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ABSTRACT

This article presents a conceptual understanding of how the powerful digital tool of augmented reality (AR) can be used for enhancing inquiry-based learning lessons (IBLLs). With an increased reliance on technology following the COVID-19 pandemic, reduced teacher preparation time, and a need to provide students with alternative student-centered lessons, we provide a simplified understanding of the often-complex nature of IBLLs using experiential learning theory (ELT). Further, we highlight the immersive qualities within AR, pair AR with the simplified foundation, provide examples within the research, and offer further applications available to current practitioners.

Keywords: Problem-based learning, educational technology, augmented reality, mobile technology, inquiry-based learning, experiential learning, distance learning

AR as a Digital Tool to Support All Learners in Inquiry-Based Lessons

Instructional practice and technology innovations, as well as state and professional standards, are undergoing significant disruptions (Basham & Marino, 2013). The pandemic and initiatives like building 21st Century Skills, have altered instruction to increasingly include problem solving, critical thinking, and collaborating in and outside the instructional environment (Nehring et al., 2019). Researchers argue that inquiry-based initiatives foster reasoning, analysis, argument construction, and strategies for working independently and with a group (Savery, 2015). Currently, there are a variety of inquiry-based approaches that can be implemented into instructional environments (Tawfik et al., 2020). When implemented in the classroom, researchers have found these methods to be more effective than traditional means of instruction (Lazonder & Harmsen, 2016). While we recognize the robust research base of inquiry-based methodologies (i.e., inquiry-based learning, problem-based learning, project-based learning), we intend to explore their experiential foundations through experiential learning theory (ELT) and will refer to them under the umbrella of inquiry-based learning lessons (IBLLs). While often complex in nature, implementing these IBLLs can facilitate independent student learning without constantly needing face-to-face instruction (Savery, 2019); something particularly relevant in today's digital-rich instructional environment.

Reliance on technology has been expedited by the COVID-19 pandemic. In the United States, approximately 56.6 million students were suddenly told they would be learning away from physical classrooms (Wilkinson-Flicker, 2019). This dramatic shift required teachers to suddenly look to digital tools to facilitate instruction at a distance. While students and teachers have returned to face-to-face instruction, digital tools, such as video conferencing, online learning platforms, mobile devices, and applications, continue to be relevant for designing and planning experience heavy instruction. Thus, the need for teachers to quickly implement digital tools like AR along with non-traditional methods of teaching such as IBLLs is imperative.

Fortunately, the explosion of technology advancement and the digital tools available to teachers and students, provides opportunities to support all students in both explicit learning of skills and replication of instruction. Digital tools such as applications (e.g., Grammarly, Discovery Education), built-in tools (e.g., text to speech, word prediction), and separate devices (e.g., voice recorder, scanner), present teachers with a variety of options for supporting students in their IBLLs (Rowland et al., 2020). One digital tool with the potential for enhancing many modes of instruction is augmented reality (AR). AR is a digital tool which can provide a platform to support struggling students in an IBLL. AR offers a technology combining the real-world with digital content and features which can be programmed for explicit instruction and replication across contexts on many platforms. AR is available on most mobile devices (e.g., smartphones, Chromebooks, iPads) that are currently being utilized in schools and homes, nationwide (Carreon et al., 2020). Further, AR can be immersive, engaging, and captivating, which can provide motivation for students who are struggling.

The purpose of this article is to present a conceptual understanding of how the powerful digital tool of AR can be used for enhancing the theoretical foundation of IBLLs. With an increased reliance on technology, reduced teacher preparation time, and a need to provide students with alternative inquiry-based, student-centered lessons, we intend to provide a simplified understanding of the complex nature of IBLLs that can be used alongside AR to support the diverse needs of all learners. For our purposes, we will focus on the immersive qualities within AR which, when implemented within the stages of ELT that ground IBLLs, can expand student engagement and further foster student learning.

