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Systematic Review of Outdoor Science Learning Activities with the Integration of Mobile Devices

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ABSTRACT

The purpose of this systematic study review was to describe how researchers integrated mobile devices into outdoor science learning, assessment of those activities, and alignment of purpose, integration, and assessment. From initial 980 search results, the authors selected 45 articles based on the eligibility criteria of: (a) empirical study; (b) learning activity with science content; (c) outdoor setting; (d) mobile device integration; and (e) assessement. Researchers designed outdoor science learning activities integrated with mobile devices for the purposes of science knowledge gain, affective domain gain, and scientific inquiry. Researchers aligned components of scientific inquiry including hypothesis formation, observation, data collection and interpretation, and communication and collaboration. Conclusions describe benefits to integrating mobile devices with outdoor science learning activities by supporting scientific inquiry skill development. Alignment of purpose and assessment provides evidence of student learning important in meeting accountability standards.

KEYWORDS

Accountability, Designers, Educators, Formal, Informal, Literature Review, Purpose, Technologists, Technology

INTRODUCTION

Many students of all ages look forward to going outside to investigate the natural world. Outdoor educational settings may heighten the senses, thereby helping students develop observation skills (Chinn & Malhotra, 2002). Science educators may engage students and facilitate cognitive knowledge in an outdoor setting by using scientific inquiry, a process of observing natural phenomena, forming explanations, gathering and interpreting data, and communicating findings with others (Martin-Hansen, 2002). To enhance the experience, mobile devices may be integrated with outdoor science learning activities as a tool for supporting and scaffolding learning (Crompton, Burke, Gregory, & Gräbe, 2016). The relationship among these issues is under-explored but is increasingly important in designing meaningful learning for students of all ages.

BACKGROUND

Designing meaningful learning experiences and measuring the impact of that learning is important to many stakeholders including education administrators, and school funding may be impacted by student performance (Ravitch, 2016). Increasingly, science educators at all levels of education experience an

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external push to design instruction towards accountability and addressing science standards (Chesky & Wolfmeyer, 2015). In the US, for example, Next Generation Science Standards guide learning outcomes for science domain learning for K-12 (ages 5-18 years) students (NGSS Lead States, 2013). Scientific inquiry, integrated with engineering design practices, serves as one NGSS dimension of the standards, along with the dimensions of cross-cutting concepts and disciplinary core ideas (NGSS Lead States, 2013). These three dimensions ideally are covered in all age and grade bands and provide a basis for postsecondary science educators to accumulate prior knowledge. There is flexibility, however, regarding how science educators implement and assess NGSS, leading researchers to recommend, "Thus, at the school and classroom level, research is needed to examine rigorously how standards are interpreted" (Fulmer, Tanas, & Weiss, 2018, p. 1095). The authors of this systematic review partially address this recommendation by examining how science educators implement an aspect of science education that some consider innovative. The authors conceptualize this innovation as science learning activities, with integration of mobile devices, in formal and informal outdoor settings for students of all ages, and aim to provide a global perspective of this issue. Although standards are not the same in many countries nor uniformly implemented at a collegiate level, all science educators should design and integrate science learning activities with intention and assess whether that intention was fulfilled. Thus, standards such as NGSS were used as a broad conceptual framework for the systematic review but were not used as a measure of attainment by each study.

The concept of alignment deserves mention, as it played a key role in this systematic review. Alignment is a term that, like scientific inquiry, has different meanings depending on context. In a broad sense, alignment is the degree of similarity in aspects of curricula, programs, or educational standards (Webb, 1997). In this study, the authors define alignment as how closely intentions or purpose for an outdoor science learning activity match the assessment. Other researchers show how science educators' intentions followed through in their assessments (Sandlin, Harshman, & Yezierski, 2015; Webb, 1997). Examining earlier work presents another cloudy concept. Words such as goals, expectations, outcomes, objectives, purpose, and intent may generally encompass what science educators intend to accomplish in terms of student learning (Sandlin et al., 2015; Webb, 1997). In this study, the authors used the words intention and purpose to capture this concept. The authors did not use the terms objectives or outcomes because those terms may have accountability connotations and the authors did not examine documents such as lesson plans in which these terms would have been precisely documented.

Scientific Inquiry

How do science educators design activities to educate students? There are two broad areas where students may gain cognitive skills: science knowledge such as key organizing concepts; and scientific process skills such as investigating a problem or question (NRC, 2012). Disciplinary core ideas, along with cross-cutting concepts, are NGSS key organizing concepts. Students gain knowledge in increasing levels of depth and sophistication by instruction over time (NRC, 2012). Students use a logic-based process called scientific inquiry to answer questions. The scientific inquiry process may be combined with engineering design practices to solve a problem. The authors of this study utilized a holistic, global perspective encompassing students of all ages. For this reason, the authors did not evaluate each study according to alignment with standards that may not apply in a particular context. Rather, the authors examined each study to understand how science educators use scientific inquiry and teach science knowledge.

The process of scientific inquiry has an ill-defined meaning, but generally the initial phase begins by forming a guiding question, hypothesis, or problem (Martin-Hansen, 2002; Rönnebeck, Bernholt, & Ropohl, 2016). In the next phase, students conduct observations and collect data and, when feasible to do so, conduct experiments to support or dispute the hypothesis (Martin-Hansen, 2002; Rönnebeck et al, 2016). Students interpret and analyze data to compose logic-based explanations and descriptions of phenomena (AAAS, 1993). The final phase relies on communication and collaboration with group members and to a larger audience (Martin-Hansen, 2002; Rönnebeck et al., 2016). Science educators may conduct scientific inquiry with students of all ages with increasing sophistication and complexity appropriate to student age and grade bands (NRC, 2012). The authors of this study used these broad areas of content-specific disciplinary core ideas and a general process of scientific inquiry as a framework to systematically review studies that involved students of all ages learning science outdoors.

