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Augmented Reality for Teaching Science Vocabulary to Postsecondary Education Students With Intellectual Disabilities and Autism

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Abstract

The purpose of this study was to examine the use of an emerging technology called augmented reality to teach science vocabulary words to college students with intellectual disability and autism spectrum disorders. One student with autism and three students with an intellectual disability participated in a multiple probe across behaviors (i.e., acquisition of science vocabulary words) design. Data were collected on each student's ability to define and label three sets of science vocabulary words (i.e., bones, organs, and plant cells). The results indicate that all students acquired definition and labeling knowledge for the new science vocabulary terms. Results are discussed in the context of applying universal design principles with emerging technologies to create authentic opportunities for students with intellectual disabilities and autism spectrum disorders to learn science vocabulary. (Keywords: augmented reality, autism, intellectual disability, science vocabulary, universal design for learning)

A fundamental aspect of developing literacy skills is acquiring vocabulary. In a review of the key components of reading, Bell and McCallum (2008) noted that vocabulary proficiency is integrally related to reading comprehension. However, reading instruction for students with intellectual disability (ID) and autism spectrum disorders (ASD) often lacks a comprehensive instructional approach advocated for by the National Reading Panel (NRP, 2000), in the *Reading Next* report (Biancarosa & Snow, 2006), and by others (e.g., Browder, Wakeman et al., 2006; Erickson, Hanser, Hatch, & Sanders, 2009). Comprehensive approaches to reading instruction provide authentic exposure to the general curriculum (Erickson, Hanser, Hatch, & Sanders, 2009), but reading instruction for students with ID and ASD has focused primarily on teaching functional sight words often isolated from meaningful context (Clendon & Erickson, 2008). Sight-word reading instruction traditionally has emphasized vocabulary related to daily living, safety, money, and independence, rather than academic content such as science, mathematics, and social studies, for students with ID and ASD (Browder, Wakeman et al., 2006; Kliewer, 1998).

The research literature on teaching science content vocabulary words to students with ID and ASD is limited. Yet knowledge of science leads to better understanding and ability for individuals with disabilities to participate in the world. Further, individuals with ID and ASD in particular are underrepresented in employment in science and related fields (i.e., science, technology, engineering, and mathematics, or STEM; Newman et al., 2011). Browder, Spooner, et al. (2006) identified only 10 studies that examined the learning of science vocabulary words for students with ID. Although limited, the research provides evidence that students with ID and ASD can acquire academic content vocabulary related to science. Students with both ID and ASD have acquired science vocabulary words through the use of systematic prompting and feedback with repeated opportunities to master specific discrete skills (Browder, Ahlgrim-Delzell, Spooner, & Baker, 2009; Browder, Lee, & Mims, 2011).

Carnahan, Williamson, Hollingshead, and Israel (2012) advocated using technology to provide balanced or multifaceted reading supports to meet the needs of students with ID and ASD when they are learning academic content. Israel, Maynard, and Williamson (2013) detailed how to use technology to support STEM learning for students with disabilties. These strategies are similar to previous research on computer-assisted instruction (CAI) for students with disabilties. For example, Strangman and Dalton (2005) used CAI successfully to provide multiple means of representing content information to facilitate vocabulary acquisition, maintenance and generalization. As early as 1985, Reinking and Schreiner (1985) demonstrated the effectiveness of CAI by having multiple literacy supports for struggling readers. These supports included additional illustrations, examples, definitions, and passage summaries. Similarly, Lange, McPhillips, Mulhern, and Wylie (2006) examined CAI vocabulary acquisition and a software application designed for struggling readers. Following CAI, students' vocabulary word meaning knowledge and reading comprehension improved.

As technology evolves, CAI becomes more sophisticated. Bosseler and Massaro (2003) implemented a computer-animated tutor to teach vocabulary to elementary students with ASD. Results indicated that all students acquired the new vocabulary words and maintained 85% of the words 30 days after CAI. Examples of CAI for students with ID include the use of an interactive animated instructor to improve science vocabulary words for students (Moreno, Mayer, Spires, & Lester, 2001) and the application of computer-based story maps with pictures to support vocabulary development (Wade, Boon, & Spencer, 2010).

Travers, Higgins, Pierce, Boone, Miller, and Tandy (2011) compared CAI and teacher-led instruction regarding word recognition and vocabulary acquisition with a group of students with ASD. Results demonstrated that students with ASD were highly engaged and motivated to use the CAI intervention and that it was as effective as teacher-led instruction on the selected literacy related tasks. In Hall, Hughes, and Filbert's (2000) meta-analysis of CAI, they noted that effective CAI was followed by initial teacher instruction, which allowed students to engage independently in their own structured practice, reinforcement, systematic feedback, and self-assessments to monitor progress.

CAI for vocabulary instruction can now be delivered on mobile devices. Smith, Spooner, and Wood (2013) implemented an iPad-based intervention to teach science vocabulary to high school students with ASD. The iPad-based intervention, which incorporates several effective CAI features such as reinforcement and self-monitoring of progress, resulted in students acquiring the science vocabulary words. Jameson, Thompson, Manuele, Smith, Egan, and Moore (2012) indicated similar results and noted that using the mobile device to learn vocabulary words was highly motivating for students with ID, as well.

Augmented reality (AR) on mobile devices is a promising new technology for extending positive results found using CAI. AR combines a live view of the physical world and digital content including pictures text, audio, and video (Craig, 2013). This technology has the potential to provide a variety of instructional supports for students with ID and ASD to learn new academic skills, such as vocabulary words, in an authentic manner. There is limited research on using AR in education (Wu, Lee, Chang, & Liang, 2013). Most studies only inve students without disabilities and focus on STEM content. For example, Yoon, Elinich, Wang, Steinmeier, and Tucker (2012) used AR as a "knowledge building scaffold" in a science museum and found that "digital augmentations [AR] can help in conceptual development of science knowledge" (2012, p. 539).

Although most AR research does not involve students with disabilities, a few studies that included students with disabilities have been published. Richard, Billaudeau, Richard, and Gaudin (2007) used AR to teach matching skills to elementary students with ID. The students successfully manipulated three-dimensional objects to improve matching skills, demonstrated a very high level of engagement, and required little training to learn how to use AR. In addition, McMahon, Cihak, Gibbons, Fussell, and Mathison (2013) used a mobile app with AR features to teach college students with intellectual disabilities to identify food allergies. The researchers found that the students quickly learned how to use the AR application to scan food items and correctly identify potential food allergens. McMahon, Cihak, and Wright (2015) used an alternating treatment single-subject design to compare AR navigation on mobile devices to mobile maps and paper maps to navigate to unknown employment opportunities. Results demonstrated that of the three navigation options examined, AR navigation was most successful for increasing independent pedestrian navigation. Although there is limited research on AR for students with disabilities, AR has the potential to provide similar positive effects as CAI and mobile devices to teach students with ID and ASD vocabulary skills but in a more authentic or contextualized manner.

