was or was not successful, and why. Tables 3 and 4 list the key categories documented for all lesson adjustment recommendations.

To provide context for Tables 3 and 4, we first provide an overview of the two lessons/labs (curriculum developer descriptions) where our adjustments occur:

- *BJC Unit 2, Lab 1, Conditional Blocks*. In this lab, students focus on conditionals to control the behavior of their programs. They learn to use predicates and to build other special-purpose predicates. They also test the direction and y position of the sprite and base actions on the results. The lab begins to focus on abstraction by analyzing tasks to break them into subtasks and then creating blocks that specialize in these subtasks before analyzing/debugging scripts.
- *CS Principles Unit 3, Lesson 3, Creating Functions*. In this lesson, students learn to define and call procedures to create and give a name to a group of commands for easy and repeated use in their code. They're introduced to functions as a form of abstraction that enables them to write code in larger, more logical chunks and focus on what something does, rather than how it does it.

Table 3. Example adaptation recommendations.	
BJC Adaptation, Unit 2, Lab 2	
Lesson information	
Section of the lesson	Teacher guide: "students will" section
Activity that might be challenging for some learners	Students are asked to analyze and create visual scripts
Disorders that make this a challenge	Math disorder; accurate math reasoning (m)
Associated underlying processes that make this activity a challenge	Procedural memory (15) Visual pattern recognition (20) Visual discrimination (22) Cognitive reasoning (29)
Why the activity is challenging	• Some students might have trouble analyzing the visual scripts because they have difficulty: recalling skills or processes to complete a task (15); recognizing or interpreting visual patterns among letters, words, or figures/shapes and labeling them accurately (20); and differentiating forms, patterns, hidden shapes, or other pictures from similar items that vary from each other in subtle ways (22). • Some students might have difficulties with "if-then" statements, inequalities, *x*/*y* coordinates, understanding degree rotation, and directional turns because they experience challenges in applying logic or problem-solving strategies; interpreting graphs or creating visual imagery; utilizing reasoning to integrate multiple ideas and facts; and cognitive flexibility, or the ability to change how they think about something (m, 29).
Team recommendations	
Adaptation recommendations (adaptations are adjustments to lessons that will benefit many students with differences in the class; adjustments that impact the whole class)	• Check for understanding during whole-class and individual discussions and clarify student understanding of script components. Highlight (with a smart pen or pointer) visual differences related to color and shape of the conditional blocks (15, 20, 22). • Illustrate "if-then" statements, inequalities, *x*/*y* coordinates, degree rotation, and directional turns for students (m, 29).

We piloted the adjusted lessons in the two Wolcott CS classes over 20 instructional days and collected data about their use. This pilot work informed our approach to adjustments for the whole set of Code.org CS Principles lessons, which the Wolcott teacher selected for use with her students for the AP CSP course in school year 2016–2017.

Data Collection and Analysis

Systematic documentation of lesson adjustments and their impact (described earlier) wasn't the only method used to answer two of our research questions during the pilot. We also created templates for written feedback and observation and focus group protocols to collect student-generated data on their experiences with the lessons (written feedback and student focus groups for each lesson/lab); collect teacher-generated data on their own and their students' experiences with the lessons (written feedback for each lesson/lab); and conduct weekly classroom observations (observation protocol). The data collection focused on the extent to which the adaptations and accommodations were or were not successful in supporting students with learning differences, what teacher implementation of those adjustments looked like in practice, and identification of new ideas that emerged during the process. This also allowed us to test out the data collection instruments before refining for Year 2 data collection, in the actual AP CSP course.

During the pilot month, our full team met weekly and worked together in an ongoing, iterative data analysis process. At each meeting, we reviewed and discussed the data for three purposes. First, the meetings facilitated a growing, shared knowledge base among all team members, thus preparing us for later comprehensive analysis and lesson revisions. Second, they informed the classroom CS teacher about any immediate adjustments to the upcoming lessons, based on emerging findings about the already enacted adjustments. And third, they helped the Wolcott CS teacher determine which of the two sets of materials she wanted to use in project Year 2 to teach AP CSP.

