



An Outdoor Project-Based Learning Program: Strategic Support and the Roles of Students with Visual Impairments Interested in STEM

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Abstract

A qualitative study was conducted to understand how middle and high school students with visual impairments (VI) engage in Science, Technology, Engineering and Mathematics (STEM). The Readiness Academy, a Project-Based Learning (PBL) intervention, was designed to provide a week-long, immersive, outdoor, and inquiry-based science education program to students with VI. We analyzed 187 photographs, camp associate intern notes, and researcher memos first using emotion coding, followed by process coding to structure initial codes and categories into seven research activities. We used axial coding as a secondary cycle coding method to determine four consistent themes across all research activities: apprenticeship, collaboration, accessibility, and independence. We found that the inclusion of purposeful accessibility, such as assistive technology and multisensory experiences, supported how students with VI engaged in STEM education. The findings reflect how students dynamically fulfilled roles as apprentices, collaborative members, and independent researchers within the program's context of PBL and outdoor science education.

Keywords Project-based learning · Middle and high school science · Inclusive education · Accessibility · Visual impairment · Blind

Literature Review

Science, technology, engineering, and mathematics (STEM) have traditionally been considered as difficult school subject areas, partly due to the complex nature of the content. However, such difficulties are greatly amplified when visual access and inclusive environments for STEM contents are not granted for a student with visual impairments (VI). For example, maps, charts, and graphs are essential components of conveying mathematical concepts, but inadequate attention has been given in making these visual media accessible (Jobling & Moni, 2004; Moon, Todd, Morton, & Ivey, 2012). Science teachers are not aware of the effective instructional strategies needed to teach science to students with VI (DeSimone & Parmar, 2006; Gagnon & Maccin, 2007; Kurth & Foley, 2014). In addition, researchers have found that general education teachers are not prepared to teach students with VI, while teachers of students with visual impairments

(TVIs) are also unprepared to teach STEM content (Kahn & Lewis, 2014; Norman, Caseu, & Stefanich, 1998).

It is difficult to ascertain an exact number of students with VI in the United States (U.S.). In the 40th Annual Report to Congress on the Implementation of the Individuals with Disabilities Education Act (OSERS, 2018), a total of 27,234 students (age 3–21) were served under the primary disability category of VI in the U.S. in 2016. The American Printing House for the Blind (APH, 2017) reported that 63,357 students were registered in its federal quota program as receiving educational services. The United States Department of Education, National Center for Education Statistics (2019) reported that 27,000 students between the ages of 3 and 21 years old were served under the Individuals with Disabilities Education Act in the 2017–2018 academic school year.

The literature lacks studies that discuss comprehensive interventions to increase STEM skills and awareness for students with VI. Basham and Marino (2013) propose that to be effective, STEM educational opportunities for students must use a curriculum that incorporates engineering design whereby teachers create engaging learning environments and encourage students to solve real-life problems. The Next Generation Science Standards (NGSS) are a

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multidimensional approach to science education, placing significant values on practical application, the authenticity of acquired knowledge, and connection to students' surroundings (Larmer, 2014). Project-based learning (PBL) has been defined as “a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic (real-life) questions and carefully designed products and tasks” (Buck Institute for Education, 2003, p. 4). Project-based learning is an instructional strategy which places learners' perspectives into action (Kubiatko & Vaculova, 2011). Instead of using a set of lesson plans or skills, this active approach organizes the interests and motivations of learners through discussion, mentoring, advising, and creating final products or artifacts (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Tal, Krajcik, & Blumenfeld, 2006). The participation of students with VI in STEM classes may not be readily available as many STEM teachers tend to be concerned about safety and liability in their laboratories (Supalo, 2012). Therefore, it is essential that access and adaptations of STEM content be provided to students with VI, while TVIs who understand the unique needs will be available to facilitate seamless integration of diverse learning experiences. Without accommodations, students with visual impairments experience difficulty using visually presented materials and understanding science concepts (Farrand, Wild, & Hilson, 2016). For this study, we used the definition of PBL suggested by English and Kitsantas (2013), where students develop their own initiative through setting up hypotheses, collecting data, analyzing data, developing conclusions, and communicating their findings. An inquiry cycle and framework suggested by (Pedaste, et al., 2015) was also used to operationalize an overall sequence of the project, while PBL strategies were used to guide student progress. We consider that this approach will compensate for the lack of access to the curriculum in a science lab, as well as help in developing overall interests and motivation of students with VI towards STEM contents through engaging learning experiences.

The Readiness Academy (Academy), an embedded component of a larger project funded by the National Science Foundation (DRL #1657201), is aimed at developing an outdoor program for students with VI while attempting to address the issue of accessibility and the lack of number of STEM teachers who understand the unique needs of students with VI, by incorporating a unique environment where scientists and candidates of TVIs work together. Most students with VI attend public schools and are served by itinerant TVIs, teachers who travel from school to school to provide educational services to individual students (Ajuwon & Oyinlade, 2008; Cameto & Nagle, 2007; Griffin-Shirley, Koenig, Layton & Davidson, 2004; Spungin & Ferrell, 2007). Many students with VI who attend general education classes with

sighted students also spend time each week in direct service with a TVI. With the support of a TVI, students with VI obtain assistance to access science labs, learn to use science testing equipment, or perform necessary observations. It is essential that STEM teachers, content experts, communicate regularly with the students with VI and their TVIs.