Besides science education, other learning domains use the outdoors as a setting for instruction, including outdoor education, environmental education, and place-based learning. Science learning activities conducted outdoors, however, typically differ in learning outcomes (Semken, Ward, Moosavi, & Chinn, 2017). Outdoor science education outcomes include science knowledge. Outdoor education, environmental education, and place-based education learning outcomes emphasize changes in behavior or attitude towards the outdoor environment, either in general (environmental education) or in particular (place-based education) (Semken et al., 2017). Educators may use scientific inquiry in designing and implementing lessons. Although the outdoors is an integral setting for outdoor education, science educators may consider an outdoor setting unusual for a typical science classroom.

Students of all ages may benefit from learning science in an outdoor setting, and the benefits have been well-known among the science education community for close to half a century. Students are located at the source of data and natural phenomena to observe. The outdoors often provides intrinsic motivation and interest to learn, and the environment generates student enthusiasm (Blough, 1973). Students may become engaged by the novelty of going outdoors, using mobile devices, playing a game, or just doing something different than a typical lesson (Orion & Hofstein, 1991). Some educators may assess emotional impacts, such as attitude, interest, and confidence about science and technology, of students embarking on an outdoor science learning activity with integrated mobile devices.

Integration of Mobile Devices

Tools to support science learning may accompany students outdoors. In fact, in a review of mobile learning trends, researchers named science as one of the leading learning domains using mobile devices outdoors (Chee, Yahaya, Ibrahim, & Noor Hasan, 2017). Mobile learning tools have evolved over time from single purpose data collection devices, such as global positioning systems (GPS) to smartphones that offer a multitude of affordances as well as access to the Internet. Evaluation of mobile device integration for educational purposes may be designated along a continuum from simple substitution of digital content to complex redefinition of the learning activity where "the technology allows for the creation of tasks that could not have been done without the use of the technology" (Romrell, Kidder & Wood, 2014, p. 82). The authors of this systematic review used the term mobile device to describe a lightweight, portable device, convenient to bring outdoors, with wireless and cell Internet accessibility, if available, and capability to include multiple software applications (apps), designed to scaffold and support various outdoor science learning purposes including scientific inquiry.

Intentionally bringing technology to the outdoors is not a new idea. Integrating technology in outdoor settings has been discussed for decades—although the actual tools change, the underlying issues do not (Carter, 1998). Using technology with a clear purpose in outdoor learning activities, ideally to facilitate scientific inquiry, is still recommended as a best practice today (Veletsianos et al., 2015). A holistic approach to science education integrates the outdoors with science by using constructivist, scientific inquiry principles (Orion, 2007). With current technology, it is important to describe how those best practices are met with the multitude of affordances mobile devices now offer.

Gaps in the Literature

Literature reviews typically describe trends in mobile learning, but this systematic review used a different approach by analyzing the alignment of mobile device use, intention or purpose for implementing the science lesson outdoors, and assessment of that lesson across 45 studies. Typical trends reported in other literature reviews include: (a) number of science domains integrating mobile devices (b) learning type (c) age and grade bands of subjects (d) type of mobile device used (e) study methodology and methods and (f) outcomes of the research (Crompton et al., 2016; FitzGerald et al., 2013; Hung & Zhang, 2012; Hwang & Tsai, 2011). The authors of this systematic review did not examine those trends, but instead used a descriptive approach to analyze trends in how science educators, henceforth referred to as researchers, implement and assess outdoor science learning activities integrated with mobile devices. Scientific inquiry in particular seems an appropriate framework to address the recommendation by Cheung and Hew (2009) to research "cognitive processes through problem-solving, in investigations and other inquiry-based approaches using handheld devices" (p. 169). The authors of this study used the previously described framework of disciplinary core ideas and scientific inquiry to examine the impact of integration of mobile devices in each study.

Although many researchers have recommended integrating mobile devices with outdoor science activities, the stages of assessment and evaluation of said activities are under-explored in the literature. In reviews of mobile learning research, researchers found most studies were design-based and focused on exploring strategies for using affordances of mobile devices, such as context and location aware services, to support learners in a variety of settings including the outdoors (Hwang, Tsai & Yang, 2008; Wu et al., 2012). How researchers assessed the impact of integration of mobile devices, however, presents a gap in the literature. Researchers have proposed assessment frameworks, but those frameworks lacked mobile device integration (Chao, Chang, Lan, Kinshuk, & Sung, 2016; Flowers, 2010; Hartmeyer, Stevenson, & Bentsen, 2016). Researchers have developed a model of alignment between scientific inquiry and mobile devices, but that model did not include assessment and evaluation of integration efforts (Cheung & Hew, 2009). This suggests to the authors that despite literature pertaining to analysis, design, and development of activities integrated with mobile devices, an investigation is needed of evaluating how purpose and assessment align.