IBLLs, AR, and Experiential Learning

As mentioned, IBLLs can encompass project-based, inquiry-based, problem-based, and problem-solving. Each method offers unique characteristics and often has differing steps to complete an experience, which in turn, can take time and expertise to master. For example, PBL Works and the Buck Institute for Education recognize seven steps for completion of a project-based learning lesson: (a) challenging problem or question, (b) sustained inquiry, (c) authenticity, (d) student voice and choice, (e) reflection, (f) critique and revision, and (g) public product (PBL Works, 2020). Whereas the Association for Supervision and Curriculum Development (ASCD) outlines nine steps for project-based learning: (a) real-life samples, (b) students become project designers, (c) background information, (d) negotiation of evaluation, (e) project creation, (f) presentation preparation, (g) presentations, and (f) reflection on project and presentations (Larmer & Mergendoller, 2010). These examples of IBLLs represent similar paths to learning, yet require varying degrees of skillset to implement individually. Likewise, other problem/inquiry-based models (i.e., IBLLs) have additional steps, elements, and/or components that operationalize application of the model within the classroom environment. While each have their own merit, the need to simplify has merit in today's ever-changing and more complex learning environment.

The ambiguity in the design and steps to implementation of specific IBLLs offers potential challenges, including confusion, time to complete, and knowledge of the many teaching strategies. Yet all IBLL models are student-centered, active learning approaches that focus on a question, problem, or real-world issue. Moreover, they encompass steps where students are asked to search for further information, make sense of the information and ideas, make conclusions, and reflect (Han et al., 2015). Overall, IBLLs focus on the student's ability to think critically, and problem solve, which means that through their engagement and involvement, learning occurs and, more importantly, the student understands (Bell, 2010). If teachers are to utilize IBLLs with limited knowledge and time, they must understand how students learn and how to quickly harness the unique experiences fostered by IBLLs.

Furthermore, understanding the alignment of digital tools to IBLLs is a critical step for educator application. To foster IBLL and digital solution (i.e., AR) implementation, effective technology adoption often requires alignment to an instructional practice or learning theory to avoid technology for the sake of technology. The way students experience IBLLs through digital tools, like AR, can be understood through many theories of knowledge acquisition. IBLLs often have been explained using information processing theory, social constructivist theory, as well as experimental learning theory. Information processing theory explains the role of prior knowledge and how problem solving helps structure knowledge and encode memory, while social constructivist theory accounts for how knowledge is socially constructed and develops as a result of language and interaction. (Hmelo-Silver & Eberbach, 2012). While both theories account for some of the process and how knowledge is explained, neither theory seeks to understand the process to which IBLLs have a cycle to teaching, learning, and reflection.

Experimental learning theory (ELT) provides a cyclical model of the learning process that is consistent with what is known about how students learn, grow, and develop throughout the entirety of an IBLL (Kolb, 1984; Mainemelis et al., 2002). Experiential learning permeates these learning models as a foundation for IBLL instructional practice and subsequent learning experiences of students. The complex and individual steps of the specific models of IBLL can be addressed in the simplified four stage ELT cycle capable of addressing what is known of learning through experience, original developed by Kolb (1984). While not a specific definition, this approach offers teachers an easy implementation framework to support an IBLL and implement technology to support students at each stage. In the ELT stages, students accumulate knowledge through participating in a four-stage cyclical process: concrete experience, reflective observation, abstract conceptualization, and active experimentation. These four stages allow the learner to accumulate knowledge based on experiences, their own thinking, actions within learning, and ongoing reflection (Kolb, 1984). A powerful concept for the demands of today's content requirement and application to the demands of the real-world setting. Utilizing ELT in place of a specific IBLL type lesson allows a teacher a level of simplicity. That is, instead of addressing seven or more steps and/or planning for various IBLL components/ elements, educators can operationalize the core components of the IBLL model through four steps (Kolb, 1984). In this way, they can plan and design for inquiry-based instruction and learning for the student. With this in mind, we will illustrate and identify the connection of AR, ELT, and IBLLs below. Furthermore, we will discuss how innovative digital tools like AR can support and enhance the teaching and learning through the four steps of ELT. As a result, teachers can integrate an innovative tool to further learner outcomes while doing so within a proven IBLL approach theory and approach.