The technology of AR applies the principles of Universal Design for Learning (UDL) (McMahon & Walker, 2014). UDL refers to three principles for planning effective instruction by providing multiple means of representation, action and expression, and engagement (CAST, 2011; Rose & Meyer, 2002). There is broad support in research and policy for the incorporation of UDL principles to improve access to the curriculum content for students with ID and ASD (Jackson, 2005; Wehmeyer, 2006). Wehmeyer recommended that teachers could improve outcomes for students with ID and ASD with UDL principles "using both technology and pedagogical strategies, to make progress in ensuring access to the general curriculum" (p. 324). Rose and Meyer (2002) indicated that once curriculum materials are in a digital media format, multiple options for displaying content to meet individual student needs are readily available. Digital media allow information to be transformed into other media, such as video, audio, and pictures.

The purpose of this study is to examine the effects of AR vocabulary instruction for students with ID and ASD enrolled in a university-based postsecondary program for students with ID and/or ASD. The researchers selected science vocabulary terms for this study because of the limited research on science learning and students with ID and ASD and because the participants were enrolled in science- and health-related courses. Specific research questions include: (a) What are the effects of marker-based AR vocabulary instruction on the acquisition of science vocabulary words of college students with ID and ASD? (b) Do college students with ID and ASD find AR vocabulary instruction socially acceptable for learning new science vocabulary words?

Method

Participants

Three students with ID (i.e., Catherine, Brenda, and Billie) and one student with ASD (Miguel) attending a postsecondary education (PSE) program at a southeastern university participated in this multiple-probe, across-skills study (Gast & Ledford, 2010). One male and three female participants ranged in age from 19 to 25 years. All students were selected based on the following: (a) participation in a postsecondary education program for students with ID or ASD, (b) no physical disability that impeded the performance of the activity, and (c) consent to participate in the study. Students' Full Scale IQ (FSIQ) standard scores (SS) ranged from 45 to 85 ($M = 100$; $SD = 15$). All participants met eligibility guidelines for admission to the PSE program (e.g. diagnosed with an ID or ASD, had an individualized education program [IEP] and received special education services in K–12 education settings, and not able to enroll and/or not likely to be successful in a "regular" college or university program with accommodations). All students were familiar with using mobile devices for academic tasks and attended a course called Digital Literacy designed for students in the PSE program. In this PSE program students also took traditional university courses alongside university students without disabilities. One of the common challenges for the students with ID and ASD in these courses was learning new technical vocabulary terms associated with the content. Because many of the students were enrolled in health- and science-related university courses, science-related vocabulary terms were deemed an appropriate intervention topic for this study.

Two months before the start of this study all participants were administered selected tests from the Woodcock–Johnson III (WJ-III) Normative Update Tests of Cognitive Abilities and Tests of Achievement (Woodcock, Schrank, McGrew, &, Mather 2007). Additionally, they completed

Table 1. Participant Characteristics

Participant	Age	IQ	Woodcock–Johnson III (Standard Score)			Brigance Transition Inventory (Grade Equivalents)	
			Processing Speed	Basic Reading	Reading Comp.	Decoding	Vocab Comp.
Miguel	25	85[a]	81	100	82	8th	4th
Catherine	25	48[b]	50	41	55	4th	2nd
Billie	19	67[c]	68	73	71	6th	2nd
Brenda	20	61[d]	52	59	70	5th	3rd

[a]Wechsler Adult Intelligence Scale III (WAIS III).
[b]Wechsler Intelligence Scale for Children (WISC III).
[c]Stanford Binet Fifth Edition.
[d]Kaufman Brief Intelligence Test 2 (KBIT2).

selected tests from the Brigance Transition Skills Inventory (Brigance, 2010) and ratings scales were completed (Vineland Adaptive Scales–II, Sparrow [Sparrow, Cicchetti, & Balla, 2008] for the three students with ID, and for Miguel, the Gilliam Autism Rating Scale–Second Edition [Gilliam, 1995]). Students' characteristics are presented in Table 1. Although individuals with intellectual disability and autism generally demonstrate a heterogeneous range of characteristics, participants in this sample presented fairly homogeneous adaptive behavioral profiles. Adaptive behavior standard scores ranged from 56 to 73 using the Vineland Adaptive Behavior Scales–II. All participants demonstrated relatively adequate daily living and motor skills. In addition, all participants used verbal speech to communicate, although all also had social-communicative challenges. Specific social-communicative deficits were present in receptive and expressive skills, social–emotional reciprocity, back-and-forth conversation, and nonverbal communicative behaviors used for social interactions.

Miguel. Miguel, age 25, was previously diagnosed with ASD, based on the *Diagnostic and Statistical Manual of Mental Disorders–IV* (American Psychiatric Association, 2000); he achieved a Full Scale IQ (FSIQ) of 85 on the Wechsler Adult Intelligence Scale–III (WAIS-III; Wechsler, 1997) and a standard score (SS) of 73 ($M = 100$; $SD = 15$, consistent with the IQ measures) on the Vineland Adaptive Behavior Scales–II. In addition, Miguel's Autism Index (Gilliam) standard score was 94 with subscale standard scores of 13, 8, and 6 for stereotyped behaviors, communication, and social interaction, respectively. Core autistic characteristics included social–emotional reciprocity, back-and-forth conversation, and nonverbal communicative behaviors used for social interactions, as well as developing, maintaining, and understanding relationships, and insistence on sameness. Compared to age peers, Miguel's results from the WJ-III indicate limited processing speed (SS = 81), average basic reading skills (SS = 100), and limited reading comprehension (SS = 82). According to the Brigance Transition Skills Inventory, Miguel's reading decoding skills were at the eighth-grade level and his reading vocabulary comprehension skills were at the fourth-grade level.

Catherine. Catherine, age 25, was diagnosed with an ID; she achieved an FSIQ of 48 on the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003) and an adaptive behavior SS of 56 on the Vineland-II. Compared to age peers, results from the WJ-III indicate very limited processing speed (SS = 50), very low basic reading skills (SS = 41), and negligible reading comprehension proficiency (SS = 55). According to the Brigance Transition Skills Inventory, Catherine's reading decoding skills were at the fourth-grade level and her reading vocabulary comprehension skills were at the second-grade level.

Billie. Billie, age 19, was diagnosed with an ID; she achieved an FSIQ of 67 on the Stanford Binet Fifth Edition (Roid, 2003) and an adaptive behavior SS of 61 on the Vineland-II. Compared to age peers, her results from the WJ-III indicate limited processing speed (SS = 68), very limited basic reading skills (SS = 73), and very limited reading comprehension proficiency (SS = 71). According to the Brigance Transition Skills Inventory Billie's reading decoding skills were at the sixth-grade level and her reading vocabulary comprehension skills were at the second-grade level.

Brenda. Brenda, age 20, was diagnosed with an ID; she achieved an IQ of 61 on the Kaufman Brief Intelligence Test 2 (Kaufman & Kaufman, 2004) and an adaptive behavior SS of 65 on the Vineland-II. Compared to age peers, results from the WJ-III indicate very limited processing speed (SS = 52), very limited basic reading skills (SS = 59), and very limited reading comprehension proficiency (SS = 70). According to the Brigance Transition Skills Inventory, Brenda's reading decoding skills were at the fifth-grade level and her reading vocabulary comprehension skills were at the third-grade level.