The purpose of this systematic studies review was to aggregate and analyze peer-reviewed literature to describe how researchers integrated mobile devices in outdoor science learning activities, how those activities were assessed, and what alignment existed between purpose, integration, and assessment. The authors used a systematic review of studies to fulfill a recommendation to examine how researchers interpret and implement scientific inquiry practices and science knowledge (Fulmer et al., 2018). The authors examined studies of outdoor science learning activities that integrated mobile devices to address other researchers' recommendations (Cheung & Hew, 2009). Finally, to address gaps in the literature relating to alignment of intention and assessment, the authors explored how each study aligned assessment with purpose for integrating mobile devices. Each study in this systematic review was examined with the following research questions in mind:

1. How did researchers intend students to learn science in an outdoor setting?
2. How did researchers integrate mobile devices to support outdoor science learning?
3. What alignment exists between intention or purpose and assessment of outdoor science learning activities integrated with mobile devices?

METHOD

Search Strategy

An electronic search by search term was conducted using university library access to locate English-language, published articles. The search was limited to peer-reviewed journal articles. The databases searched included ProQuest, ERIC, EBSCOHost, PsycINFO, and JSTOR. The following search terms were used: outdoor science with mobile learning; outdoor science with handheld, tablet, iPad, and smartphone; outdoor science and technology with experiential learning, social constructivist, constructivism, science inquiry, nature of science, observation learning, engineering, and context-aware learning; and outdoor science learning with assessment and with mobile and technology. These terms were used because they frequently appeared in the literature. Terms discarded that appeared in the literature included process, practice, and authentic in the belief that the words were modifiers and would be included under the search terms. Also discarded were terms for specific technologies such as GPS and GIS because those terms, without education-term qualifiers, could pertain to studies not relevant to the research questions. Studies were included if they had taken place outside of the US; in fact, a large number were conducted in Asia. For this reason, search terms specific to US K-12 science standards such as NGSS, SEP, and engineering design practices were discarded.

Study Selection

The initial search using the terms previously mentioned yielded 980 articles. Table 1 illustrates the process from initial search to final articles included for analysis. The initial 980 returns were screened for duplicate entries and relevance to this study by title. If the article was not encountered elsewhere, the abstract was examined for relevance to the research questions. Screening for relevance and duplication eliminated more than three-quarters of the initial returns (824), leaving 156 articles. A second screening consisted of a scan of the article, which resulted in 76 potential articles for inclusion in this systematic review. Examination of the 76 articles according to inclusion and exclusion criteria, which are described in the following section, brought the final number to 45 articles selected for analysis.

Inclusion and Exclusion Criteria

All levels of education from preschool to post-secondary were considered. The date of publication was considered, and no cut-off date was established. Because mobile devices did not become common until at least 2000, the studies tended to date from mid 2000 onward. A few articles appeared to describe the same study. In that case, the articles were combined and analyzed together as one. This was the case for seven articles, which were combined into three (Hung, Hwang, Lin, Wu, & Su, 2013; Hung, Hwang, Su, & Lin, 2012; Hung, Lin, & Hwang 2010; Hwang, Chu, Chen, & Cheng, 2014; Hwang, Chu, Shih, Huang, & Tsai, 2010; Su & Cheng, 2015, 2013). Literature reviews were excluded. Articles describing design studies for activities without implementation of such were excluded. The authors included articles based on the eligibility criteria (a) empirical study, (b) learning activity with science content, (c) outdoor setting. (d) integration of mobile devices, and (e) assessed. Please see Appendix 1 for a complete list of included articles and how each fit into themes. Figure 1 displays the alignment, and organization of articles selected for review after initial criteria were applied, as well as the number of articles that aligned in each aspect.

Table 1. Flow chart table of article selection process

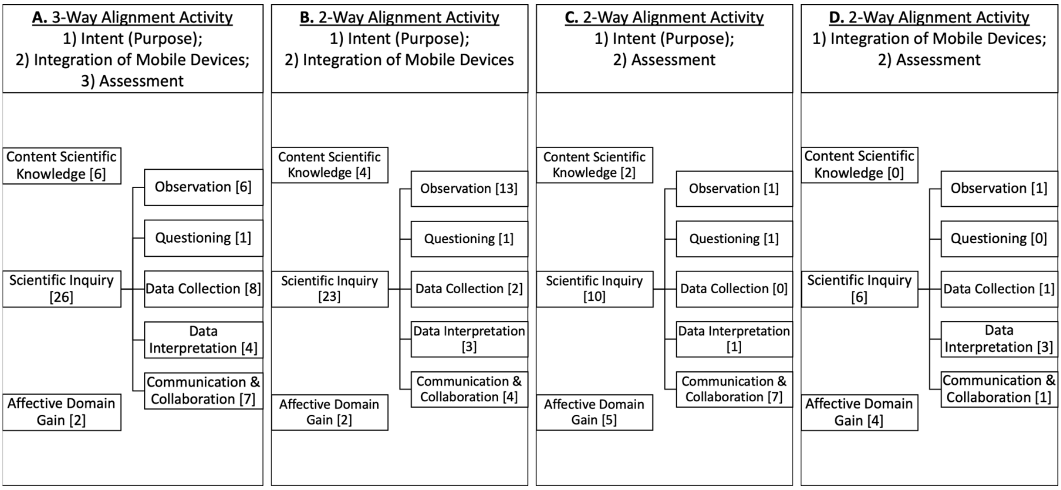
Databases searched and initial yield: Psych INFO: 50 JSTOR: 207 ERIC: 304 EBSCOHost: 96 ProQuest: 323
Articles identified through keyword search: **980**
Articles remaining after duplicates removed and title/abstract screen: **156**
Articles remaining after second screen of abstract & article scan: **76**
Excluded based on full-texts: 31 Reasons for exclusion: Meta-Analysis/Literature Review: 2 No outside: 4 No study: 1 No mobile devices: 11 Combined as same study: 7=3 No science: 9
Included based on inclusion/exclusion criteria: **45**