The Academy is designed to provide immersive, inquiry-based science programs to Academy participants, while TVIs and science educators collaboratively work side by side. The program contained various core science projects such as sky island ecology, earth science, chemistry, hydrology, and astronomy, which were developed to meet Arizona State Science Standards. One of the unique dimensions of the program was the integration of topics across scientific disciplines, while simultaneously implementing PBL as its primary framework. Within the program, University of Arizona (UA) graduate students majoring in science served as science instructors or Sky School Scientists (SKS). Interning candidates of the UA TVI program maintained ongoing communication before and during program implementation and provided input to the SKS throughout the Academy.

The development and administration of activities within an outdoor environment were unique characteristics of the Academy and allowed students to engage in science education beyond typical descriptive and verbal presentations. Students with VI were encouraged to utilize multisensory aspects of science learning through the senses of hearing, taste, touch, and smell. Students with VI designed and carried out their own scientific inquiry projects, learned to operate various science instruments, and had opportunities to maintain post-trip communication with the SKS.

Research Questions

This study was developed to answer the following two research questions: (1) What are the roles of students with VI in a STEM education program and (2) What are effective strategies in implementing outdoor STEM education activities for students with VI?

Method

An explorative, qualitative study was conducted with nine middle school and high school students with VI interested in pursuing STEM careers, eight SKS, and four Camp Associate Interns (Interns). In the Academy, students underwent problem-solving processes, as the SKS made connections to their personal STEM professions, while simultaneously supporting and integrating meaningful field experiences (Capraro & Slough, 2013). Interns supported the students and SKS in recommending on-site accommodations, as well as practical learning and teaching strategies. In this study,

authors analyzed Academy activity photographs captured by the authors and journals written by the interns according to the principles of substantive grounded theory (Glaser & Strauss, 1967). This study was reviewed and approved by the Human Subject Committee of the University of Arizona.

Settings and Materials

The academy was conducted in a setting available to all school-aged students meant to provide additional learning opportunities for students during the regular academic year and summer. Additional information can be found on <http://poem.coe.arizona.edu>. The Academy was a

5-day outdoor science program, scheduled as a week-long summer experience for students with VI. Only students with VI took part in the Academy. Students arrived at the outdoor educational facilities on Sunday and departed on Friday afternoon. Upon arrival, students toured the science facilities and spent the evening settling into the dorms. Inviting inquiry and PBL activities approximately ranged from 8 a.m. to 7 p.m., Monday through Thursday. Students completed the Academy and departed the outdoor educational facility on Friday morning. See Academy Daily Agenda in Table 1. See Tables 2 and 3 for the types of assistive technology used by students with VI with descriptions of materials used by the instructors and students.

Table 1 Readiness academy daily agenda

Day	Readiness Academy Topics and Researchers
Day 1 morning	Inviting Inquiry: Hive Insects and Exploration Lead Researcher(s): SKS Entomologist Inviting Inquiry: Insect Identification and Taxonomy Lead Researcher(s): SKS Entomologist Inviting Inquiry: Soil Formation and Identification Lead Researcher(s): SKS Environmentalist
Day 1 afternoon	Inviting Inquiry: Chemistry and Water Quality Lead Researcher(s): SKS Chemist Inviting Inquiry: Lecture and Lab with LabQuest Lead Researcher(s): Invited SKS Chemist
Day 1 evening	Inviting Inquiry: Sonification and Analyzing Telescope Data Lead Researcher(s): All SKS instructors
Day 2 morning	Inviting Inquiry: Bonding Chemically Through Role Play Lead Researcher(s): SKS Chemist Generating Hypotheses: Group Hikes and Twenty Questions Lead Researcher(s): All SKS instructors
Day 2 afternoon	Generating Hypotheses: Group Project Proposal Sharing and Peer Feedback Lead Researcher(s): Students
Day 2 evening	Inviting Inquiry: Exploring the Solar System Lead Researcher(s): Invited SKS Astronomer
Day 3 morning	Inviting Inquiry: Slopes and Basins Lead Researcher(s): SKS Environmentalist Data Collection: Data Collection and Sampling Lead Researcher(s): Students
Day 3 afternoon	Data Collection: Data Collection and Sampling Lead Researcher(s): Students
Day 3 evening	Data Analysis: Data Analysis Preparation Lead Researcher(s): Students
Day 4 morning	Inviting Inquiry: How Not to do an Effective Presentation Lead Researcher(s): All SKS instructors Data Analysis: Data Analysis and Presentation Preparation Lead Researcher(s): Students
Day 4 afternoon	Data Analysis: Data Analysis and Presentation Preparation Lead Researcher(s): Students Inviting Inquiry: Organic Chemistry Presentation and Experiments Lead Researcher(s): Invited Organic Chemist
Day 4 evening	Results and Final Presentations: Group Presentations and Peer Feedback Lead Researcher(s): Students

