Original Article

Empowering K–12 Students With Disabilities to Learn Computational Thinking and Computer Programming

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Mr. Rose, a third grade general education teacher, and Ms. Smith, a special education teacher, co-teach in an urban elementary school with a high number of students receiving free or reduced-price lunch. The school integrates computer science and computational thinking into curriculum as part of their science, technology, engineering, and mathematics (STEM) initiative. Mr. Rose and Ms. Smith have identified several challenges they will need to address to meet the needs of several of their students with learning disabilities. These challenges include difficulty with complex, multistep problem solving, lack of access to and experience with technology, and difficulty with fine motor skills.

There is an increased focus on including computing and computational thinking in K-12 instruction within science, technology, engineering, and mathematics (STEM) education and to provide that instruction in ways that promote access for students traditionally underrepresented in the STEM fields, such as students with disabilities (Israel, Pearson, Tapia, Wherfel, & Reese, 2015). Several reasons drive this focus on computing for a broad range of learners. First, of all the STEM fields, the greatest demand for workers exists in computer science. In fact, the U.S. Department of Labor has estimated that there will be 1.4 million job openings for computing-related jobs by 2020, but at the current rate of people being prepared for those positions, only approximately 30% of those positions will be filled (Bureau of Labor Statistics, U.S. Department of Labor, 2014). The National Science Foundation (2009) explained that beyond traditional computer science and programming positions, computing is becoming necessary in other career paths including journalism and the creative arts. Second, Code.org (n.d.), a nonprofit industry aimed at expanding computing education opportunities in K-12, has predicted that approximately two thirds of all computing jobs will be outside of the technology industry in areas such as banking, retail, government, entertainment, manufacturing, and health care. Thus, the demand for workers who are skilled in computing will be across industries. In addition to the pipeline rationale, there are several instructional benefits for students that result from the inclusion of computing within K-12 programs. These include:

- Creating real-world applied contexts for teaching mathematics, algorithmic problem solving, and collaborative inquiry (Fessakis, Gouli, & Mavroudi, 2013; Jona et al., 2014)
- Building higher-order thinking skills (Kafai & Burke, 2014)
- Increasing collaborative problem solving (Kafai & Burke, 2014)
- Increasing positive attitudes about computer science and computer science skills (Baytak & Land, 2011; Lambert & Guiffre, 2009)

Thus, providing computing experiences for K-12 students with and without disabilities can open the doors to multiple career paths and provide broad educational benefits.

Despite national attention on computer science, many teachers have naïve conceptions about what computational thinking and computing entails because computing has not yet been fully integrated into teacher

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preparation. To address this confusion, the Computer Science Teachers Association and International Society of Technology in Education (2011) broadly defined *computational thinking* as a "problem-solving process" that includes

> formulating problems in a way that enables us to use a computer and other tools to help solve them; logically organizing and analyzing data; representing data through abstractions such as models and simulations; automating solutions through algorithmic thinking (a series of ordered steps); identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combinations of steps and resources; and generalizing and transferring this problem solving process to a wide variety of problems. (p. 1)

It can be gathered from this definition that students with disabilities who struggle with complex problem solving, mathematics, and abstract reasoning may face numerous challenges when presented with instruction in computing. For example, students with disabilities may struggle with abstract computing processes such as a multistep procedure for using "if, then" commands and with new vocabulary such as *algorithm* (Israel et al., 2015). Consequently, the national focus on increasing computer science and computing education directly influences the work of special educators. Teachers working with students with disabilities must now consider how to best support their learners within these inclusive educational environments so that they can meaningfully engage in and benefit from computing education.

How Is Computing Typically Taught in K-12 settings?

There are many ways to integrate computing education into K-12 instruction, and the resources to support this instruction continue to grow. Computing education may involve either linear progression through discrete computing skills with tutorial software that teaches computing (e.g., Code.org or the Khan Academy) or open exploration/inquiry where students and their teachers use programming software for their instructional purposes. Younger students often begin learning computing (i.e., how to use a computer) and programming (i.e., how to code) with graphically intuitive tile-based software such as the open-source software Scratch. Older students may begin with these same programs or learn how to program within professional programming languages such as Java or Python. Table 1 provides a list of popular computing and programming curricula used in K-12 settings, and Figure 1 provides an example of an elementary student's project within Scratch. In addition to teaching computing in isolation, computer science instruction can also be integrated into the content areas, especially in math and science. For example, when teaching geometry, students can program animations for different polygons. Israel and colleagues (2015) found that elementary school teachers often integrated computing into content area instruction due to a lack of dedicated time for computing instruction.