The authors examined outdoor science learning activities as one aspect of science education, and they examined researchers' purpose for setting the science learning activity outdoors. If the stated intent included mention of science content or scientific inquiry, the article was included. The authors excluded social science, cultural learning, literature, poetry, and other studies with a non-science focus even if they included description of an inquiry process (Chu, 2014; Jong & Tsai, 2016; Shih, Chuang, & Hwang, 2010; Shih, Chen, Chang, & Kao, 2010; Shih, Tseng, Yang, Lin, & Liang, 2012). Environmental and place-based education intentions that addressed the affective domain, such as attitude or behavior change toward the environment, were included if the researchers also described intentions for students to learn science content or practice scientific inquiry (Carrier, Tugurian, & Thomson, 2013). Likewise, the authors included engineering design activities that took place outdoors if the stated purpose for the activity incorporated science content or scientific inquiry. Articles that met the criteria of an empirical study with the intent of learning science were further organized by intention and alignment with mobile device use and assessment as illustrated in Figure 1. Intentions included science knowledge gain, affective domain gain, and scientific inquiry skill gain with scientific inquiry further broken down into components. The reader can find the intentions or purposes in the analysis framework section.

The authors examined how researchers in each study used mobile devices to support the specified purpose for learning science outdoors, and they included studies in which researchers required students to use mobile device affordances (e.g., camera, location-aware services) as an integral part of the activity. The authors excluded studies in which students did not use mobile devices while outdoors (Wojdak et al., 2010). Figure 1 illustrates the number and organization of studies of outdoor science learning activities with integration of mobile devices and the alignment with intention and assessment.

The authors examined how the researchers assessed an outdoor science learning activity in each study. Informal, non-formal, and formal educational settings were included because assessment was not necessarily absent in informal settings. Assessment could be formal or informal; formative or summative; assessed by self, peer, or instructor; or any mixture. Studies in which researchers examined data logs and other analytics of mobile devices for indication of participation levels were included. Figure 1 illustrates organization of studies by assessment of science knowledge gain, scientific inquiry skills, or affective domain gain and alignment with intention and integration of mobile devices.

Figure 1. Organization of articles in the systematic review; numbers in parentheses indicate studies that aligned accordingly. Authors would like to acknowledge Mike Borowczak, University of Wyoming, for his assistance with this figure.



Analysis Framework

Please refer to Table 3 in Appendix 1 for a complete list of reviewed studies. The authors created a spreadsheet to collect data and organize each study, which formed the basis for open coding. The authors developed and refined codes by an inductive process (Merriam & Tisdell, 2016). Themes were developed from codes by constant comparison of the purpose for outdoor science learning activity, integration of mobile devices, and assessment (Merriam & Tisdell, 2016). Through discussion, the authors reached agreement about codes and themes.

The authors further organized intent of scientific inquiry into subthemes of forming questions or hypotheses, observation, data collection, data interpretation, and communication and collaboration. The subthemes emerged among purpose of outdoor science learning outcomes, purpose for integration of mobile devices, and assessment. These subthemes loosely follow components of scientific inquiry process (AAAS, 1993; Martin-Hansen, 2002; Rönnebeck et al., 2016). Many state and national standards include these components of scientific inquiry. The US NGSS includes engineering design practices along with scientific inquiry components to form science and engineering practices, one dimension of the overall framework for science education (NGSS Lead States, 2013). However, engineering design practices, for example, prototype, testing, reiteration, and design, did not emerge in the process of coding. Although the US has combined science and engineering practices into one dimension of science education, other countries might not have done so. While it is an area deserving of future research, description and comparison of national science standards on a global level is beyond the scope of this study.

The *content* theme encompassed researchers' intent or purpose of science knowledge, sometimes referred to as learning gain. Although researchers could have included an intent of knowledge gain to meet national science standards (NGSS Lead States, 2013), not all of the studies were conducted in the US. The authors did not collect data about national standards because it was outside the scope of this study. Furthermore, many researchers did not define science knowledge or learning gain. For that reason, the authors did not further organize by discipline or rigor studies that mentioned science knowledge.

The affective theme encompassed an emotional purpose for the activity. Affective domain knowledge is also referred to as attitude learning and entails instructional design strategies designed to bring about attitude formation and change, such as engagement, interest, attitude towards science, and confidence about science and technology (Smith & Ragan, 2005). Attitude learning is a common learning outcome in outdoor education, environmental education, and place-based education, although not as common in outdoor science education (Semken et al., 2017). Nevertheless, in some studies researchers integrated mobile devices and/or assessed for attitude learning. The authors did not further organize the affective theme because researchers often described intended affective domain gain towards using mobile devices, which was outside the scope of this study.

FINDINGS AND DISCUSSION

The authors designated how each of the 45 studies described an intent or purpose for the outdoor science learning activity, integration of mobile devices, and assessment (Table 3 in Appendix 1 has a complete list of studies and organization by theme). Researchers may have described more than one purpose for the outdoor science activity, integration of mobile devices, or assessment. The 45 studies referred to 117 purposes for outdoor science activities, 112 purposes for mobile integration, and 108 assessments. Thus, each study averaged more than two purposes for outdoor science learning activities, purposes for integrating mobile devices, and assessments. Table 2 illustrates themes and number of studies that fit those themes.