Table 2 Inviting inquiry presentations: assistive technology, models and real objects

Topic areas	Assistive technology, models and real objects
Etymology	Assistive Technology: none Models: insects Real Objects: bees, butterfly, ladybugs, pollen, moth, beetle, hive, trap
Environmental Science	Assistive Technology: none Models: soil basin, water Real Objects: soil and water
Chemistry	Assistive Technology: Total Dissolved Solids kits Models: none Real Objects: water
Astronomy	Assistive Technology: telescope, LabQuest, laptop, JAWS, ZoomText, Excel, JAVA Models: craters, sun, planets Real Objects: balls, magnets, asteroids, meteors/meteorites, rocks from space, comets

Table 3 Student-led group projects: assistive technology and materials

Group project activities	Assistive technology and materials
Hypothesis	Assistive Technology: laptop, JAWS, Word Materials: white board, pen, pencil, trees
Project proposal	Assistive Technology: Perkins Braille Writer Materials: Students' notes, lichen, bark
Data collection	Assistive Technology: laptop, JAWS, ZoomText, Excel Materials: knife, plastic bag, tape, trees, bark, lichen, tag, staples, paper labels
Data analysis	Assistive Technology: laptop, JAWS, ZoomText, Excel, scale, microwave oven Materials: index card, stapler, label, tree, lichen, bark, NPK Test, soil
Results	Assistive Technology: Perkins Braille Writer, Laptop, JAWS, ZoomText, PowerPoint Materials: tactile graphs, students' notes
Presentation	Assistive Technology: Perkins Braille Writer, laptop, JAWS, ZoomText, PowerPoint Materials: tactile graphs, students' notes, labeled lichen, labeled bark

Note: We excluded Inviting Inquiry from this list as the assistive technology and materials are listed on Table 2

Participants

Students. Nine students were recruited using the following inclusion criteria: (a) be in grades 7–11, (b) have an Individualized Education Plan (IEP), (c) be independent in their self-care, (d) have academic skills within 1 year of grade level for reading and writing, and within two grade levels for mathematics, and (e) have an interest in STEM and/or in learning about STEM and potential STEM-related careers. Participant criteria for student recruitment included screening questions about their interest in STEM. Student academic achievement was self-reported. We have accepted students who were one to two grades lower in grade level in math. This was to compensate for gaps which may result from a lack of access to STEM contents (Rule, Stefanich, Boody, & Peiffer, 2011; Supalo, Isaacson, & Lombardi, 2014). Of the nine students participating in the Academy, five female and four male students were recruited. Two students were 16 years old, two students were 17 years old, one 12-year-old student, two 15-year-old students, and two

14-year-old students. All students had VI. Students' visual conditions included Leber's congenital amaurosis, macular degeneration, X-linked juvenile retinoschisis, amblyopia, strabismus, optic nerve degeneration, and cone-rod dystrophy. No students self-reported having additional disabilities. All students attended public schools and received services from teachers of students with VI an average of 2 hours per week. Four students self-identified as Hispanic, four as White, and one as White/American Indian. To complete their group projects, students were grouped by grade level, with five students between grades 6 and 9 in one group, and four students between grades 10 and 12 in a second group.

Sky School Scientists. The Sky School Scientists were graduate science education students employed as instructors throughout the Academy. Areas of expertise among the SKS included entomology and insect science, ecology and evolutionary biology, environmental science, and chemistry. In addition to the SKS, two chemists and two astronomers were also invited to provide guest lectures and facilitate activities during the Academy.

Camp Associate Interns (Intern). Four Interns were available to support the students and SKS throughout the Academy. All four interns were graduate students of a collegiate teacher education program for TVIs. The four interns were compensated for their work throughout the Academy and earned internship hours toward certification.

Data Collection

Qualitative data were used to understand the degree and context of participation and engagement in PBL outdoor science education experiences among students with VI. The authors captured student interactions via photographs for visual and qualitative analysis (Taylor, Bogdan, & DeVault, 2015). All interns completed handwritten daily journals in which they were asked to briefly describe each activity and how each student completed each activity. Authors also collected field notes and memos focused on how the students engaged in PBL during the Academy through recording hands-on activities, accommodations and questions raised by the students.

Data Analysis

In this study, authors captured student activities and reactions throughout the Academy and asked interns to collect field notes regarding how students participated and engaged in STEM activities. Post fieldwork, the first and the second authors reviewed the data and developed codebooks through three iterations of coding cycles. The authors applied emotion coding, process coding, and axial coding to photographic and journal data to determine four overarching themes across seven activities.

Within the first cycle coding, the authors used emotion coding as an effective method and process coding as an elemental method (Saldaña, 2016). Emotion coding was first applied to the photographic data to explore the students' emotional reactions and interactions within the context of PBL outdoor science education. The authors reviewed 187 photographs and retained 155 for photographic analysis. Thirty-two photographs were eliminated from the analyses because they either had no students in the photograph, the emotions of the students were indiscernible, or students were asked to smile within group photographs. Each author then independently described the student's affective experiences in each photograph using one or more singular adjectives. The authors used investigator triangulation to determine the consistency and convergence of student affective experiential descriptions (Brantlinger, Jimenez, Klingner, Pugach, & Richardson, 2005). Ultimately, the authors agreed on 25 photographic descriptions to analyze the photographs together via constant comparison until there was 100% agreement.