Strategies That Increase Access and Engagement in Computing Education

Teaching Computing Through the UDL Framework

Universal design for learning (UDL) is an instructional planning framework for meaningfully engaging a range of learners, including students with disabilities, by proactively addressing barriers to learning (Center for Applied Special Technology [CAST], 2011; Rose & Meyer, 2002). There is a growing body of research demonstrating the educational efficacy of teaching through the UDL framework (e.g., Marino et al., 2014; Rappolt-Schlichtmann et al., 2013). Within the context of computing education, UDL can serve as the instructional framework in which teachers can embed the necessary supports, technologies, and strategies that lead to effective instruction for a broad range of learners. Table 2 showcases how the UDL principles, guidelines, and checkpoints can support accessible computing instruction.

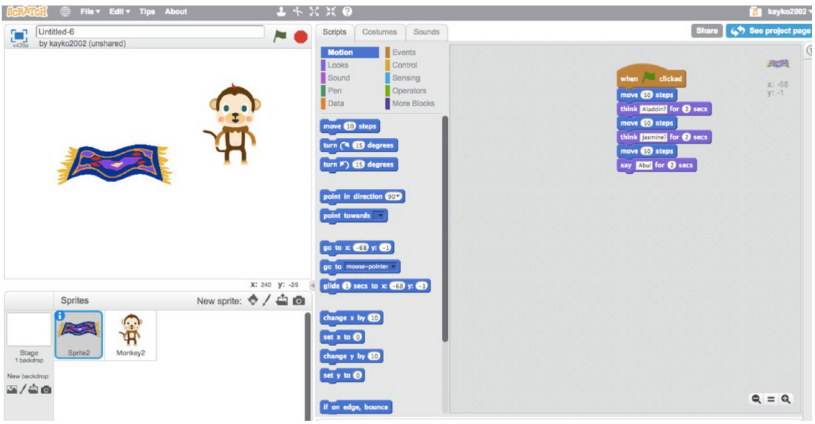
UDL encompasses three central principles that can be applied to computing education.

1. *Multiple means of representation.* Principle 1 emphasizes that teachers should present instruction in multiple ways so that students have different methods of accessing that information. During computing instruction, this principle is critical as students often benefit from a variety of different presentation methods. Depending on their needs, students can observe the teacher model the use of computing software (such as Scratch or Alice), see the code that the teacher created afterward, watch videos and demos of that code used online, or break apart existing code that their teacher modeled. For some students a combination of these engagement options or variation in sequence of presentation is required.
2. *Multiple methods of action and expression.* Principle 2 emphasizes

Table 1. Computing Tools and Curricula

Resource	Type and curricular aims
Scratch http://scratch.mit.edu/	Software; tile-based, open-inquiry programming. Main topics cover both specific operations and project-based instruction with a primary focus on how to use the operations.
Alice http://www.alice.org/index.php	Software; tile-based, open-inquiry programming. It is a 3D programming environment focused on creating animations and story telling. It is focused on fundamental programming concepts.
Code.org http://code.org	Web site tutorials; basics of programming in a gamified linear "level up" process of solving increasingly complex puzzles. Topics include fundamental concepts, JavaScript, unplugged activities, and tutorial apps on a variety of platforms, app development, and an "other" section.
Khan Academy https://www.khanacademy.org	Web site tutorials; basics of programming through advanced Java Script, HTML, and CSS including drawing, games, and simulations. There is also content about computer science careers.
CS Unplugged http://csunplugged.org	Web site unplugged computing lesson plans; activities that introduce students to computer science concepts such as binary numbers, algorithms, and data compression through play with cards, strings, cups, and other manipulatives.

Figure 1. Screenshot of an elementary student's project in Scratch



Note. Scratch is developed by the Lifelong Kindergarten Group at the MIT Media Lab. See http://scratch.mit.edu.

the use of multiple methods for allowing students to express their understanding. In computing, this principle can be achieved fairly effortlessly because computing activities inherently have flexibility built into them. There is not typically only one way of coding or demonstrating understanding of that code. Students can use programming software in different ways including creating their own projects, replicating the teacher's program, expanding on the teacher's program, or using templates that the teacher created with partially created codes. They can also explain how they designed their program and provide directions to help peers replicate their programs.