Setting

Students attended a PSE for individuals with ID and/or autism located at a public university. Each participant was enrolled in traditional university courses for audit credit, recreational classes, student work internship, and program-specific core courses that included life skills, career development, and digital literacy. The core courses were designed specifically for college students with ID and/or autism enrolled in the PSE program. Each participant was included in traditional university courses, specially designed program activities, and job training activities for a minimum of 35 hours per week. All phases of this study occurred in a computer lab located on campus.

Materials

Assessment Materials

Vocabulary tests were developed to assess student knowledge of words on three science-related word lists: (a) human bones, (b) human organs, and (c) cell biology. Ten target vocabulary words were identified for each word list. Each vocabulary test consisted of 20 items that included two questions for each of the 10 vocabulary words on the list. One question was designed to measure the ability of the student to correctly match a description or definition of the vocabulary word and was referred to as the *definition question*. Definitions were adapted to simplify language from their original dictionary and/or textbook definitions. For example, in the definition of *femur*, "the proximal bone of the hind or lower limb that extends from the hip to the knee," the word *proximal* was revised to a description of where the bone is located on a person. The revised definition of femur was "The femur is the bone in the human thigh and the largest bone in the human body." The readability of these assessments ranged from 3.6 to 5.8 grade level on the Flesch–Kincaid readability assessments (Kincaid, Fishburne, Rogers, & Chissom, 1975). Definition questions were presented in a multiple-choice format in which the definition was provided and the student identified the correct vocabulary word from a field of four choices (one correct and three incorrect responses). The three incorrect responses were the other science vocabulary words from the target list being assessed. For example, during the bones word list phase all of the incorrect choices were bones. The second question type required the student to use the vocabulary word to label either a diagram or a figure with the correct vocabulary term. A word bank of targeted vocabulary words was included for the labeling section of the assessment. The pictures used were royalty-free, selected by the investigator, and modified if necessary (i.e., arrows pointing to a specific structure). Additionally, three assessment versions of each set of vocabulary words were created that varied the order of questions, possible answers, and labeling activities to reduce the likelihood of the students simply remembering correct responses. The nine assessments (three assessments per science list) were intended to measure understanding of the vocabulary terms by measuring both the ability to define and correctly label the selected science terms.

Intervention Materials

The mobile app used was Aurasma (Aurasma, 2014), which provides thousands of different AR content viewing experiences. This app also allows users to create their own AR experiences by matching trigger images/objects with user-created digital content that can include images and video. The Aurasma app uses live video from the mobile device's camera to identify an object, in this case a printed marker. When an individual views the printed marker using the Aurasma app, the marker is detected by the app. This then triggers the display of the programmed digital content in an AR view. AR content generally displays after a 2- to 3-second time delay. Aurasma is available on a variety of mobile device platforms and was implemented using iPads in this study.

One trigger image was created for each of the 30 science vocabulary terms in the study. Each trigger included a large print (72 point font) of the vocabulary term and a unique design comprised of different shapes in order to provide enough detail for the app to distinguish one trigger from another. The triggers were produced using Microsoft's PowerPoint and then printed as handouts, and they were stapled to create a 10- page book of "AR vocabulary cards" for each word list.

AR Content

The AR content displayed was a short (25 to 30 seconds) video created by the first author for each vocabulary term. The elements of each video included (a) a title slide of the vocabulary term, (b) a video with audio of the definition text being read aloud electronically, (c) the same free-to-use image used in labeling activity for the vocabulary term with the correct vocabulary term labeled, (d) video of a three-dimensional (3D) simulation showing the location of the vocabulary term, during which the audio from the definition being read aloud was repeated, and (e) repeat of the image of the vocabulary term as shown in the labeling part of the assessment with the audio of the definition being played a third time. The video clips either were created by the first author (definitions, bones, and human organs) or were used with permission (i.e., parts of the plant cell).

The videos were edited in the video editing program iMovie. The movie clips ranged from 25 to 30 seconds. Within the Aurasma app, each movie was programmed to play when the corresponding AR vocabulary card was detected (full instructions available from Aurasma, 2014). During the intervention phase, an iPad (third generation), equipped with the Aurasma app and this content, was provided to each participant. When the user moved the mobile device so the marker was visible in the camera view, the app detected the printed vocabulary card and displayed the corresponding AR vocabulary content. This AR experience provided the user a view of the vocabulary word card and overlaid digital information in the form of spoken text, pictures, and video designed to teach the meaning and location of the term. Figure 1A shows an example of the physical AR content being overlaid with vocabulary card AR as displayed on the mobile device.

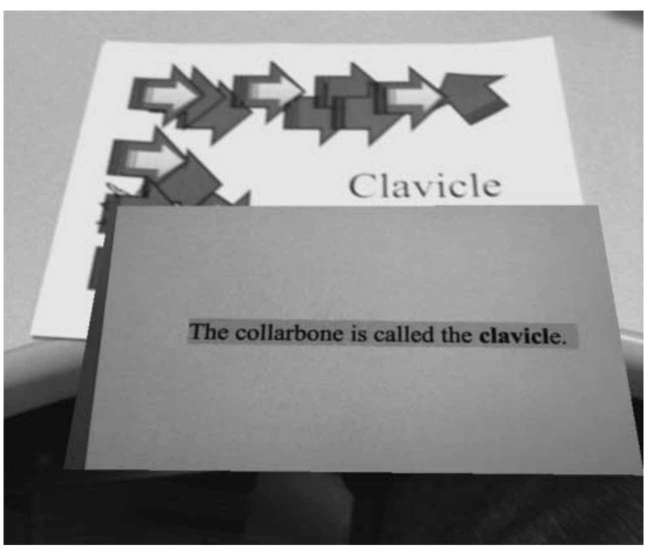

Figure 1. Screenshot from the mobile device displaying the AR content.

Variables and Data Collection

The independent variable of this study was the use of the AR app to learn new vocabulary words. AR instruction was systematically implemented across the three science vocabulary lists. The dependent variable was defined as the number of correct responses on each of the 20-item vocabulary assessments. The vocabulary assessments were read aloud to students individually. The number of correct responses per assessment was disaggregated to record the number of definition questions and the number of labeling questions scored correctly. Criteria for mastery for these assessments was set at 80% or greater for the definition items and 80% or greater for the labeling items, and students had to achieve 80% correct on both definition and labeling on three consecutive assessments to achieve mastery. Questions were ordered randomly across three different assessment versions targeting the same vocabulary words to reduce practice effects. If the participant correctly answered the question, then it was recorded as a correct response. If the participant did not answer the question correctly or did not respond, then it was recorded as an incorrect. At the start of each session, students were instructed: “Try your best.”