IBLLs and AR in Education

Students who struggle in IBLLs may need to be explicitly taught strategies and interventions (Hardman & Dawson, 2008). These strategies and interventions can address some of the challenges exhibited including poor planning and prioritizing, task initiation, identifying the problem, brainstorming and the ability to connect concepts necessary for the solution step, and similar struggles (Rankin-Erickson & Pressley, 2000). Yet these skills are often assumed to be innate to the learner and thus, explicit or direct instruction may not be included as an integral part of IBLLs (Ananiadou & Claro, 2009). The lack then of systematic and explicit instruction with limited or no repeated opportunities to practice in order to master a targeted skill, offers challenges for IBLL instruction for specific learners (Leko & Brownell, 2011). Furthermore, limited or no explicit instruction may lead to academic challenges, frustration, and in turn, failure (Hardman & Dawson, 2008). If these students are going to succeed in these rapidly changing instructional settings, they need explicit support to develop these skills along with embedded supports to facilitate this development. Fortunately, the growth of digital tools and the recent expansion of these technologies in everyday instruction present several built-in elements for student learning.

With the growth of digital tools and solutions, students are increasingly gaining access to innovations that can further foster the application of IBLLs. There are many digital tools available to support students through IBLLs that can increase success of the learners (Ozerbas & Erdogan, 2016). AR is one of several emerging digital technologies with the ability to add systematic and explicit instruction making IBLLs feasible for all learners. Traditionally defined, AR combines the "real" or physical world with the digital world to create a unique and consistent learning environment (Azuma, 1997). In AR, an application uses a device camera or GPS to recognize a location, object, or another unique identifier, known as a marker. The application then recognizes the marker and overlays digital content. Technology, however, continues to evolve with many modern applications of AR incorporating more features. Almost all digital content is available to teachers to utilize, such as sound, video, text, three-dimensional graphics, links, and more. This furthers the ability to customize and personalize learning to support all students.

AR has the ability to guide a learner through a series of instructional experiences where the student is confronted with challenges and/or questions and then required to come up with the appropriate solutions (McMahon et al., 2015). As a result, AR works to facilitate the IBLL approach. AR contextualizes the learning experience offering students opportunities to determine appropriate ways to address instructional questions and determine correct solutions. Most importantly, AR is interactive, engaging, often easy to use, and allows a significant degree of user independence through features included in many AR apps (McMahon et al., 2015). In other words, AR can be an innovative tool for many learners and as a result, foster and support the unique characteristics of learning in an IBLL.

The unique interaction with digital and real-world content has been explored in a limited scope over the past two decades in varying educational areas. Several reviews have highlighted the potential of AR in education to produce gains in learning, motivation, engagement, and collaboration (Garzón et al., 2019; Garzón & Acevedo, 2019; Akcayir and Akcayir, 2017). These influential reviews highlight the impact AR can have if harnessed in all levels of education (e.g., P-12, higher education). Likewise, Radu (2014) completed a literature review on research articles comparing AR and non-AR instruction (e.g., Smartboards, Chalkboards, Bookwork). Radu found AR to produce higher levels of comprehension, retention, and content contextualization.

Further studies indicate that AR has been used successfully to learn vocabulary (McMahon et al., 2016; Solak & Cakir, 2015), identify science concepts (Wan et al., 2018; Sin & Zaman, 2010), practice daily living skills (Cihak et al., 2016), navigate to unknown locations (Smith et al., 2017; McMahon et al., 2015) and increase social/emotional learning (Chen et al., 2015; 2016).

Supporting IBLLs with AR through ELT

Teacher expertise and time are important considerations in today's reality; thus, teachers need alternatives to traditional methods that are easy to understand. To this end, we present and define the four stages for teachers to better understand how students experience IBLLs throughout a student-centered ELT approach. The intent is to simplify, in four stages, the complexities of varying inquiry-based teaching. We then describe how, IBLLs can directly connect to the four primary stages of ELT with AR to simplify the approaches into an easier to understand framework. Finally, we describe how AR can support each stage along the experience, and provide research and specific examples to illustrate the potential of AR. See Table 1 for a list of additional AR applications, stages associated with the technology, cost, and ease of implementation.