The authors then used story lining (Saldaña, 2016) as an analytic strategy to further explore the emotional stories within seven activities specific to the Academy. The authors sorted camp associate journals into seven activities: *inviting inquiry*, *hypothesis*, *project proposal*, *data collection*, *data analysis*, *results*, and *presentation*. The authors then compared photographic emotion codes to camp associate intern descriptions and applied process coding to both the photographic and camp associate intern journal data using qualitative data analysis software, InVivo (version 12). Process coding or 'action coding' was used to document observable activity and general conceptual actions to complement the photographic storyline (Saldaña, 2016, p. 111). Lastly, the authors applied axial coding as a second cycle coding method to categorically organize the authors' application of emotion and process coded data (Saldaña, 2016). The authors worked collaboratively to use axial coding to reconstruct the triangulated photographic and journal data and compared activity storylines to axial coded subcomponent categories: apprenticeship, collaboration, accessibility, and independence.

First, we used the term, apprenticeship as a mode of learning, where experts attempted to mediate learners' engagement and experiential processes (Billett, 2016). Process codes such as guiding, requesting, exploring, etc. captured this apprenticeship facet of PBL. Apprenticeship gerunds highlighted observable student behaviors and reactions to activities facilitated by the SKS that were meant to motivate and gain student interests while pursuing real-life questions (Buck Institute for Education, 2003).

Second, collaboration referred to processes of negotiation where dynamic and interdisciplinary modes of learning activities were offered and where testing ideas, modifying representations, and identifying proper communication skills were promoted (Bednar, Cunningham, Duffy & Perry, 1991). Process codes such as teaming, grouping, and pushing through variables, etc. captured this collaboration facet. Collaboration gerunds highlighted observable student behaviors and reactions within the process of scientific inquiry and how students searched for solutions to real-life questions within small groups (Buck Institute for Education, 2003).

Third, accessibility was operationalized through timely provisions of materials and technology options (Butler, Holloway, Marriott, & Goncu, 2017). Process codes such as integrating visual, tactile and auditory materials, deciding, taking, and utilizing tools, etc. captured this accessibility facet, which highlighted how students used tools across multiple environments and interactions to create and design products (Blumenfeld et al., 1991; Tal, Krajcik, & Blumenfeld, 2006).

Fourth, student activities and behaviors were coded as independence when students initiated, directed, and regulated their own methods of investigations, selecting

strategies and skills, and evaluating outcomes (Livingston, 2012). Process codes such as taking charge, putting the narrative together, leading a project, etc. captured this independence facet, which highlighted how students actively engaged in acquiring knowledge and skills through personal agency to organize their interests and motivations (Buck Institute for Education, 2003).

Results

Authors used qualitative methods to identify seven Academy activities: *inviting inquiry*, *hypothesis*, *project proposal*, *data collection*, *data analysis*, *results*, and *presentation*. The authors have posed a question for each of the seven Academy activities and aligned responses within the themes of apprenticeship, collaboration, accessibility, and independence.

How to Introduce Students to Building Interest in Science?

On the first day of the Academy, the SKS entomologist instructor gave a presentation to students about insect identification, orders of insects, insect life cycles, and introduced bug trapping tool usage. The entomologist brought various sample materials. After this activity, a SKS shared a soil formation and identification presentation and integrated hands-on activities into the presentation. Students were asked to determine sandy loams by having students make mudballs, toss the mudballs, and make soil ribbons. Later, the SKS chemist taught the students about water quality exploration. Students were guided to touch the water to measure what is in it and to assess its qualities. In the evening of the first day, students explored a telescope tactually and gathered information about a local telescope and its functions with an invited scientist. An invited SKS taught students how the telescope works throughout the night to collect and record auditory and visual information. On the second day, an invited SKS astronomer shared a solar system scale presentation. The astronomer prepared and brought tactile materials, real objects, and models for students to tactually explore objects found in the solar system.

Apprenticeship. In inviting inquiry lessons, the SKS integrated opportunities for apprenticeship through directly addressing questions and providing answers to questions posed by students, as well as modeling how to share accessible presentations. Students asked technical questions regarding the navigation and use of comma separated value (CSV) files, as well as, language and computing platforms (JAVA). Students also asked career-related questions, such as workplace accessibility and challenges experienced by the SKS. For example, one student asked how a SKS experienced working conditions within a facility emulating Earth's environment and about the

representation of higher education STEM majors within the Earth emulation facility.

Collaboration. The Sky School Scientists integrated opportunities for collaboration through helping and sharing with peers, as well as reporting experimental reactions. The Sky School Scientists, who invited inquiry and collaboration, actively integrated activities which required students to use materials and work with one or more students. For example, one activity required one student in each small group to hold a bag of water, while other students manipulated the additional devices to observe and record observable reactions.