Procedures

Baseline. During baseline, each participant completed a minimum of three science vocabulary assessments (human anatomy bones, human anatomy organs, and parts of a plant cell). Although the test was read aloud, no additional feedback or prompts were provided. Students were instructed to answer the vocabulary questions on the assessment and were told they could skip questions they did not know the answers to. This process occurred for a minimum of three sessions until three sets of 10 unknown science terms were identified or until the data were considered stable. Stability was determined using the “80%–20%” criteria of the stability envelope (Gast, 2010). If 80% of the data points fell on or within 20% of the mean of baseline, the data were considered stable.

AR training. Students were trained in how to use the Aurasma application to scan vocabulary cards to trigger the AR content to display (picture, video narration of defined term). Students were informed that the designs on the cards were just to help the mobile app recognize what video to play but they should learn the printed word. Students were paired up and shown various denominations of U.S. currency that triggered an AR animation to appear. Model-Lead-Test procedures (Adams & Englemann, 1996) were implemented to train the students. First, the researchers modeled how to use the mobile device app to scan the trigger and view the content in the display. Then, students were led in practice using the device to scan the markers and to display the AR content. When students were observed operating the device incorrectly for 10 seconds to view the AR content (e.g., too close, hand over the camera), a system of least-to-most prompts was implemented to teach them the correct way to view the AR content. A 4-second delay occurred between each prompt level. The least-to-most prompt hierarchy consisted of the following levels: (a) verbal prompt (e.g., “[Name] do you see the marker?,” (b) gesture plus verbal explanation (e.g., pointing to the barcode and saying “[Name] scan the marker”), and (c) physical assistance plus verbal explanation (e.g., investigator and participant holding the iPad or iPhone together, guiding the device to scan the marker, and saying “[Name] scan the marker”). Lastly, students were tested until each was able to independently scan the vocabulary word and trigger the AR definition display for three consecutive trials. During the testing sessions, no additional prompts or assistance were provided. If a participant did not operate the mobile device app to scan the trigger and view the content in the display independently within 10 seconds, then the participant participated in an additional practice or lead session. Afterward, the participant was retested.

AR vocabulary intervention. At the start of each intervention session, students completed the vocabulary assessment. Afterward, they used the AR vocabulary intervention to practice learning the science vocabulary words. Students completed one session per day for three days per week. During this AR vocabulary intervention students used headphones to listen to the AR content individually. The AR intervention was first introduced to target the 10 vocabulary words on bones in the human anatomy. Students were given the vocabulary words, mobile device, and instructions to “try and beat the definition." That is, students tried to verbally define the word before the 2- to 3-second lag time until the AR content providing the definition was displayed. The purpose of this was to prime the student's attention for the AR content. After the students practiced the first vocabulary word, they proceeded to the second vocabulary word and so forth, until all 10 words were practiced. Students then practiced all 10 words two additional times for a total of three practice opportunities (approximately 12 to 15 minutes total). The students continued to practice defining the bones vocabulary words until they performed 80% on three consecutive assessments for both the definition and labeling items. After reaching criteria, students were then provided human organ vocabulary words and the AR intervention to "try and beat the definition." After reaching criteria, students were introduced to parts of the plant cell vocabulary words and AR intervention. An example of the AR vocabulary experience is shown in Figure 2, in which a student is using the mobile device to interact with the trigger for the word *phalanges* from the bones word list and viewing the AR content providing the definition, images, and three-dimensional video simulations.

Design

A multiple-probe across-behaviors/skills design (Gast & Ledford, 2010) was used to examine the relation between the AR-based vocabulary intervention and each participant's performance to correctly identify and label the meaning of the science vocabulary word. The AR intervention was introduced systematically across three science vocabulary word sets. First, AR was introduced to target words related to human anatomy bones. Then AR was introduced to target human anatomy organs words, and finally AR was introduced to teach plant cell biology words.

Interobserver and Procedural Reliability

Two research assistants (graduate students in Special Education) aided in the collection of interobserver reliability (IOR) and procedural reliability data. IOR data were collected during a minimum of 60% of baseline and intervention sessions for each participant. The two research assistants independently scored the number of vocabulary items defined and labeled correctly on the permanent product vocabulary tests. Interobserver agreement was calculated by dividing the number of agreements of participant responses by the number of agreements plus disagreements and multiplying by 100. Reliability was defined as 90% or greater; if the IOR had reached lower than 90%, then the

Figure 2. Student using the AR vocabulary intervention. Students interact with the AR experience by viewing the "trigger" or "marker" for the vocabulary term, in this example the human anatomy organs word list term *phalanges*, with the Aurasma app on a mobile device.

two observers would have met and reviewed all test items and responses. For all students' assessments, the percentage IOR was 100% ($M = 100\%$).

Procedural reliability data also were collected during a minimum of 60% baseline and intervention sessions for each participant. The investigator provided students with the necessary materials (i.e., iPad with the AR intervention, vocabulary word markers), a read-aloud vocabulary test, and a system of least prompts contingent on observing students operating the device incorrectly. The research assistant was provided a task analysis of the procedures to mark procedures completed as intended. The procedural agreement level was calculated by dividing the number of observed investigator's behaviors by the number of planned investigator's behaviors and multiplying by 100. Procedural reliability was defined as 90% or greater. If the procedural reliability was lower than 90%, the investigator and observer met to clarify all intervention procedures and to practice procedures. The overall mean treatment integrity was 96% (range = 92–100%). Miguel's treatment integrity ranged from 92% to 100% ($M = 94\%$), Billie's ranged from 92% to 100% ($M = 96\%$), Catherine's ranged from 93% to 100% ($M = 98\%$), and Brenda's ranged from 92% to 100% ($M = 96\%$).

Social Validity

The social validity of an intervention for the students is an important factor to measure for new interventions (Wolf, 1978). Following the conclusion of the intervention phase, each participant was asked to complete a 10-item, Likert-type survey to ascertain their opinions and acceptability of using the AR intervention to learn new vocabulary. The question items were read aloud individually to the students. Each survey item used Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*) with the addition of "frowning faces" (1 *strongly disagree*) to "smiling faces" as indicators on the scale to support comprehension of the question. The social validity survey also included two open-ended social validity questions in which the answers were scribed by the investigator.

Results

Baseline scores on the vocabulary assessments for the students indicated that the students had very low initial knowledge of the science vocabulary words across the three word lists. Correct responses during the baseline period generally appeared to be random chance because they were not consistently matched with a corresponding correct definition and labeling. Due to the nature of multiple-choice questions and word bank labeling, some baseline correct responses were expected. For example, simply by guessing on the multiple-choice definition questions the students had a 25% chance of selecting the correct response. For two students, when both the labeling and definition scores appeared to be ascending, additional baseline measures provided confirmation that the correct responses were by chance.