Technology	Description	ELT Stages (CE, RO, AE, AC)	Cost	Ease of Use (Beginner, Intermediate, Advanced)
Adobe Aero	Adobe suite app to build, view, and share AR experiences.	CE, RO, AE, AC	$0	Intermediate to Advanced (Time depends on technical knowledge)
ClassVR	Premade AR lessons and devices are available to purchase as a kit.	CE, AE, AC	Pricing Unavailable (Quotes Available)	Beginner (Most material is premade, attached to a lesson plan, and ready to use)
Cospaces.edu	Web and app-based tool for the creation of 3D AR experiences.	CE, RO, AE, AC	$0-$5.50 per student per year	Intermediate (Time depends on technical knowledge)
Google LiveView	AR-enhanced navigation program for Google Maps.	CE, AE, AC	$0	Beginner (Only need to press a button and enter an address)
Halo AR	App creates AR experiences with most modern mobile devices. Take a picture and enhance it with an overlay.	CE, RO, AE, AC	$0	Beginner to Intermediate (Time depends on technical knowledge)
Unite AR	Application to create AR apps, plug-ins, and experiences	CE, RO, AE, AC	$89-$827 per year	Advanced (No Coding but requires technical knowledge)

Note: CE: Concrete Expression. RO: Reflective Observation. AE: Active Experimentation. AC: Abstract Conceptualization.

Table 1. Available AR technologies with a description, associated ELT stage, cost, and ease of use rating.

Concrete Experience

In the first stage, concrete experience, the process is one of "learning by doing." In this stage of the cycle, students participate in hands-on experiences with a given task. This requires students to engage in applied problem solving rather than simply learning through observation, direct instruction, or reading (Kolb, 1984). Research has shown physical interaction or "learn by doing" can be an effective strategy for teaching students (Lindgren et al., 2016). In an IBLL, students are often presented a real-world problem of interest and are tasked with determining how they will examine the identified problem (Larmer & Mergendoller, 2010). The ensuing investigation becomes the concrete learning experience as students must devise and carryout steps toward a solution.

Digital tools are innately interactive and offer the "learn by doing" interaction necessary for IBLLs and the concrete experience stage. During the concrete experience stage, AR can provide an all-encompassing form of digital tool available to teachers with features that align well to concrete experience and the subsequent stages. AR requires the use of a device to enable content, whether through created or location-based markers. AR users can visualize their real-world environment while experimenting with the digital content projected on the screen (McMahon et al., 2013).

Not having a concrete example often makes comprehension and learning of content difficult. Concepts that are not easily seen or understood remain complex. AR can serve as the tool to contextualize. For instance, field trips offer a way to have an experience but are often costly or even unobtainable (i.e., long travel, dangerous location). However, AR and digital tools offer a way to experience a digital field trip. In research, Bursztyn and colleagues (2017) successfully implemented an AR field trip to the Grand Canyon for nearly 1000 students. They reported successful outcomes in not only knowledge acquisition but also student engagement. Similarly, Liou et al. (2017) created an AR experience for exploring the moon and adjacent constellations. In their experimental design, they found that the AR group outperformed the control in the learning performance and task performance of moon phases. Not only do the above examples allow students to experience a difficult topic, an AR support can allow students to replicate the experience as many times, in multiple locations, as needed without any degradation or change in content.

Reflective Observation

Reflective observation occurs during and after concrete experimentation. Reflection is the core of ELT as the role of evaluations in the experience reflection has shown to be a powerful strategy in knowledge acquisition (Moon, 2004). During this second stage, an individual reflects on the experience before making any final judgements associated with outcomes (Kolb, 1984). Students respond to questions about what they witnessed or thought during or after the experience. In many IBLLs, students must support their solutions to the problems and therefore, must reflect on why they believe their solution represents the best choice. Reflection is represented in all specific forms of instruction under the umbrella of IBLL. Furthermore, reflection along the path to solving the problem can also be a useful tool for teachers to understand student growth, and for students to reinforce what has been learned already (Kolb, 1984). Reflective observation can occur independently, can be facilitated by a teacher, or prompted via technology, like AR, with the goal to review the situation and find meaning. Students can utilize technology to reflect as individuals and also as part of a group. This reflection often requires students to pause during the learning activity or follow-up immediately upon completing the task, to ask higher level and reflective questions (e.g. How can this help solve the problem? Where else can this be applied?).

AR can provide an ideal platform to provide different reflective observation opportunities for all students (Chen et al., 2016). AR allows students to reflect by questioning throughout the learning project and at the completion. Both students and teachers can generate questions associated with the concrete experience stage which can be facilitated face-to-face, through digital mediums, and directly in learning applications. The inclusion of questions through AR technology is fairly new, however, Chen and colleagues (2016) utilized an AR children's storybook to identify emotions for students with autism spectrum disorder. Following the AR experience, students had to digitally match 6 facial expressions to match the screen depictions. Their findings indicate that AR has the potential to increase the understanding of emotion recognition through digital reflection following an AR experience.