3. *Multiple ways to engage students.* Principle 3 asserts that teachers should include multiple options for engaging students. Teachers can do so by providing choices in computing projects that involve the same skills in different way and encouraging collaboration. It is also important to include culturally relevant computing activities such as highlighting careers of computer scientists with different cultural backgrounds, genders, and disabilities and helping students

Table 2. Teaching Computing Through the UDL Framework

Multiple means of representation	Multiple means of action and expression	Multiple means of engagement
Provide options for perception • Model computing using an interactive whiteboard, videos • Give access to modeled code while students work independently • Provide access to video tutorials of computing tasks	Provide options for physical action • Provide teacher's codes as templates • Include CS Unplugged activities that show physical relationship of abstract computing concepts • Use assistive technology including larger/smaller mice, touch-screen devices	Provide options for recruiting interest • Give students choices (choose project, software, topic) • Allow students to make projects relevant to culture and age • Minimize possible common "pitfalls" for both computing and content
Provide options for language mathematical expressions, and symbols • Teach and review content specific vocabulary • Teach and review computing vocabulary (e.g., code, animations, computing, algorithm)	Provide options for expression and communication • Give options of computing software and materials (e.g., Scratch, Code.org, Alice) • Give opportunities to practice computing skills and content through projects that build prior lessons	Provide options for sustaining effort and persistence • Remind students of both computing and content goals • Provide support or extensions for students to keep engaged • Encourage peer collaboration by sharing products
Provide options for comprehension • Activate background knowledge by making computing tasks interesting and culturally relevant • State lesson content/computing goals • Encourage students to ask questions as comprehension checkpoints	Provide options for executive functions • Guide students to set goals for long-term projects • Record students' progress (have planned checkpoints during lessons for understanding and progress for computing skills and content)	Provide options for self-regulation • Communicate clear expectations for computing tasks, collaboration, and seeking help • Develop ways for students to self-assess and reflect on own projects and those of others

Note. UDL = universal design for learning. For more information on UDL principles, see www.cast.org.

make connections between computing and their own lives. Teachers can also provide different learning options. Some students may prefer "level up" practice within gamified tutorial programs such as Code.org and others may like to practice those skills in a more open exploration using software such as Scratch.

Strategies to consider computing through the UDL framework are provided in Table 2.

Balancing Explicit Instruction With Open-Inquiry Activities

Explicit instruction is a systematic and direct approach to teaching. This type of instruction has been demonstrated as effective for students with learning disabilities and others who struggle with following multistep directions within complex tasks inherent in computing activities (Israel et al., 2015). In their book, Archer and Hughes (2011) researched 16 elements of explicit instruction illustrating roughly 30 years of evidence-based instructional strategies. Table 3 offers several of these strategies and how they can be applied for computing instruction.

Explicit instruction can reduce students' frustrations in computational tasks because each step is explained concisely and monitored until students have mastered the step. Allowing students ample opportunities to develop and practice skills that have been taught is an essential component of delivering effective instruction. With that said, it is important to balance explicit instruction of discrete skills with open-ended inquiry for students to have the opportunity to use skills learned through explicit instruction to engage in open-ended, problem-solving computing tasks (Israel et al., 2015; Kafai & Burke, 2014).

The balance between explicit instruction and more open computing instruction can be a challenge for teachers. Explicit instruction can be either provided prior to open-inquiry activities or embedded within those activities. Israel and colleagues (2015) described a model wherein teachers cycled through computing mini-lessons followed by short periods of open exploration. Through this process, teachers provided explicit instruction that allowed for more successful open inquiry for students who needed that level of support. Israel and colleagues described one teacher, for example, who modeled how to animate an object in Scratch and provided step-by-step directions on the interactive white board. She then had students use those skills within a constrained inquiry activity wherein