Miguel

Miguel learned the three sets of science vocabulary terms using the AR vocabulary instruction. Miguel's baseline average correct responses for the first word list, human bones, were 30% for the definition questions and 12.5% for the labeling questions. After using the AR vocabulary intervention his results immediately improved in the next session. During the AR intervention, on the first word list (bones), Miguel reached criteria of 80% correct definition and labeling responses for three consecutive sessions after his fourth session on the bones word list. Miguel's baseline average correct responses for the second word list (human organs) were 15% for the definition questions and 17.5% for the labeling questions. On the second word list, organs, he reached criteria of 80% correct definition and labeling response for three consecutive sessions after his fifth session using the AR vocabulary instruction. Miguel's baseline average correct responses for the third word list (parts of the plant cell) was 20% for the definition questions and 18% for the labeling questions. On the final word list, using the AR vocabulary experience he reached criteria of 80% correct definition and labeling responses for three consecutive sessions after his fifth session using the AR vocabulary instruction. Visual analysis shows that his definition score and labeling score improved at approximately the same rate. Across all conditions, Miguel immediately improved his science knowledge using the AR vocabulary as measured by the ability to find the correct definition and the ability to correctly label the term. Miguel's results are presented in Figure 3. In addition, Miguel's percentage for nonoverlapping data (Scruggs, Mastropieri, & Casto, 1987) average for definition questions on the three word lists was 85%, which indicates an effective intervention (Scruggs & Mastropieri, 2001).

Catherine

Catherine learned the three sets of science vocabulary terms using the AR vocabulary instruction. Catherine's baseline average of correct responses for the first word list human bones was 26.7% for the definition questions and 6.7% for the labeling questions. During the AR intervention, on the first word list (bones), Catherine reached criteria of 80% correct definition and labeling responses for

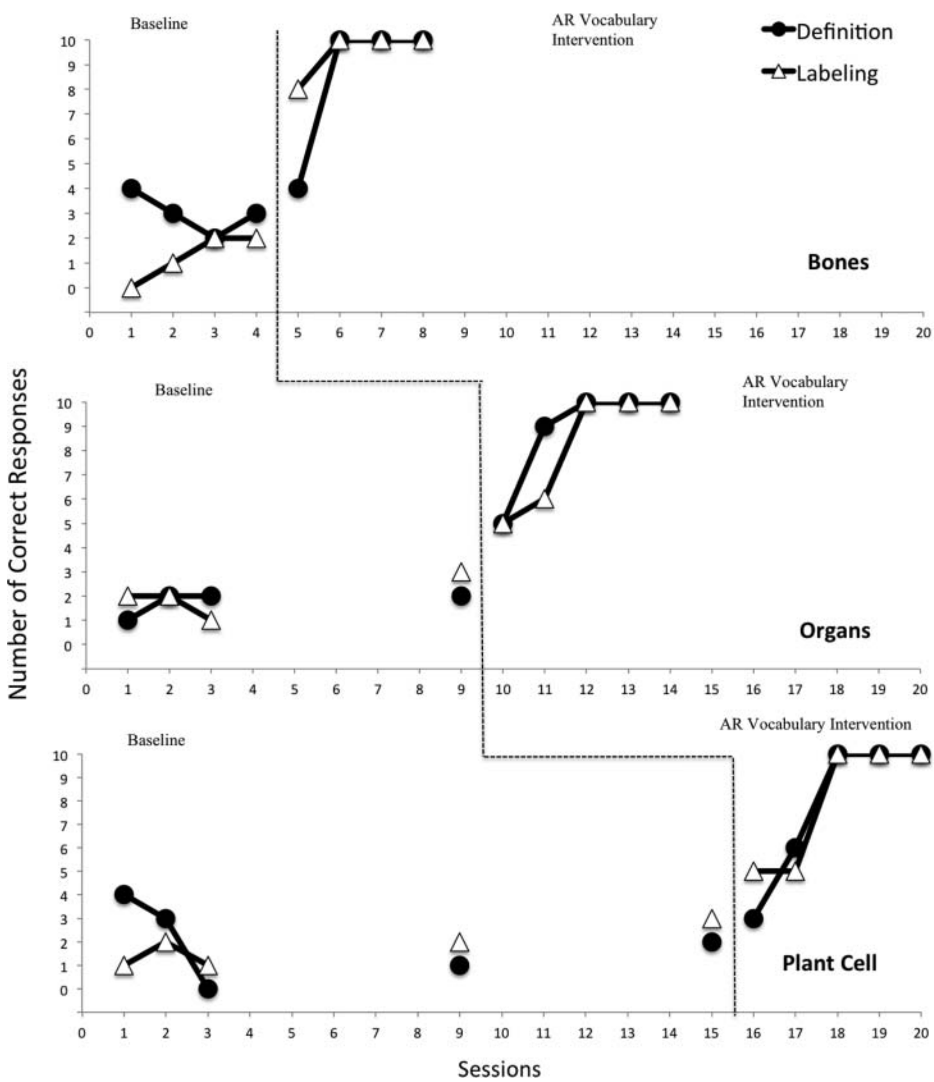

Figure 3. Miguel's results. Data show the amount of sessions required for Miguel to master each of the three science-related vocabulary word lists at 80% accuracy for three consecutive probes on both the definition and labeling assessments.

three consecutive sessions after her eighth session on the bones word list. Catherine's baseline average of correct responses for the second word list (human organs) was 7.5% for the definition questions and 20% for the labeling questions. On the second word list, organs, she reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her 11th session using the AR vocabulary instruction. Catherine's baseline average correct responses for the third word list (parts of the plant cell) was 10% for the definition questions and 18% for the labeling questions. On the final word list, using the AR vocabulary experience, she reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her 11th session using the AR vocabulary instruction. Visual analysis shows that her definition score and labeling score improved at approximately the same rate for the bones word list, but her ability to correctly label improved faster than her ability to correctly find the definition on the organs and parts of the plant cell. Across all conditions, Catherine immediately improved her science knowledge using the AR vocabulary as measured by the ability to find the correct definition and the ability to label correctly the term. Catherine's results are presented in Figure 4. In addition, Catherine's percentage of nonoverlapping data (Scruggs, Mastropieri, & Casto, 1987) average for definition questions on the three word lists was 89.8% and 89.77% for labeling questions, which indicates an effective intervention (Scruggs & Mastropieri, 2001).

Billie

Billie learned the three sets of science vocabulary terms using the AR vocabulary instruction. Billie's baseline average correct responses for the first word list human bones were 30% for the definition questions and 7.5% for the labeling questions. During the AR intervention, on the first word list (bones), Billie reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her seventh session on the bones word list. Billie's baseline average correct responses for the second word list (human organs) were 20% for the definition questions and 22.5% for the labeling questions. On the second word list, organs, she reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her eleventh session using the AR vocabulary instruction. Billie's baseline average correct responses for the third word list (parts of the plant cell) was 16% for the definition questions and 14% for the labeling questions. On the final word list, using the AR vocabulary experience she reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her seventh session using the AR vocabulary instruction. Visual analysis shows that her definition score and labeling score improved at approximately the same rate for all three sets of vocabulary. Across all conditions, Billie immediately improved her science knowledge using the AR vocabulary as measured by the ability to find the correct definition and the ability to correctly label the term. Billie's results are presented in Figure 5. Billie's percentage of nonoverlapping data (Scruggs, Mastropieri, & Casto, 1987) average for definition questions on the three word lists was 94.43% and 79.77% for labeling questions, which indicates a highly effective intervention (Scruggs & Mastropieri, 2001).