Overall, researchers intended students to learn science in an outdoor setting by conducting scientific inquiry, but they also intended students to gain science knowledge, and to a lesser extent gain in affective domain. Observation, a component of scientific inquiry, prominently stands out as a purpose to incorporate the outdoors into science activities (67%). In some studies, researchers intended students conduct a full scientific inquiry from questioning to communication, but most researchers intended students to conduct some but not all of the components of scientific inquiry. The authors provide a more detailed investigation of each component in the following sections.

To support outdoor science learning activities, researchers integrated mobile devices for the purpose of scaffolding and supporting components of scientific inquiry such as observation skills and data collection (44%) and integrated mobile devices as a resource for content (49%). Researchers did not commonly integrate mobile devices for the purpose of affective domain gain (8%).

To answer the research question regarding alignment of purpose and assessment, researchers in many studies aligned purpose and assessment, and often aligned integration of mobile devices as well. A single study could align by purpose, integration and assessment along more than one theme. However, not all of the studies demonstrated alignment, thus the discrepancy in percentages between Table 2 and the tables illustrated in Appendix 2. The authors discuss alignment of studies in the following sections.

Scientific Inquiry

Of the 45 studies analyzed, researchers used scientific inquiry in a holistic sense (11; 24%) to design outdoor science learning activities, mobile device apps, and assessments. For example, a mobile device app scaffolded learning by prompting students to perform background research, enter, compile, and evaluate data on the device, interpret their data in tables, charts, and graphs, and share their findings (Marty et al., 2013). Researchers could formatively assess the inquiry process by examining the quantity of observation posts in the online journal and the quality of scientific questions posed (Marty et al., 2013). In another example, researchers developed an assessment targeting scientific inquiry skills (Sharples et al., 2015). The assessment measured gains in scientific inquiry skill after students completed an activity that focused on questioning and collecting data, supported by a mobile device app that scaffolded those skills (Sharples et al., 2015). Besides tracking development of scientific inquiry skills holistically, many researchers concentrated on components of the scientific inquiry process, such as questioning, observation, data collection, data interpretation, and scientific communication and collaboration, and the authors describe those components in detail in the following sections.

Table 2. Themes and number and percent of studies that fit those themes

Theme	Purpose for Outdoor Science Activity	Mobile Integration	Assessment
Scientific Inquiry –Questioning	14/45 31%	2/45 4%	2/45 4%
Scientific Inquiry –Observation	30/45 67%	20/45 44%	8/45 18%
Scientific Inquiry –Data collection	16/45 36%	20 /45 44%	9/45 20%
Scientific Inquiry –Data interpretation	11/45 24%	16/45 36%	18/45 40%
Scientific Inquiry -Communication & collaboration	20/45 44%	13/45 29%	20/45 44%
Content	18/45 40%	22/45 49%	16/45 36%
Affective	8/45 18%	4/45 8%	17/45 38%

Questioning and Forming Hypotheses

Although one-third of studies identified questioning as a purpose for the outdoor learning activity (33%), use of mobile devices to support questioning and assessment of the process were rare (4%). In an example of a study that assessed questioning, researchers developed a rubric that scored questioning ability and refinement of questions through iterations supported by peer interactions (Hung et al., 2014). This suggests that designing outdoor science learning activities with a purpose to refine questioning and hypothesis formation is feasible. View Table 4 in Appendix 2 to view the studies that focused on questioning/hypothesis formation in purpose, mobile device integration, and assessment.

Observation of Phenomena

Overall, the most common purpose of an outdoor science learning activity was students observing natural phenomena (67%). Many studies integrated mobile devices by using photo and video to capture observations outdoors (44%). However, observation skills were rarely assessed (18%), which indicates a missed opportunity to align purpose with assessment. That is regrettable considering the time and effort put forth into developing mobile device apps. View Table 5 in Appendix 2 to view the alignment of studies that focused on observation in purpose, mobile device integration, and assessment.

Thoughtfully designed mobile device apps including note-taking and photos help develop observation skills and support assessment of developing observation skills. To develop observation skills, researchers developed apps that incorporated guides for describing observations, decreasing levels of support over time and practice, and ongoing formative assessment (Chen, Kao, & Sheu, 2005; Hung et al., 2013; Hung et al., 2010; Randell, Price, Rogers, Harris, & Fitzpatrick, 2004). Researchers assessed observations by evaluating data logs of the students' observation notes (Chen et al., 2005) or by scoring rubrics used in the field (Hung et al., 2013). These examples showcase the feasibility of assessing development of observation skills in outdoor science learning activities supported by mobile device integration.

While mobile devices offer potential for deep integration between observations and their documentation through image, video, or sound, the authors of this study were troubled that many studies did not assess the development of observational skills. Researchers assessed technical skills (Holloway & Mahan, 2012), knowledge gain (Chien, Su, Wu, & Huang, 2017), or satisfaction with the mobile app (G.-J. Hwang et al., 2010). Some researchers assessed a final product (Scott & Boyd, 2016). These examples showcase impressively sophisticated apps to scaffold observation skills, but regrettably also represent a missed opportunity to measure how observation skills developed.

Data Collection

Many researchers integrated mobile devices to collect data (44%). Researchers described data collection as a purpose for the outdoor science learning activity less commonly (36%) than observation. Assessment of data collection occurred less frequently (20%). View Table 6 in Appendix 2 to view the alignment of studies that focused on data collection in purpose, mobile device integration, and assessment.