Table 4. Example accommodation recommendations.	
CS Principles Accommodation, Unit 3, Lesson 3	
Lesson information	
Section of the lesson	Teacher and student: "assessment" section
Activity that might be challenging for some learners	Students are asked to read "assessment" questions and write (type) responses
Disorders that make this a challenge	Reading disorder: reading decoding (b) Written expression disorders: all types (e)
Associated underlying processes that make this activity a challenge	Phonological awareness (10) Language processing (11) Fine motor (17)
Why the activity is challenging	• Some students might have difficulty reading the assessment questions (b, 10). • Some students might also struggle with written language elements like spelling, and formulating their responses (e, 11). • Some students might have difficulty with the physical act of typing (e, 17).
Team recommendations	
Accommodation recommendations (accommodations are adjustments to lessons that target the needs of learner subgroups)	• Allow students to use text-to-speech software to listen to questions (b, 10) and to listen to their own written responses so they can edit their writing (e, 10, 11). • Students might need dictation software to write their extended free response (e, 17).

A comprehensive analysis of the data collected during the 2016–2017 school year is currently underway. Initial findings from the pilot work are presented below.

Potential Barriers for Students with Learning Differences: Findings from the Pilot

Upon looking across all the pilot CSP lessons reviewed, we identified the most prevalent barriers to learning for students who learn differently. More specifically, in all of the pilot CSP lessons, 35 percent of the identified barriers across the BJC and Code.org CSP lessons were those related to disorders in language; 27 percent related to attention; and 20 percent related to reading (see Figure 1).

When we looked at barriers in each set CSP lesson by curriculum, we found some similarities but also a few differences. For example, in the Code.org materials, the most common barriers identified were related to language disorders (38 percent), followed by attention (21 percent) and reading disorders (20 percent). Fewer barriers specific to disorders related to written expression (13 percent) and math (5 percent) were identified in the Code.org materials, with 3 percent of the barriers related to underlying process challenges and no particular learning or attention deficit disorders.

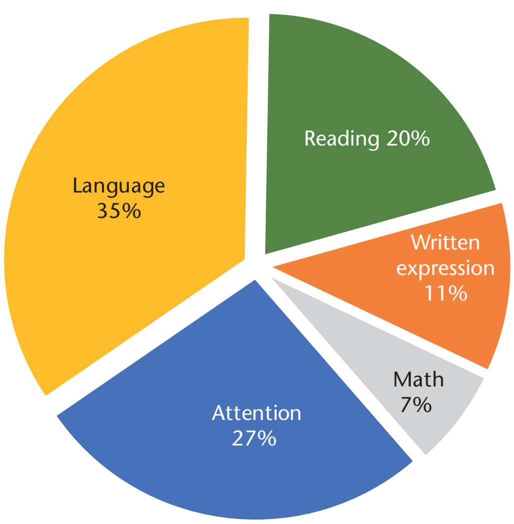

Figure 1. Potential barriers to learning in BJC Unit 2 and Code.org Unit 3 pilot lessons combined.

In the BJC materials, on the other hand, the most common barriers identified were related to attention deficit disorders (38 percent), followed by language (25 percent), reading (20 percent), and math disorders (10 percent). Fewer barriers specific to disorders related to written expression (7 percent) were identified in these materials. As

Table 5. Suggested strategies to address typical barriers in CSP lessons.

Common CS class activities	Why these activities pose challenges for students with learning differences: some may have difficulty…	Alternate strategies to remove these potential challenges (sample)
Whole-group discussions	• recalling or retrieving information • expressing their thoughts because they can't find the correct words and phrases to articulate what they mean	• Check for understanding of the discussion prompt. If necessary, rephrase and restate prompts and clarify vocabulary. • Provide example guidelines about how to provide feedback, such as only one person talks at a time; active listening; be prepared for differences of opinion; be respectful of all opinions.
Partner or small-group work	• reading social cues • reflecting and identifying the reasoning behind their approaches to problem solving	• Circulate around the room and model phrasing for students who might have difficulty connecting their thoughts to language and in retrieving words they want to use.
Reading and writing in activities or assessments	• jotting down their ideas quickly and accurately because spelling and phrasing are challenges • reading and comprehending the questions • putting their thoughts into words	• Read questions aloud as a group and clarify vocabulary and phrasing by rephrasing information and guiding students to revisit a running classroom glossary. • Offer students the use of text-to-speech software to read the questions.

both sets of lessons were programming-focused, these statistics reflect the differences across two versions of CSP in our main adjustment categories outlined in Table 1, specific to presentation of material for students, expectations around how students respond and demonstrate understanding, and instructions around student social interactions while engaging in the work.

Our Year 1 pilot study yielded some general recommendations related to instructional practices that are applicable to any teacher in a CS classroom. These strategies came from the project learning specialists and students alike and are presented below.