Table 3. Explicit Instruction in Computing Education

Select explicit instruction elements within computing education	Examples
Focus instruction on critical content by teaching skills and concepts associated with the big ideas in computing education.	Decide which computational skills to teach such as animating objects.
Begin lesson with clear goals and expectations and review prior learning. Provide content and computational goals.	Give real-world example of the computing tasks in the lesson to showcase its importance.
Provide step-by-step demonstrations that break down complex tasks. Model procedures the way you want the student to perform the skills.	Model step by step the code that students will use and do example on the interactive whiteboard.
Use clear and easy-to-understand language that is consistent. Avoid or clarify terminology that is ambiguous or confusing.	When using language such as scripts and coding, provide definitions and use these consistently in instruction.
Provide numerous opportunities for guided practice. Provide more scaffolds in the beginning and reduce scaffolds as student is mastering the material.	Include support during computing time as students try new scripts and skills. Encourage risk taking and independent problem solving.
Carefully monitor student performance and use data to decide when to adjust and intervene to facilitate student mastery.	Based on student work and products, teachers note where students had difficulties to address in the next class.
Provide immediate and corrective feedback. Students recognize errors if their code does not produce expected results.	When students expect code to produce an animation and it does not, the teacher can ask guiding questions that lead to correction, provide a scaffold in finding solutions, or model correct code for the student.

students had choice in what they could animate but had to use the discrete skills she modeled. Finally, once the students demonstrated proficiency in those skills, they had options for independent practice within more open computing activities of their choice.

It should be noted, in computing, students will know if they used code as intended based on whether the inputted code produces the expected outcome. This is different from other areas of instruction (such as writing a grammatically correct paragraph) because in traditional instruction, the students may not always know if their work is correct. Table 3 provides strategies that account for this inherent feedback within computing.

Mr. Rose and Ms. Smith are planning to teach students about the process of corn and soy production. To integrate computational thinking with this content goal, the teachers decide to engage students in writing programs for a seed to travel through a food production maze using Scratch. Ms. Smith suspects that students with learning disabilities will struggle with "if, then" codes required to complete this assignment. She, therefore, models writing such a code explicitly, and she leaves her example on the interactive whiteboard for the students to view as they create their mazes. Once students finish writing their codes, they can either continue to embellish their maze by adding more features or discuss their finished product with peers to gain new perspectives and feedback.

Encouraging Student-to-Student Collaboration

Computing is often highly collaborative because of the focus on creativity and finding solutions to ambiguous or ill-defined problems. As in other areas of student collaboration, students with disabilities and their peers may need to be taught the necessary skills to work successfully in collaborative environments. McMaster and Fuchs (2002), in their review of collaborative learning studies, described multiple training procedures to prepare students for collaborative learning activities. One cannot assume that students will know how to ask a peer for help when problems occur or that they know how to offer support to a peer who is struggling in a manner that promotes skill acquisition and independence. Teachers can facilitate these interactions through cooperative learning strategies.

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Cooperative Learning

Cooperative learning involves students working together to help each other learn content and discover new information (Slavin, 1991). It requires active student involvement and relies on student interaction as a primary means for promoting complex reasoning, critical thought, and the development of problem-solving skills (Rose, 2004). It can span across all grade levels from elementary through high school and fits well within the context of computing education. For example, teachers can form groups and assign roles for students to program. Roles could include animation leader, content leader, coding leader, and sound effects leader.

Research indicates that successful cooperative learning is dependent on individual accountability and group rewards (Slavin, 1991). Individual accountability requires each member of the group to perform an individual task that contributes to the overall completion of the assigned group goal (Johnson & Johnson, 1999). Group rewards is a form of recognition to all team members upon the successful completion of the task. Both factors can be the incentives for students to actively participate in cooperative learning.

McMaster and Fuchs (2002) found that individual accountability and group rewards have the potential to increase achievement of students with learning disabilities. The roles of students with disabilities should capitalize on their strengths and allow for modified expectations if necessary. For example, if they are collaboratively creating a game in Scratch, students who struggle with planning multistep projects may require preplanning with the teacher to determine individual goals prior to the group collaboration.