Outdoor science learning focused on data collection often used that data to quantify and visualize a phenomenon. Researchers developed mobile apps that scaffolded and prompted data collection, logged number of attempts to collect data per task, assessed data for accuracy (Peng & Sollervall, 2014), and assessed how students transferred data collection to data interpretation creating bar charts and graphs (Peters & Scott, 2017). These studies showcase how mobile device integration may *redefine* learning activities (Romrell et al., 2014).

Peer assessment of a shared database could help determine the practical validity of the data. For example, peer assessment determined practical significance of a shared database (Guertin, 2006; Nugent, 2018). Students critically assessed a data collection tool (GPS), by using error statistics and determining constraints on data collected outdoors (Johnson & Guth, 2002). In another study, students aggregated, quantified, and evaluated noise level data collected on a mobile app (Wyeth & MacColl, 2012). In these examples, peers informally assessed data by alerting others of outliers, thus establishing credibility to the database.

Data Interpretation

Data interpretation often overlapped with both data collection and communication and collaboration, representing a pivotal point in purpose for scientific inquiry in outdoor science learning activities (24%). The authors noticed the pivot point in assessment (40%) as either the data collection process was assessed or the communication of findings to an audience was assessed. Researchers in outdoor science learning activities that pivoted towards data collection used an augmented reality mobile app that overlaid various probes and queries to collect data (Kamarainen et al., 2013). In studies that pivoted towards assessment of communication and collaboration, researchers typically integrated mobile devices to support data interpretation. Researchers accessed data logs to assess participation levels from students (Song, Wong, & Looi, 2012). View Table 7 in Appendix 2 to view the alignment of studies that focused on data interpretation in purpose, mobile device integration, and assessment. The relative lack of alignment in data interpretation compared to other components of scientific inquiry represents this pivot in outdoor science learning activities.

Scientific Communication and Collaboration

In many studies, researchers emphasized communication and collaboration as the purpose for the outdoor science activity (44%) and assessed those intentions (44%). This represents a close alignment between purpose and assessment. However, researchers integrated mobile devices less commonly for communication and collaboration (29%), which represents a missed opportunity. Mobile devices equipped with presentation apps helped students communicate their findings to a wider audience, for example, field guide podcasts and digital stories presented to classmates (Connors, 2011; Holloway & Mahan, 2012). Other studies used mobile device apps to scaffold group work by enabling data and information to be shared among classmates (Yang & Lin, 2010) or by scripting the collaborative learning process by prompting groups to collect data by taking photos (Nouri & Cerratto-Pargman, 2015). Students used mobile device apps in the field to communicate with those in the lab by sending annotated multimedia—locations, images and tags with description—back and forth for scientific discussion (Goh et al., 2012), and other students used co-created knowledge claims communicated by text messages to construct mind maps (Laru, Järvelä, & Clariana, 2012). These examples demonstrate the feasibility of integrating mobile devices to support development of communication and collaboration skills. View Table 8 in Appendix 2 to view the alignment of studies that focused on communication and collaboration in purpose, mobile device integration, and assessment.

Science Knowledge (Content)

The content theme of science knowledge pertains to key organizing concepts in science domains. It also loosely corresponds to disciplinary core ideas and cross cutting concepts (NGSS Lead States, 2013). The authors did not further organize the content theme due to lack of details in the reviewed studies. Instead, the authors grouped intentions for increase of knowledge in any science domain and at any education level. Just under half of the studies (40%) mentioned science knowledge as a purpose for the outdoor science activity, and almost as many (36%) assessed for knowledge gain. Almost half of all the studies analyzed overall (49%) integrated mobile devices to provide a resource for science knowledge. View Table 9 in Appendix 2 to view the alignment of studies that focused on science knowledge gain in purpose, mobile device integration, and assessment.

Integration of mobile devices for science knowledge gain represents a missed opportunity to fully leverage affordances of mobile devices. In many studies with science knowledge intent, researchers integrated mobile devices as an electronic textbook or guidebook to look up information, aid identification of species, and provide vague additional resources (Chang, Chen, & Hsu, 2011;

Huang et al., 2010; Liu, Tan, & Chu, 2009). Other apps included lesson-tailored worksheets and course-specific information (Hung et al., 2012). These studies integrated mobile devices as substitution technology for analog tools such as guidebooks or worksheets rather than transformative technology in which mobile devices bring affordances not previously available such as adaptive learning tools (Cheung & Hew, 2009; Romrell et al., 2014). Simple substitution of digital for analog tools may not be the most effective use of mobile devices for outdoor science learning.

The authors found difficulty attributing knowledge gain to the outdoor science learning activity. Researchers did not always provide details about the assessments or fully describe how they measured knowledge gain, which was shown as a comparison of an overall score on a pretest and posttest or at several points throughout the project (Liu et al., 2009). Many researchers did not describe how assessments aligned with the science knowledge specifically delivered during the activity (King, Dordel, Drzic, & Simard, 2014). The confounding variables present difficulties determining if science knowledge gain was due to the interventions of the outdoor science activity, mobile device integration, or both (Cheung & Hew, 2009). How mobile device integration, especially when functioning as substitution technology, influenced science knowledge gain was murkier still.