Accessibility. The Sky School Scientists shared materials with auditory, tactile, and visual properties and used several assistive technology devices in inviting inquiry lessons. For example, the SKS integrated hands on opportunities into their presentation by sharing insects, models of bugs and planets, pollen, trap, soil, meteorites, and magnets. Students also held, felt, and compared hands on materials such as beach balls to demonstrate relative sizes of planets. Rocks from space were used to simulate multi-sensory experiences. Interns described students as interested, noting students used their functional vision and/or hands to explore the materials, while also appearing to be careful and serious during the activities. Students also used assistive technology devices within the inviting inquiry lessons. For example, students used testing total dissolved solids (TDS) kits to measure the hardness of water distillation and used ions to determine the potential of hydrogen in water samples. Interns noted the following: "Students had general knowledge and information on how to use assistive technology (JAWS, a screen reading software program and ZoomText, a screen magnification software program) to access the experiment. Students were serious and independent." See Table 2 for a list of materials and assistive technology devices integrated into the Inviting Inquiry Presentations.

Independence. In inviting inquiry lessons, the SKS integrated opportunities for independence by giving students opportunities to ask questions, share ideas, and use materials. For one activity, students directly tested water, solids, and particles by asking for additional directions. In this activity, students were described as focused, determined, and careful. Also, during the presentations, students were curious and asked questions to the presenting SKS. For independence, interns noted the following statements: "Students were confident and independent in asking questions, even if they were unsure of the results of the activity. Students actively asked and answered challenge questions."

How Did The Experts Support the Process of Identifying and Refining a Research Question?

Students observed and explored the environment to generate a hypothesis for their group projects on the second day of the

Academy. Students were divided into two groups, generated their hypotheses, and encouraged by the SKS to develop several possible research questions within their groups. The Sky School Scientists provided continuous feedback within each group. The categories of collaboration, independence, accessibility, and apprenticeship described how students generated hypotheses for their group research projects.

Apprenticeship. Two groups worked separately. The Sky School Scientists guided each group in the process of generating, producing, and improving their research questions. While generating hypotheses, students asked about environmental features such as trees and lichen. In the group, the SKS structured team building exercises and practiced making hypotheses through hands on activities such as using a rope to create one large shape with team members holding the outside of the shape, followed by a game of 20 questions after lunch. In the 20-question activity, students were asked to share questions they thought of during lunch and state them after several rounds of having students share out loud. In another group, students hiked to a cliff and sat at the edge of the trail and actively practiced reflecting on questions they had about their environment and how they can address their questions.

Accessibility. In both groups, the SKS integrated tactile and auditory materials and verbally described the environment and allowed for environmental features such as finding young lizards along the trail route, using tools to explore the density of rocks, and exploring bird nests found in a nearby tree. Students also learned about the physical characteristics of lichen and determined the age of trees through touch. The students were guided by the SKS in each group to narrow down their research questions into one, easily testable question.

Collaboration. In both groups, the SKS initially played an important role in creating opportunities for students to discuss ideas with their group members. In both groups, students discussed and generated several possible research questions within their groups. For example, in one group, the instructors gave all the students opportunities to share their ideas with a group and modeled how to give feedback. Students not only collaborated with their group members, but also with the SKS to better address their research questions. For example, while students asked questions about lichen, the SKS wrote down student questions on a whiteboard to help the students formulate hypotheses. After brainstorming as a group, students collectively determined their group research questions and each group generated testable hypotheses.

Independence. Students had opportunities to collect information based on their interests to generate hypotheses. For example, students explored and observed trees and lichen independently. Interns noted the following statements: “students were teachers and teachers were students”.

Students helped the SKS understand how to describe environmental features and how to adapt inaccessible materials. For example, students asked the SKS to describe trees verbally. One SKS instructor also sought student support in learning how to write braille on a Perkins Braillewriter and the students taught the SKS instructor how to write letters in braille.

How Did Students Create a Project Proposal?

After developing their research questions and hypotheses, students prepared and presented their project proposals on the second day of the Academy. Students prepared and presented their project proposals through three processes: discussions about roles and responsibilities, leadership structure, and accessibility. The categories of collaboration, independence, accessibility, and apprenticeship were used to describe how students engaged in preparing and presenting their project proposals.

Collaboration. Within their small groups, students collaboratively decided their individual parts of the presentation. Students also discussed ideas such as who would start and end the presentation. While preparing their project proposals, interns noted how students were “joining the conversation without prompts”. Interns also noted that one student who did not actively join the conversation eventually, “... added quite a bit of information to the group discussion”, near the end of the group discussion. Students also took on various roles such as, “helping decide which variables to focus on and providing additional methodologies to use”. While most all students collaborated with their group members, a student was also described as, “listening attentively, but not adding to the discussion or helping to make group decisions”. In this instance, the group members asked direct questions and positively encouraged input or worked on tasks together.

Independence. While group discussion participation slightly varied during project proposal preparations, leaders were prominent in both groups. Peer leaders were described as “getting group mates to stay on task throughout the activity”. In one group, one student assumed a clear leadership role and was observed, “... pushing the team to work on the problems at hand”. A student also demonstrated his leadership abilities by assisting his group members in identifying specific methodologies. Interns noted the student, “tended to lead the discussion” within this particular discussion. As all students neared the presentation proposal event, interns noted more students began to, “take charge at the end”.