Brenda

Brenda learned the three sets of science vocabulary terms using the AR vocabulary instruction. Brenda's baseline average correct responses for the first word list human bones were 2.5 for the definition questions and 1.0 for the labeling questions. During the AR intervention, on the first word list (bones), Brenda reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her seventh session on the bones word list. Brenda's baseline average correct responses for the second word list (human organs) were 2.75 for the definition questions and 2.25 for the labeling questions. On the second word list, organs, she reached criteria of 80% correct definition and labeling responses for three consecutive sessions after her 11th session using the AR vocabulary instruction. Brenda's baseline average correct responses for the third word list (parts of the plant cell) was 1.8 for the definition questions and 1.4 for the labeling questions. On the final word list, using the AR vocabulary experience she reached criteria of 80% correct definition and

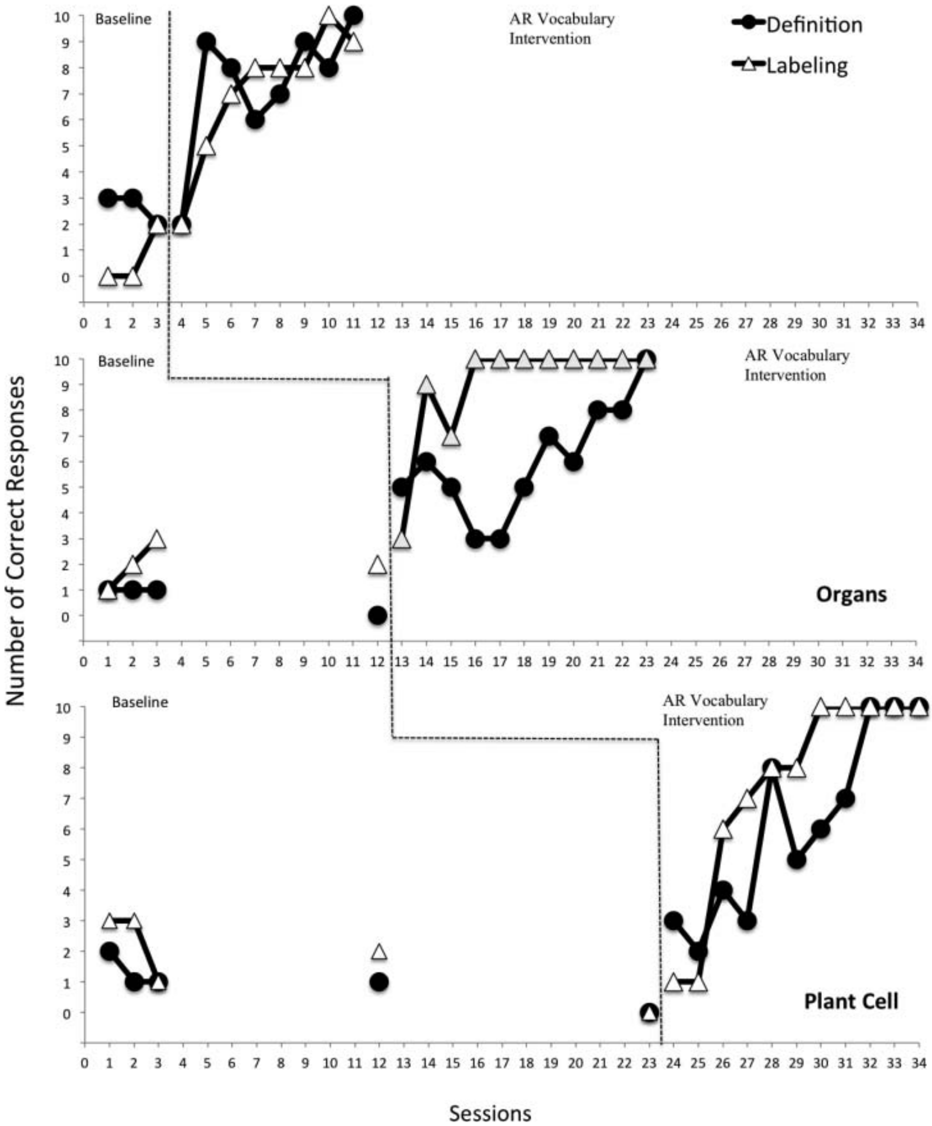

Figure 4. Catherine's AR vocabulary results. Data show the amount of sessions required to master each of the three science-related vocabulary word lists at 80% accuracy for three consecutive probes on both the definition and labeling score.

labeling responses for three consecutive sessions after her seventh session using the AR vocabulary instruction. Visual analysis shows that her definition score and labeling score improved at approximately the same rate for the all three sets of vocabulary terms. Across all conditions, Brenda immediately improved her science knowledge using the AR vocabulary as measured by the ability to find the correct definition and the ability to correctly label the term. Brenda's results are presented in Figure 6. In addition, Brenda's percentage of nonoverlapping data (Scruggs, Mastropieri, & Casto, 1987) average for definition questions on the three word lists was 100% and 91.9% for labeling questions, which indicates an highly effective intervention (Scruggs & Mastropieri, 2001).

Social Validity Results

After the conclusion of the intervention, students completed a social validity questionnaire regarding the use of AR to learn new vocabulary words. All students reported that using AR to learn