Affective Domain

Affective domain gain represents an emotional change in the learner. Affective domain gains were assessed in terms of student engagement, interest, attitude towards science, and confidence about science and technology (38%). View Table 10 in Appendix 2 to view the alignment of studies that focused on the affective domain in purpose, mobile device integration, and assessment. Researchers rarely integrated mobile devices for the purpose of affective domain gain (8%), and rarely described the purpose for the outdoor learning activity as affective domain gain alone (18%). Researchers often associated affective domain gain with knowledge gain, presumably because increased motivation, interest, and confidence helps students learn (Su & Cheng, 2015; 2013). It is difficult, however, to pinpoint what triggered the affective domain gain. Researchers have long established that novelty effects such as going outdoors or using a mobile device may influence perceived learning (Blough, 1973; Orion & Hofstein, 1991). Affective domain gain was measured by self-reported surveys, questionnaires and interviews, and although it presents a value-added component to the overall outdoor science learning activity, confounding variables such as novelty complicate association with knowledge gain.

Limitations

A major limitation of this systematic review was that the authors had to examine each study at face value. Publication word limits may have prevented a full description of purpose, mobile device integration, and especially assessments. Because the authors of this study did not ask for details of the included works or peruse documents such as lesson plans, to a certain extent, an absence of evidence was treated as evidence of absence. Studies could have been misinterpreted due to incomplete information. What roles the included study researchers played, and whether they also functioned as designers and/or educators, is unknown.

Bias may have impacted the detail with which assessments were described, particularly assessments of science knowledge, and may have given the authors of this study the impression of more confounding variables and unclear assessment than may have been the case. Although pursuing objective examination, the authors hold a bias favorable towards scientific inquiry stemming from past experiences in secondary and postsecondary teaching using the scientific inquiry process and anecdotally finding the outdoor science learning activities effective for engaging students.

A third limitation is that the authors did not sort studies by education level, nor did they sort studies by science knowledge. Although researchers may conduct scientific inquiry and teach disciplinary core ideas with students of all ages, some limitations as to complexity and sophistication, especially with integration of mobile devices, undoubtedly exist. Researchers in different contexts may teach and assess science knowledge differently.

As with any systematic review, limitations lie in the temporal nature of the snapshot-in-time style of collecting and analyzing studies. Outdoor science learning activities and mobile device integration may need time to further mature in terms of work on assessment and evaluation. For that matter, standards are not the same in all countries or uniformly implemented, which limits generalizability of this research.

Recommendations for Future Research

A recommendation for further research is to replicate this systematic review and explore other important differences. Refinement of search terms may lead to different studies to analyze or may locate studies in areas outside of educational technology design and development. Future analysis of studies may find the fields have matured and emphasized assessment and evaluation of established activities. Comparing science and technology standards may be revealing, as well as a comparison of national standards on a global level.

A curious result was that studies that mentioned engineering design practices as an outcome, purpose for using technology, or assessment were quite rare. Just one study used engineering design practices to build water bottle rockets, but the activity was not described as engineering (Wilson & Boldeman, 2012). Engineering often takes place outdoors and utilizes technology to a high degree. Although examination of why outdoor science does not include engineering is beyond the scope of this study, one reason for the lack of engineering in outdoor science may be that, because this systematic review included studies conducted worldwide, some countries may not have combined science with engineering in their standards. Investigation of this issue presents a rich area for future research.

CONCLUSION

The results of this systematic review suggest researchers design outdoor science learning activities mainly for the purpose of developing scientific inquiry skills or for science knowledge. In many studies, researchers focused on components of scientific inquiry: (a) questioning/hypothesis formation; (b) observation; (c) data collection and analysis; and (d) communication and collaboration. To a lesser extent, other researchers focused on affective domain gain.

Mobile devices, ideally through apps, offer capabilities for redefining learning by scaffolding and supporting development of scientific inquiry skills. However, there is room for growth in assessment of scientific inquiry skill development. Integrating mobile devices for affective domain gain may not be necessary as there is already novelty in outdoor learning shown in previous literature (Orion & Hofstein, 1991).

Also described in previous sections, confounding variables present difficulties determining if science knowledge gain was due to the interventions of the outdoor science activity, mobile device integration, or both (Cheung & Hew, 2009). Using mobile devices as simple substitution for analog tools not be the most effective use of mobile devices for outdoor science learning (Romrell et al., 2014). Although mobile devices offer access to resources, students do not necessarily need to research while outdoors.

This systematic review benefits researchers, science educators, and instructional technologists who design for science learning by describing how mobile devices are integrated with purpose and how purpose aligns with assessment. Alignment of purpose and assessment helps to provide evidence of learning called for by many accountability standards. By leveraging affordances of mobile devices to maximize scientific inquiry skill development and mobile device apps that scaffold the scientific inquiry process, assessment of the scientific inquiry process on a granular level becomes possible.

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APPENDIX 1

Table 3. List of Analyzed Studies and Themes Each Study Addressed. Key: A=Alignment of Purpose, Mobile Use, and Assessment. B=Alignment of Purpose & Mobile Use. C=Alignment of Purpose & Assessment. D=Alignment of Mobile Use & Assessment.