Accessibility. During the project proposal presentations, groups shared tactile objects and shared their project ideas verbally. In addition to presenting their information verbally, one group also brought samples of lichen, two different tree bark species and rocks for their audience. Audience

members were encouraged to pass around and feel the samples, while the group commented on the object properties—for example, the difference between Aspen and Ponderosa Pine bark.

Apprenticeship. Unlike the inviting inquiry and generating hypotheses activities, the SKS did not play an active role in guiding students in preparing for the project proposals, nor did the students ask for assistance from the SKS. While collaborative discussions slightly varied between groups, leaders in both groups guided and managed components of the project proposal. While interns noted how students strongly demonstrated their leadership abilities, the SKS were not mentioned within the camp associate transcripts during the project proposal preparation and presentation activity.

How Did Students Collect Data?

Students collected data throughout the third day of the Academy. Students engaged in data collection through using tools and assistive technology, utilizing mini lessons, collecting samples or creating data collection records, and fulfilling independent roles and sharing students' summative progress among group members at the end of the data collection period. The categories of accessibility, apprenticeship, as well as independence and collaboration were used to describe how students collected data.

Accessibility. Students decided when to utilize resources such as assistive technology, staff, and tools at their own discretion. In both groups, students broke themselves into smaller groups to collect samples for their respective projects or record data. When collecting samples, students used flags to tag trees and a knife to remove tree bark samples. In another group, students used a trowel to dig around roots and used a rock to measure the depth near the root. Students used laptops with screen reading and magnification software to record data.

Apprenticeship. Throughout the data collection period, the SKS also guided students in exploring, discovering, and learning about environmental features. For example, while hiking between sites, the SKS facilitated mini lessons to teach students about ladybugs, lizards, and trees through touch. In the lesson with pine needles, the SKS taught students how to determine the tree species by counting the number of pine needles on collected samples.

Independence and Collaboration: Independent of Collaboration. Students were described as careful, independent, serious, and focused while collecting and organizing their data. Without a formal discussion, students independently selected their roles within the data collection process. Students also gathered, entered, and organized data independently using their primary media. Students were described as

experts or “providing paragraphs of knowledge” in explaining their individual roles at the end of data collection.

What Materials and Strategies Did Students Use for Data Analysis?

Students prepared their data for analysis at the end of the third day and analyzed their data throughout the fourth day of the Academy. Students analyzed data, collected data from all team members, and analyzed data for various criteria. Students also planned and organized presentation methods independently. The categories of accessibility, collaboration, as well as independence and apprenticeship were used to describe how students analyzed their data.

Accessibility. Students engaged in data analysis through recording, studying, and discussing results. As all students either had low vision or were blind, students contemplated how to make their analyses accessible to all team members. Students were described as leaders as they problem solved how to make the process of analyzing data visually and tactually accessible for all team members. For example, interns noted the following statements: “[Students] were responsible for sorting 30 bark samples and recording with peer made labels. Staples signified which species, which tree and orientation (North and South).[Students] categorized Lichen by touch”. Students also provided the following statements to describe their coded data: “We [students] need to quantify roughness... Label for tree species, first, lower left one staple for first species and vertical staples for which tree number”. In these examples, students transformed visual/auditory data created as an electronic file and created sample labels using an intricate tactile coding system using paper and staples.

Collaboration. Students worked in their small groups to sort, weight, record, and analyze results. Students were described as happily and confidently collaborating within their groups. Students were described as both “...doing the test and analyzing data.[Students] did not take a leadership role”. When students did assume an active leadership role, interns noted the students, “... prompted other students to express their opinion”.

Independence and Apprenticeship: Independently Seeking Apprenticeship. Throughout the data analysis period, students each determined when they took a break and how they managed their overall time. There were students from each group who used their break time to seek guidance from the SKS. Questions included interpreting standard deviations and to determine how much the data deviates from the mean, as well as contemplating soil texturing results and looking at grounds schematics. The categories of independence and apprenticeship manifested as opportunities initiated by students seeking guidance from the SKS for technical assistance and discussing student project findings.

How Did Students Connect Conclusions to Accessible Results?

Students prepared their project results after the students analyzed the data on the fourth day of the Academy. Students developed their project results by computerized data analysis methods, development of tactile graphics, and accessible presentation methods. The categories of collaboration, independence, accessibility, and apprenticeship were used to describe how students shared their research project results.

Accessibility and Apprenticeship. Both students and SKS focused on sharing and providing accessible information through tactile, visual, olfactory, and auditory sensory channels to show their results. Students used assistive technology devices, such as braille and computer screen reader software to create their results.

Apprenticeship. The Sky School Scientists guided students in the careful use of computer software and creation of tactile graphs. Students also discussed the data with a SKS about what graphs to use to represent data and conclusions. For example, one of the students said “I don’t know how to do this”, and the SKS showed the students an example of braille graphs. Also, the students were guided to put data into graphs for the presentation. Students wrote Braille labels, created tactile graphs, and took their own notes to describe results verbally.