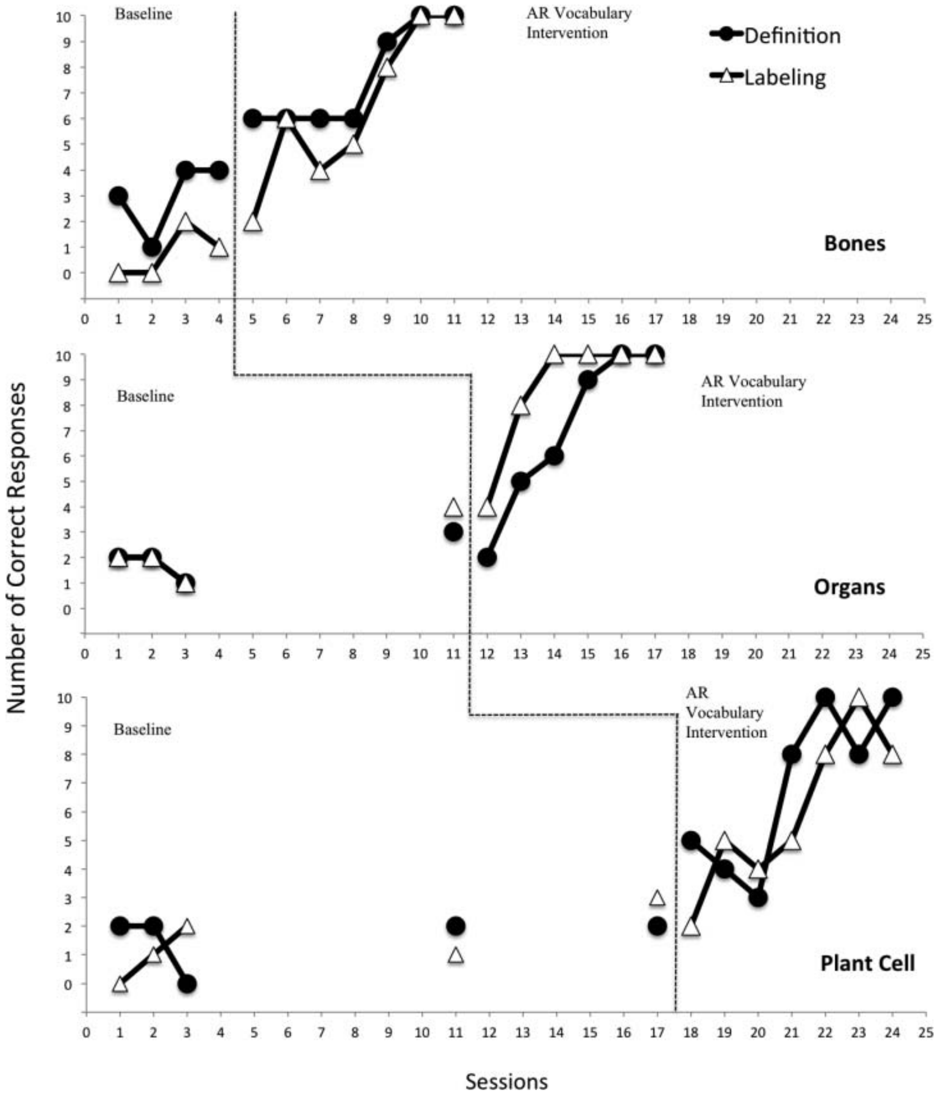

Figure 5. Billie's AR vocabulary results. Data show the amount of sessions required to master each of the three science-related vocabulary word lists at 80% accuracy for three consecutive probes on both the definition and labeling score.

vocabulary words was socially acceptable (see Table 2). Results also indicate all four students agreed or strongly agreed that (a) they liked seeing the vocabulary word and information about it at the same time using AR, (b) the AR tools helped to improve their science vocabulary, (c) AR vocabulary instruction was easy to use "on my own," (d) hearing the definitions was easier than reading them, and (e) they would like to use AR more to learn new things. The open-ended questions from the social validity survey also indicated that the students enjoyed using the AR experience to learn new science vocabulary.

Discussion

Key Findings

The purpose of this study was to examine the effects of a marker-based AR technology to teach science-related vocabulary words to college students with ID and ASD. Visual analysis procedures revealed that the AR instructional intervention was an effective strategy for improving science

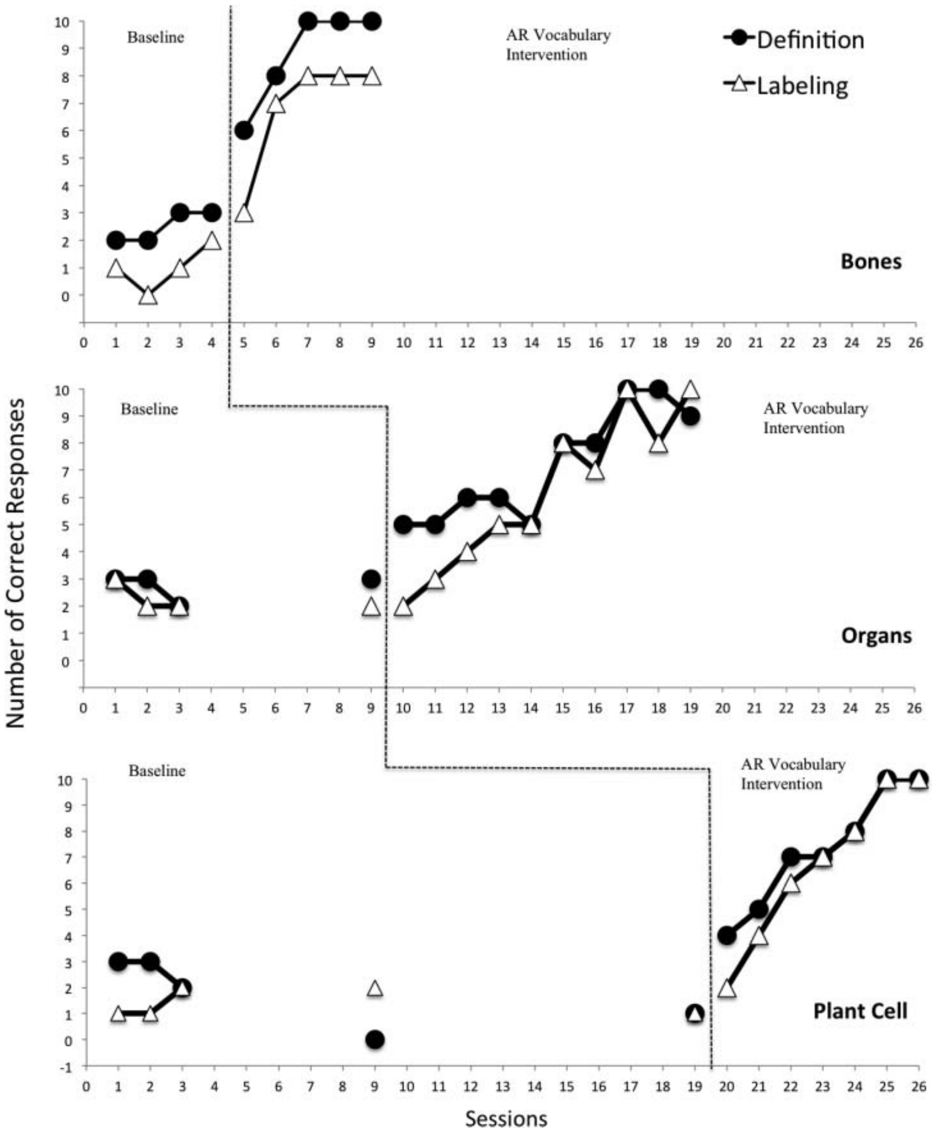

Figure 6. Brenda's AR vocabulary results. Data show the amount of sessions required to master each of the three science-related vocabulary word lists at 80% accuracy for three consecutive probes on both the definition and labeling score.

vocabulary acquisition for all the students. Effect size averages also indicated that the use of AR instructional intervention was an effective strategy for teaching science vocabulary. All students demonstrated improvement in their ability to define and label science terms upon each systematic application of the AR vocabulary instruction to a new set of vocabulary terms and science content. These findings support previous results that CAI is an effective tool for teaching vocabulary to students with ID and ASD (Bosseler & Massaro, 2003; Browder, Lee, & Mims, 2011; Wade, Boon, & Spencer, 2010). Additionally, current results support previous findings on using mobile devices to teach vocabulary to students with ID and ASD (Jameson et al., 2012; Smith, Spooner, & Wood, 2013).