Author(s) and Date	Observe	Data Collect	Data Interpret	Comm. & Collab.	Content	Affective
Boyce et al., 2014	A					B
Hung et al., 2013, 2012, 2010	A					
Hwang et al., 2014; Hwang et al., 2010	A			A		A
Marty et al., 2013	A	A	B	B		
McClain & Zimmerman, 2016	A			C		
Randell et al., 2004	A					
Guertin, 2006		A	C			
Horton et al., 2013	C	A				
Johnson & Guth, 2002		A	A			
Nugent, 2018		A				
Peters & Scott, 2017		A	A			
Sharples et al., 2015		A	A			
Wyeth & MacColl, 2012		A		C		
Kamarainen et al., 2013	B		A			C
Avraamidou, 2013				A		
Goh et al., 2012				A		
Hung et al., 2014	B			A	D	
Kalathaki, 2017		B		A		
Nouri & Cerrato-Pargman, 2015				A	B	
Chang et al., 2011					A	
Chien et al., 2017	B				A	
Huang et al., 2010					A	
King et al., 2014					A	
Liu et al., 2009			D		A	C
Ratnayaka, 2017	D				A	
Su & Cheng, 2015, 2013					C	A
Chen et al., 2005	B		B		D	
Hance, 2014	B					
Holloway & Mahan, 2012	B			C		
Hougham et al., 2018	B					C
Lai et al., 2014	B					
Land & Zimmerman, 2015	B			C		
Scott & Boyd, 2016	B			C	D	
Song et al., 2012	B		D		B	
Zhang et al., 2014	B				D	C
Anastopoulou et al., 2012		B		B		C
Peng et al., 2009			B			
Laru et al., 2012				B		
Yang & Lin, 2010				B	C	
Osawa et al., 2007					B	
Wilson & Boldeman, 2012					B	B
Peng & Sollervall, 2014		D				
McBroom et al., 2015			D	C		
Connors, 2011				D		
Dove & Zitkovich, 2003				C		

APPENDIX 2

Appendix 2 contains tables of studies organized by themes of scientific inquiry, science content knowledge gain, and affective domain gain. Scientific inquiry is further organized into subthemes of questioning/hypothesis formation, observation, data collection, data interpretation, and communication and collaboration. Science educators may have described a study's intention having more than one theme and/or subtheme. If so, the authors of this study recorded all the themes each study addressed. Thus, the authors have repeated some studies in the following tables.

Table 4. Questioning: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Hung et al., 2014			X	
Sharples et al., 2015	X			
Marty et al., 2013		X		

Table 5. Observation: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Marty et al., 2013	X			
Chen et al., 2005	X			
Hung et al., 2013, 2012, 2010	X			
Boyce et al., 2014	X			
Randell et al., 2004	X			
Scott & Boyd, 2016		X		
McClain & Zimmerman, 2016		X		
Chien et al., 2017		X		
Holloway & Mahan, 2012		X		
Hwang et al., 2010		X		
Kamarainen et al., 2018		X		
Hougham et al., 2018		X		
Lai et al., 2014		X		
Land & Zimmerman, 2015		X		
Hung et al., 2014		X		
Hance, 2014		X		
Zhang et al., 2014		X		
Song et al., 2012		X		
Horton et al., 2013			X	
Ratnayaka, 2017				X

Table 6. Data collection: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Marty et al., 2013	X			
Sharples et al., 2015	X			
Nugent, 2018	X			
Guertin, 2006	X			
Peters & Scott, 2017	X			
Johnson & Guth, 2002	X			
Horton et al., 2013	X			
Wyeth & MacColl, 2012	X			
Anastopoulou et al., 2012		X		
Kalathaki, 2017		X		
Peng & Sollervall, 2014				X

Table 7. Data interpretation: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Sharples et al., 2015	X			
Peters & Scott, 2017	X			
Johnson & Guth, 2002	X			
Kamarainen et al., 2013	X			
Chen et al., 2005		X		
Marty et al., 2013		X		
Peng et al., 2009		X		
Guertin 2006			X	
Liu et al., 2009				X
McBroom et al., 2015				X
Song et al., 2012				X

Table 8. Communication & Collaboration: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Goh et al., 2012	X			
Laru et al., 2012	X			
Nouri & Cerrato-Pargman, 2015	X			
Avraamidou, 2013	X			
Kalathaki, 2017	X			
Hung et al., 2014	X			
Hwang et al., 2014	X			
Marty et al., 2013		X		
Anastopoulou et al., 2012		X		
Yang & Lin, 2010		X		
Land & Zimmerman, 2015			X	
McClain & Zimmerman, 2016			X	
Wyeth & MacColl, 2012			X	
Scott & Boyd, 2016			X	
McBroom et al., 2015			X	
Holloway & Mahan, 2012			X	
Dove & Zitkovich, 2003			X	
Connors, 2011				X

Table 9. Content domain: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Chien et al., 2017	X			
Liu et al., 2009	X			
Huang et al., 2010	X			
King et al., 2014	X			
Chang et al., 2011	X			
Ratnayaka, 2017	X			
Nouri & Cerrato-Pargman, 2015		X		
Osawa et al., 2017		X		
Song et al., 2012		X		
Wilson & Boldeman, 2012		X		
Su & Cheng 2015; Su & Cheng, 2013			X	
Yang & Lin, 2010			X	
Scott & Boyd, 2016				X
Chen et al., 2005				X
Hung et al., 2014				X
Zhang et al., 2014				X

Table 10. Affective domain: Studies that aligned purpose, mobile device integration, and assessment

Study	Purpose, mobile use, & assessment alignment	Purpose & mobile use alignment	Purpose & assessment alignment	Mobile use & assessment alignment
Su & Cheng, 2015; Su & Cheng, 2013	X			
Hwang et al., 2014	X			
Boyce et al., 2014		X		
Wilson & Boldeman, 2012		X		
Anastopoulou et al., 2012			X	
Liu et al., 2009			X	
Kamarainen et al., 2013			X	
Hougham et al., 2018			X	
Zhang et al., 2014			X	

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