Collaboration. Students orchestrated their responsibility together to present their results. The students assigned themselves into smaller groups to create accessible results. One group worked with Excel and were guided to enter data and create graphs. Another group made tactile graphs with the braille and collage materials.

Independence. Students voluntarily took charge of using both the computer and braille writer during the graphing process. The students worked independently to put their segments of the collective narratives together. The students argued and made the graphs according to their peers’ needs. In this activity, students were described as happily collaborating, creating amusing scripts, and orchestrating together for the presentation to create accessible results.

What Materials and Strategies Did Students Use to Present Their Results?

Students presented their project results by developing PowerPoint slides on the fourth day of the Academy. Students were guided by the SKS in preparing PowerPoint slides, creating tactile graphs, and interacting with their audience. Students discussed their roles before the presentation and practiced their presentations. The categories of collaboration, independence, accessibility, and apprenticeship were used to describe how students engaged in presenting results for the research project.

Independence and Collaboration. According to interns’ notes, the students were independent and determined to present accessible results using visual, tactile, and auditory media to convey their ideas to their audience. The students independently interacted with audiences by asking and answering questions. Even though students presented and answered questions posed by the audience, students were described in the picture coding as pensive and nervous about drawing conclusions from the data. At the end of the presentation, the students were described as happy and excited to conduct future science experiments. For example, when the students introduced hypotheses with amusement, authors noted students smiling in post presentation photographs.

Collaboration. Students decided their roles for the presentation based on their interests, such as introducing the team and describing the origin of the question and hypothesis, explaining the methods used in data collection, and presenting the data analysis graphs and results to the audience. The interns noted that throughout the presentation, each student knew their roles and was able to recite information and answer questions from the audience.

Apprenticeship. Before giving the presentation, the SKS discussed possible questions that might be asked by audiences and prepared them to respond to those questions in different ways. During the presentation, one SKS was responsible for operating the PowerPoint slideshow for students.

Accessibility. Students discussed methods to make the presentation accessible, such as Rob the Rock, labeling tree bark with staples and creating tactile graphs. During the presentation, students used PowerPoint slides, verbal descriptions, and tactile graphs. The students explained directions verbally and shared tactile graphs with their audience and described them clearly.

Discussion

What are the Roles of Students with VI in a STEM Education Program?

Independence was one of the primary outcomes of this program. Consistent with existing studies, the PBL program allowed students to become independent thinkers and learners (Gültekin, 2005; Supalo, 2012; Supalo, Isaacson, & Lombardi, 2014). Our result of this program demonstrated that, during the Academy, students with VI were guided and encouraged to ask questions, share ideas, explore the environment, and use tools independently. For example, in the activity of testing water hardness, the student came up with his own question, which had been reflected as “independence” and “serious” by interns. When considering that students with VI are not provided with ample opportunities for being engaged independently in science classes

(Rule, Stefanich, Boody, & Peiffer 2011), their participation through this program served as a vehicle where their independence could be demonstrated and promoted.

Apprenticeship and collaboration have been noted as another significant characteristics of the program since students with VI in a public school setting may not be given with these types of arrangements. Dividing the students into two groups allowed the SKS to focus on the individual needs more closely, while maintaining experiences of collaboration. This also allowed the interns to demonstrate relevant types of assistive technology. An apprenticeship model of training allowed the SKS to design the context of the particular learning environment, serving the vested interests of both SKS and students with VI. Students were encouraged to ask questions, seek for alternative approaches, and design and modify their approaches methodically.

This finding aligns with the apprenticeship development model suggested by Dennen (2004) where learning based on context, engaging into authentic learning through scaffolding, gradual removal of scaffolding as students develop competence, and independent practice of learned skills are sequentially happening. These two characteristics define the nature of this program where the expert and novel researchers were interacting freely, while interests and motivations towards science were shared.

What are Effective Strategies in Implementing Outdoor STEM Education Activities for Students with VI?

Previous research (Aldrich & Sheppard, 2001; Fisher & Hartmann, 2005; Kizilaslan, Zorluoglu, & Sozbilir, 2020; Supalo, Isaacson, & Lombardi, 2014) support the notion that students with VI are able to engage in any STEM activities when accommodations are provided. The Sky School Scientists made STEM learning enjoyable and meaningful for all students with VI through the provision of accessible materials and content. During the outdoor science activities, the SKS offered multisensory learning opportunities by including real objects, 3D tactile models, adapted materials, assistive technology tools, as well as allowing all students to see, hold, feel, smell, and compare the materials.

The use of real objects encouraged the connection between science and the real-world for students with VI. The students had opportunities to feel what exists in reality, such as structure, texture, and temperature (Roberts et al., 2018). In the present study, the SKS entomologist provided real objects for students with VI to explore the anatomy and diverse aspects of the wild bees. The photographs revealed that students with VI smiled and encouraged each other to hold the bees.