This study extends the use of mobile learning technologies by incorporating AR technologies. Blending the physical world with digital information (Craig, 2013), the students readily obtained supplemental relevant information augmented over the context of their physical environment. The findings demonstrated how mobile devices and AR can create a mobile learning environment that moves with the learner (Ogato & Yano, 2004). By pairing science vocabulary words with

Table 2. Student Responses to Social Validity Questions

Social Validity Likert Questions	Likert Average
I liked using AR view the vocabulary words.	4.25
I liked seeing the vocabulary word and information about it at the same time using AR.	5
Learning how to use these tools helped me to improve my science vocabulary.	4.5
The AR vocabulary instruction was easy to use on my own.	5
I was able see both the word and definition videos in the augmented reality app.	4.5
I learned the definitions faster than the labeling.	3.5
I learned the labeling faster than the definitions.	3.5
Hearing the definitions was easier than reading them.	5
I learned the vocabulary words faster on my own using the AR vocabulary instruction than I would normally from a teacher.	4.5
I would like to use augmented reality more to learn new things.	5

Social Validity Open Ended Questions

Student	Q: What was it like to use the augmented reality vocabulary instruction?	Q: What did you like or not like about the augmented reality vocabulary instruction?
Catherine	"You point the camera at the paper and it explains it."	"This really is helping me learn my science."
Brenda	"The app made the words come to life and showed what they did."	"Seeing the video and the word together helped me to learn where they go [to be labeled]."
Miguel	"The definition just popped up from nowhere with pictures telling about the word."	"How it just popped up out of nowhere. How did it do that?"
Billie	"It helps you learn the science [vocabulary words]."	"I liked how the pictures float above the science word when you look at the science word. So you can learn about it."

supplemental digital information, students can access meaningful content information to facilitate vocabulary learning.

This study also extends the literature by teaching science vocabulary to students with ID and ASD. Carnahan, Williamson, Hollingshead, and Israel (2012) suggested that technology-integrated vocabulary instruction is a promising strategy for students with ID and ASD to gain contextual and meaningful vocabulary understanding. Science knowledge has an inherent value for all learners in order to help them understand and participate in the world around them. One critical area of participation for individuals with ID is employment. Young adults with ID and ASD are less likely to find employment opportunities in STEM-related fields compared to students with other disabilities and students without disabilities. According to the National Longitudinal Transition Study 2 (Newman, Wagner, Knokey, Marder, Nagle, Shaver, Wei, with Cameto, Contreras, Ferguson, Greene, & Schwarting, 2011), no students with ID reported working in computers, engineering, or science-related jobs, whereas 3.8% of students with other disabilities found employment in these fields. In order to increase employment opportunities for students with ID and ASD, additional opportunities to learn STEM content is needed. However, educators have had few strategies for teaching science content that links to state standards for students with ID and ASD (Browder, Trela et al., 2012). Courtade, Spooner, and Browder (2007) identified a limited number of studies that targeted science content for students with ID and ASD. This study adds to the research literature regarding teaching science content to students with ID and ASD, as well as a promising emerging technology-based instructional strategy.

In addition, student-specific outcomes emerged. One student (i.e., Catherine) acquired labeling more rapidly than defining the science terms, especially for the organs word list. Catherine had the lowest reading ability of the students, which may have contributed to her longer mastery time.

Although additional research is needed, students might have been distracted when terms included multiple similar organs. For example, several organs were involved in digestion functions, including pancreas, gallbladder, small intestine, and large intestine. In an effort to differentiate clearly among the organs, definitions tended to be five to eight words longer for the organs words than for the bones or plant cell words. The word length of specific definitions presents an area of potential future research.

Limitations of the Study

One of the limitations of this study, like all single-subject research, is the small sample size ($n = 4$), limiting external validity and generalizability. In addition, all of the participating students were highly motivated adults with disabilities attending a PSE program. All students also participated in a digital literacy course. Students had relatively strong basic computer skills. All students were familiar with the types of mobile devices used in this study. Although AR was new to the students, they often used computers and mobile devices for learning. The novelty of AR might have influenced the students' learning. Students who use AR on a more regular basis might have performed differently. Additionally, the assessment of science terms was conducted through read-aloud administration and therefore did not measure reading comprehension or application of the science terms beyond labeling. Additional and varied vocabulary assessments are needed to more fully assess the student's actual understanding of these science terms. Future studies should also compare AR vocabulary instruction to established vocabulary instruction strategies in terms of effectiveness, time involved, and cost benefits. Another limitation of this study was the lack of maintenance probes. Although students acquired the science vocabulary words relatively quickly, longer term effects of AR vocabulary instruction are needed. Time constraints prevented the collection of maintenance probes in this study, but maintenance should be addressed in future research.

In addition, the AR application required access to the Internet. This study could not have been implemented in a location without reliable Internet access. The content delivered through AR instructional media is likely to continue to require Internet access in order to retrieve and display information that is registered in the real world. Despite these limitations, the results of this study demonstrate the positive effects of use of AR instruction on mobile devices to teach science vocabulary. Researchers can expand on these findings through examinations of additional AR interventions designed to meet the academic and functional needs of people with disabilities.

Implications for Practice

The UDL guidelines provide a research-based instructional framework for examining how technologies, like the AR intervention used in this study, can be implemented to teach vocabulary and reading skills for students with disabilities. For example, the UDL principle of multiple means of representation was demonstrated by the AR content displaying both audio and video representations of the science vocabulary. As described by one student, "the definitions just pop up with videos right beside the word." The UDL principle of action and expression was demonstrated through the students' physical interaction with the device and the environment to learn or find the information. The UDL principle of multiple means of engagement was exhibited in the AR intervention's ability to optimize relevance and authenticity by making the unknown vocabulary word trigger a display of its meaning. This study presents AR as a new medium for blending digital content and physical world to support the needs of students with disabilities. While the participants of this study were students with disabilities, the UDL principles of this intervention likely make it applicable to a broad range of learners. Additionally, while this study occurred in a classroom setting, the AR intervention used can work anywhere with Internet access and a mobile phone or tablet. AR is a viable vocabulary instruction tool for students and is capable of delivering content inside and outside of the classroom.

Recommendations for Future Research

Future research is needed to replicate this study's methods and procedures. Future research should include other disability populations and age groups. Similarly, AR instruction requires investigation of other content areas such as reading, mathematics, and social studies, as well as functional life skill and adaptive skill domains. In addition, the instructional AR component requires further examination in order to explore which AR features lead to positive outcomes without distracting the learner. These AR instructional components include the overall length of AR content, video and/or static pictures, complexity of definitions provided (e.g., word length), and use of audio information. A series of comparative intervention studies could be used to examine these instructional AR components systematically. Lastly, AR instruction to teach vocabulary should be compared to more established vocabulary instructional procedures, such as time delay, read-alouds, and picture-to-text matching.

Summary

The AR vocabulary intervention produced a positive impact on student mastery of the science vocabulary terms through its combination of real-world and digital content. Using the AR vocabulary intervention was a positive experience for all the students according to the social validity data. The findings of the study support further examination of AR as a medium for science and vocabulary instruction for students with ID and ASD.

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