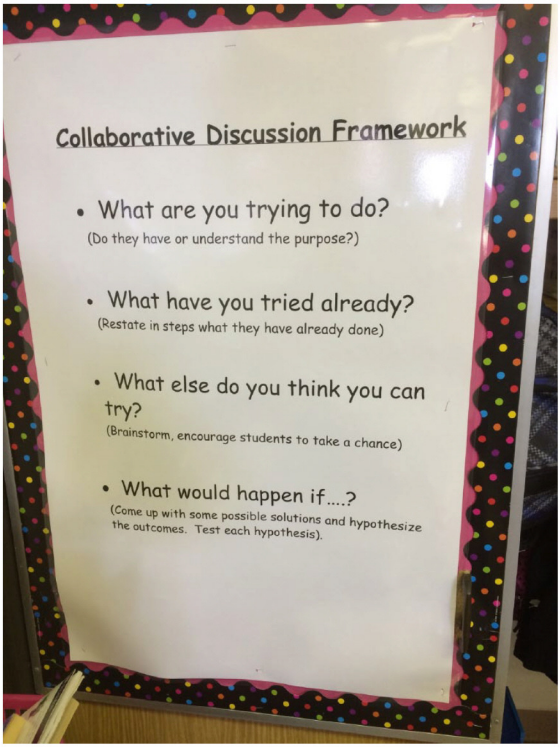
Student-to-Student Help Seeking

When students cannot find a solution to a computing problem, they often get frustrated and want the teacher or another student to help them find solutions. To get students to articulate those problems effectively, studies such as Webb, Ing, Kersting, and Nemer (2006) and Karabenick and Dembo (2011) recommended providing students with specific prompts to encourage them "to give elaborated explanations, to explain materials in their own words, and to explain why they believe their answers are correct or incorrect" (Webb et al., 2006, p. 81).

Accordingly, teachers can encourage collaborative discourse that provides students with language to assist them in seeking and giving help. For example, Park and Lash's (2014) collaborative discussion framework (see Figure 2) encourages students to collaborate during computing activities. This framework guides student conversations through four questions when they are stuck on difficult task: (a) What are you trying to do? (b) What have you tried already? (c) What else do you think you can try? And (d) what would happen if . . . ? (see Figure 2). This framework should be explicitly taught to students as a strategy to seek help from other students before asking the teacher.

Mr. Rose and Ms. Smith encourage collaborative problem solving in their classroom. They introduced their students to the Collaborative Discussion Framework as a tool that promotes collaborative problem solving and reduces learned helplessness and overreliance on teacher assistance.

Figure 2. Example of Collaborative Discussion Framework classroom poster



Students with disabilities use this framework as a prompt to seek help from their peers without feeling embarrassed for not knowing how to solve the problem.

Experiment With Different Software and Hardware to Increase Accessibility

To include a broad range of learners in computing, teachers should consider whether the software and hardware that the students access present barriers to learning and participation. For example, students with fine motor difficulties may struggle with using a mouse. Because of these barriers, teachers must examine the accessibility of the hardware and software their students use.

Assistive technologies (AT) and instructional technologies (IT) go hand in hand when considering access issues during computational thinking activities. Students with disabilities who have access to AT during traditional instruction that includes technology (such as word processing) will likely need access to these technologies during computational thinking instruction. The same type of process for making AT considerations in traditional instructional areas should be afforded to computational thinking instruction. For example, teachers and individualized education program teams make AT determination decisions based on students' needs and abilities, the required tasks, and the learning environment. These same areas should be considered during computational thinking instruction.

Ms. Smith observed Thomas, a student with fine motor difficulty. She noticed that although he loves engaging in computer-based learning, he is not engaged in the planned computing activity. Upon further observation, she noticed that he had difficulty with dragging the coding tiles and making changes within those tiles. She first gave him a different mouse to use, but he still had a difficult time navigating Scratch. She then allowed Thomas to use the interactive whiteboard to do his computing with his hands rather than a mouse, which was much more effective for Thomas.

Other tools that teachers can use to respond to student challenges include the following:

- Fine motor challenges: touch-screen computers with either different styluses or using finger gestures, different size mouses, or the use of interactive whiteboards
- Memory challenges: video tutorials readily available or video models created by the teacher, peers, or the participating students
- Complex problem-solving challenges: experiment with different software that provide both linear and open computing activities. For example, Code.org and Khan Academy offer linear lessons, whereas Scratch and Alice offer a more open platform for using those skills.

Final Thoughts

There are many strategies special educators can employ to increase opportunities for students with learning disabilities to succeed in computing education. Because computing education is a new area of instruction, many special educators may not know how to provide support to students as they learn computing. In this article, several strategies and resources were outlined that special educators can implement to support students who find computing challenging. These instructional practices should be considered alongside the individual needs of each student to develop meaningful, engaging, and accessible computing experiences for students with disabilities.

References

Archer, A. L., & Hughes, C. A. (2011). *Explicit instruction: Effective and efficient teaching (What works for special-needs learners)*. New York, NY: Guilford.