The finding showed that real objects provided unique experiences with tactile, auditory, olfactory, and kinesthetic

sensory information to students with VI in science learning. Since students with VI learned science “by doing” via hands-on outdoor science activities with real objects, they found science exciting and fun, but at the same time, had opportunities to make observations that usually are not found in a typical classroom setting as in the case where a SKS astronomer integrated real meteorites and rocks from space to explore the topic of space science. An interesting finding was also the overlap between accessibility and apprenticeship, particularly when students later recalled this interactive presentation and decided to share their samples, as well as their measuring device rather than “... just talking about it”. Within this finding, the SKS not only shared real objects but also modeled how to make presentations visually, tactually, and auditorily accessible and ensured equal access prior to the presentation.

Prior literature (Novak & Wisdom, 2018; Rule, 2011; Teke & Sozbilir, 2019) supports how 3D models and tactile materials have a positive impact on students’ performance in STEM learning. Therefore, the SKS structured activities with 3D models to deliver meaningful content for students with VI. For example, the astronomer provided 3D craters, asteroid, graphs, and a model of the sun to describe the solar system. Students indicated that these hands-on activities helped them better understand the content. The results from Rule (2011) also indicated how students experienced a higher level of enjoyment for students with VI while participating in science lessons at Space Camp when compared with participating in lessons in their schools.

Assistive technology has also served an important role in students with VI gaining better access to STEM activities (Bell & Silverman, 2019). Our findings showed that the implementation and use of accessible tools were quite effective in getting students actively engaged in outdoor science activities. Both students and the SKS focused on providing and sharing accessible information through multisensory channels such as tactile, visual, olfactory, Braille, and auditory by using assistive technology devices. Lastly, the findings indicated that accessibility components for science programs may not always have to be expensive high-tech devices. For example, during the data analysis, students with VI sorted 30 bark samples and recorded their data with peer-made labels. Students innovatively used staples and note cards to label each species, tree and orientation. See Table 3 for a list of materials and assistive technology devices integrated into student group projects.

Similar to the findings in Supalo et al. (2009) and Wild, Hilson, and Farrand (2014), it revealed mutually beneficial mentoring relationships between students and the SKS, as well as a willingness for the SKS to learn alongside students. As the SKS guided students, students were described as engaged and ready to explore within group projects and presentations with hands-on opportunities. The invited SKS

were also described as attentive, ready to guide students, careful, and helpful.

Multisensory STEM learning workshops and camps have been used to encourage students to share knowledge, build student confidence, minimize sighted assistance, learn effective problem-solving skills, and increase student self-efficacy in effort and collaboration (Supalo et al., 2009; Supalo, Wohlers, & Humphrey, 2011; Wedler et al., 2014; Wild, Hilson, & Farrand, 2014). Students assumed the roles of teachers and taught the SKS braille. As time progressed, students became more confident in asking the SKS to describe environmental characteristics specific to their group projects. For example, students inquired how to tactually distinguish the difference between Aspen and Ponderosa pine bark, as well as pine tree species. Photographs captured students independently using assistive technology and assuming roles within a collaborative process of data collection, data organization, and final presentation rehearsals.

The importance of collaborative team efforts such as working together, active involvement, and fulfilling different roles, such as modeling leadership overlap with prior literature (Supalo et al., 2009; Supalo, Isaacson, & Lombardi, 2014; Wild, Hilson, & Farrand, 2014). Photographs of students smiling, sharing specimens, introducing their hypotheses in their final presentations, and post final presentation photographs reflected facets of positive collaboration. The use of photographs uniquely documented the facial expressions of middle and high school students with VI and blindness, as well as how students used and produced multisensory media in their overall journey in this outdoor science education program. The analysis of photographs provided an opportunity for authors to reconsider the effectiveness of lecture only and explore how the SKS positively engaged students in subsequent instructor led presentations.

Limitations

There are potential limitations for this study. One limitation is the small number of participants, which limited generalizability of the findings to all students with VI. Second, the participants were observed over a relatively short period of time. Student behavior may not accurately reflect normal, long-term behaviors of engaging in science education. Third, it was difficult to objectively code each activity, as not all Academy activities had the same proportion of photographs, thus impacting how authors accurately documented student behaviors for each activity. Furthermore, some photographs were difficult to code for students' emotions, despite adhering to the protocols for photograph inclusion. For this reason, video recording may be considered an additional resource in documenting students' emotions more objectively.

Conclusion

The Academy was overall helpful for motivating science awareness of students with VI. Various elements of the activities were accessible and technology options were used effectively. Collaboration between SKS and interns provided a joint effort to embed accessible and meaningful science content for students with VI. The Academy as an outdoor PBL science education program created a unique opportunity where multisensory learning for students with VI was well implemented.

Data Availability The data that support the findings of this study are available on request from the corresponding author GT. The data are not publicly available due to privacy/ethical restrictions.

Code Availability Not applicable.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest. This study has been completed through support of the National Science Foundation and a statement has been added to indicate that the result of the study is independent from the view of the National Science Foundation.

Ethics Approval An Institutional Review Board at the University of Arizona reviewed and approved this research study in accordance to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research.

Consent to Participate Written informed consent was obtained from the parents of individual participants included in the research study.

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