Learning Specialist Suggestions

After completion of lesson review and adjustment for the pilot period, the learning specialists compiled a list of strategies that can be employed when certain types of activities occur in CS lessons but that could pose challenges for students who learn differently (particularly those with challenges related to language, reading, attention, and written expression). For example, the instructional format of the two types of CSP lessons in our study both at times incorporate whole-group discussion, partner or small-group work, and reading and writing related to activities or student assessment. However, with some lesson adjustment, these types of learning opportunities are more accessible for students who learn differently. Table 5 provides some sample strategies.

Student Suggestions

Students who learn differently are also critical members of our research team because they're poised to provide real expertise[21] related to approaches and strategies to meet the needs of students like themselves. Initial coding and reconciliation of their written lesson feedback and notes from the weekly student focus groups about experiences with the CSP lessons highlighted several key suggestions for addressing lesson barriers:

- highlight/bold keywords and phrases, and offer important information in multiple formats other than text;
- provide an accessible glossary and highlight the relevant words for each new lesson;
- devote time to review words used in a new context (such as a programming environment);
- help students break down activities or steps into smaller parts;
- routinely offer tips so students can focus on the activity, not small distractions keeping them from starting or continuing the activity; and
- provide the time and space for practice and feedback

When these students were asked about their feelings related to CS at the end of the pilot period, over three-quarters expressed positive feelings about it. In fact, 46 percent of students reported "I love it," 31 percent reported "I like it," and 15 percent reported "It's okay."

Limitations of the Study

It's important to address the main limitation of this exploratory research: the unique environment of our study, Wolcott School. While not directly representative of a larger public school, Wolcott is an ideal partner for this exploratory research for a variety of reasons. Among the most important is the support of parents and students that in turn enables the research team to have full access to the most sensitive student-level data (such as specific learning disability diagnoses). When doing foundational work, it's essential to have a collaborative setting, in this case to have a more "rarified" environment so there's greater confidence that project findings will be as strong as possible. The goal for our work is to determine if the adjustments that we make to CSP lessons work for students whose primary issue is a learning disability or related attention deficit disorder. A next step is to conduct an implementation study to examine how the materials work in more typical public settings with all the supports (and impeding barriers) that affect their use and potential impact, and how to address needs of learners who have disabilities beyond those specific to learning and attention. At this point, however, when developing and testing an educational innovation (such as adjusted CSP instructional materials) for the first time, this work is best done in a more "ideal" setting, to ensure that the team can determine what's possible before attempting to bring it to more varied settings and examine efficacy.

Tackling practical challenges to grow the CS education movement requires collaboration across stakeholders, perspectives, and areas of expertise. The CS education knowledge base is still developing, and finding solutions to problems of practice calls for bringing everyone—particularly practitioners and students—to the problem-solving table. As CS becomes more prevalent in classrooms across the US, there's a particular need to give more attention to the accessibility of instruction and curriculum now, and to ensure that looking ahead, materials and teaching approaches are explicitly designed to include students with learning differences. This can only be done with an interdisciplinary team spanning research and practice.

This work is among the very few research-based studies in CS education that target the needs of students specific to learning disabilities and attention deficit disorders. Our efforts aim to identify the barriers to learning these students might face in CSP curriculum as written so that future research can further develop and share appropriate strategies to remove these barriers. Inclusion of students with learning differences themselves as key problem solvers in this process highlights for others the importance of collaboration across a wide range of expertise to address critical issues that affect instructors and learners alike. Findings from our multiyear activities will serve as a starting point for empirical understandings of how to make CS teacher instructional practices and student activities more accessible for students who learn differently.

As CS opportunities increase for all learners, we must be ready to provide research-informed recommendations to teachers and schools about what works for students who learn differently in CS and why. If learners encounter barriers as they simply seek to access and communicate computing information in a way that works for their neurological structures and functions, these students, and other learners like them, will be driven away from CS learning opportunities. What we do now, and how well we do it, will have implications for the future of K–12 CS education for all.

At this pivotal moment in our nation's history with so much attention and interest in K–12 CS, we must not rely on guesswork about what "works" for students, particularly those historically excluded from critical learning opportunities. There are simply too many students who learn differently (diagnosed or undiagnosed) who will be denied opportunities unless we develop and share strategies for addressing their learning needs in CS courses. We must collaborate across education research and practice to ensure our next steps are firmly rooted in evidence to increase successful participation of students traditionally underrepresented in K–12 CS, including those with learning differences. ■

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