Baytak, A., & Land, S. M. (2011). An investigation of the artifacts and process of constructing computers games about environmental science in a fifth grade classroom. *Education Technology Research Development*, *59*, 765-782. doi:10.1007/s11423-010-9184-z

Bureau of Labor Statistics, U.S. Department of Labor. (2014). *Occupational outlook handbook, 2014-15 edition: Computer and information research scientists*. Retrieved from http://www.bls.gov/ooh/computer-and-informationtechnology/computer-andinformationresearch-scientists.htm

Center for Applied Special Technology. (2011). *About UDL*. Retrieved from http://cast.org/publications/UDLguidelines/version1.html

Code.org. (n.d.). *Make computer science in K-12 count!* Retrieved from http://Code.org/files/convince_your_school_or_state.pdf

Computer Science Teachers Association and International Society of Technology in Education. (2011). *Operational definition of computational thinking for K-12 education*. Retrieved from http://csta.acm.org/Curriculum/sub/CurrFiles/CompThinkingFlyer.pdf

Fessakis, G., Gouli, E., & Mavroudi, E. (2013). Problem solving by 5-6 years old kindergarten children in a computer programming environment: A case study. *Computers & Education*, *63*, 87-97. doi:10.1016/2012.11.016

Israel, M., Pearson, J., Tapia, T., Wherfel, Q., & Reese, G. (2015). Supporting all learners in school-wide computational thinking: A cross case analysis. *Computers & Education*, *82*, 263-279. doi:10.1016/j.compedu.2014.11.022

Johnson, D. W., & Johnson, R. T. (1999). Making cooperative learning work. *Theory into Practice*, *38*, 67-73. doi:10.1080/00405849909543834

Jona, K., Wilensky, U., Trouille, L., Horn, M., Orton, K., Weintrop, D., & Beheshti, E. (2014, January). *Embedding computational thinking in science, technology, engineering, and math (CT-STEM)*. Paper presented at the Future Directions in Computer Science Education Summit Meeting, Orlando, FL.

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. Cambridge, MA: MIT Press.

Karabenick, S. A., & Dembo, M. H. (2011). Understanding and facilitating self-regulated help seeking. *New Directions for Teaching and Learning*, *126*, 33-43. doi:10.1002/tl.442

Lambert, L., & Guiffre, H. (2009). Computer science outreach in an elementary school. *Journal of Computing Sciences in colleges*, *24*(3), 118-124.

Marino, M. T., Gotch, C. M., Israel, M., Vasquez, E., Basham, J. D., & Becht, K. (2014). UDL in the middle school science classroom: Can video games and alternative text heighten engagement and learning for students with learning disabilities? *Learning Disability Quarterly*, *37*, 87-99. doi:0731948713503963

McMaster, K. H., & Fuchs, D. (2002). Effects of cooperative learning on the academic achievement of students with learning disabilities: An update of Tateyama-Sniezek's review. *Learning Disabilities Research & Practice*, *17*, 107-117. doi:10.1111/1540-5826.00037

National Science Foundation. (2009). *A week to focus on computer science education* (Press Release 09-234). Retrieved from http://www.nsf.gov/news/news_summ.jsp?cntn_id=116059

Park, M., & Lash, T. (2014). *The collaborative discussion framework*. Champaign, IL: Unit 4 School District. Retrieved from http://ctrlshift.mste.illinois.edu/2015/04/03/collaborative-discussion-framework/

Rappolt-Schlichtmann, G., Daley, S. G., Lim, S., Lapinski, S., Robinson, K. H., & Johnson, M. (2013). Universal Design for Learning and elementary school science: Exploring the efficacy, use, and perceptions of a web-based science notebook. *Journal of Educational Psychology*, *105*, 1210-1225.

Rose, D. H., & Meyer, A. (2002). *Teaching every student in the digital age: Universal Design for Learning*. Alexandria, VA: ASCD.

Rose, M. A. (2004). Comparing productive online dialogue in two groups styles: Cooperative and collaborative. *American Journal of Distance Education*, *18*(2), 73-88.

Slavin, R. E. (1991). *Student team learning: A practical guide to cooperative learning*. Washington, DC: National Education Association. doi:10.1016/j.ijer.2004.06.011

Webb, N. M., Ing, M., Kersting, N., & Nemer, K. M. (2006). Help seeking in cooperative learning groups. In S. A. Karabenick & R. S. Newman (Eds.), *Help seeking in academic settings: Goals, groups, and contexts* (pp. 45-88). Mahwah, NJ: Lawrence Erlbaum.

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