Furthermore, AR experiences are typically completed on a mobile device and can be easily recorded through either internal features or a screen capture program. By recording an entire experience, students can watch their own recording of the learning sequence and reflect on both the overall process, as well as each individual task, before attempting the task again. The replication of viewing the task allows greater opportunities to reflect, which has benefits for all learners, specifically students who struggle with self-reflecting on a lesson experience. The repetition, reminders, and overall reflection can be powerful in enhancing learning throughout an IBLL experience.

Abstract Conceptualization

The third stage, abstract conceptualization, is the process in which students attempt to make sense of what they experienced during the project. Students must interpret events and identify relationships among concepts. Further, instruction paired with digital tools can be designed to aid student identification of themes, problems, patterns, and/or issues necessary for learning the new content (Kolb, 1984). Students utilize background knowledge and collect information to begin to apply it to solutions. Abstract conceptualization builds on previous knowledge and creates an environment where students generalize acquired knowledge in future environments. IBLLs require students to research a problem or question, often with technology, to gain knowledge on the topic to be addressed. They then must synthesize the new knowledge and decide how to apply the information to the problem. This can be accomplished through a synthesis of research, experimentation, and reflection. Through the first three stages, students begin to develop solutions to problems (PBL Works, 2020).

Experiences in AR can provide an avenue for students to build theories and questions from research and hands-on learning about how to apply new knowledge or skills. Through the creation of learner theories and inquiry, students can begin to develop a mastery before applying them to novel situations. For example, students with complex support needs often require assistance in independent navigation. These students can examine and research how to navigate streets using street signs through an AR fieldtrip, during the concrete experience stage, in the safety of the classroom. Following reflection of the activity, an AR application to safely navigate directions to a specific location can be introduced. These AR experiences can be programmed with directions, prompts, safety skills, and distances that may typically be provided by a teacher or paraprofessional. With the supervision of a teacher, parent, or other adult, a student can practice the skills learned in the classroom and apply them in a realistic and novel environment. For example, Smith et al. (2017) provided undergrad students with disabilities an AR application to find buildings on campus necessary to their daily life. They found the application to be significantly effective in improving students from 0% in baseline to nearly 100% upon completion of intervention. In a similar study, McMahon and colleagues (2015) compared the effectiveness of a paper map, Google Maps, and an AR application on the successful navigation to unknown businesses for students with disabilities in an undergraduate program. They found all interventions to improve independent navigation, but they noted that the AR condition was able to assist students to their destination without the need for in-person assistance.

Active Experimentation

Finally, active experimentation requires the student to generalize what they learned across environments. Students use newly acquired knowledge learned during abstract conceptualization and apply it to solve new or similar problems. Students are taught to ascertain how new knowledge can be implemented in different situations and contexts. If the student does not understand how learning will be useful or practical, then knowledge is likely to be forgotten rather quickly (Kolb, 1984). IBLLs often ask students to investigate problems, attain information on the problem, and formulate possible solutions. While the problems presented can vary immensely, they often lead students to form new questions. The cyclical nature of IBLLs allows students to take their newly formed understanding and apply it to the future problems as background knowledge.

AR is innately mobile, therefore, the ability to update, create new supports, and change environments allows it to be very useful in transitioning to another problem, project, or issue. Teachers can create markers in almost every environment and for almost every situation. This is done through pictures, objects, and locations. Using the navigation example from above, after safely navigating with a teacher, the AR application can become a lifelong tool for independent navigation to locations, such as a job or store. The device can be used for all navigation in almost any situation where GPS is available. Another practical example can be used for math experiences. Students can have formulas and processes available as a marker in the classroom. When examining a problem or question on a more difficult math topic, these formulas are always available for students. Since math topics often overlap, this would allow for explicit and replicable instruction available to all students, specifically students who struggle in math. In fact, Chao and Chang (2018) compared the use of an AR math application to a control and found the AR math application had statistically significant learning effects for students. Furthermore, students reported heightened motivation at a statistically significant level compared to the control. Overall, students will take what is learned in the stages and continue to use AR in different settings over time.

Supporting IBLL with Technology

The four stages of ELT offer the essential elements for today's IBLL experiences that align to implementation and are supported with technology. Again, we recognize inquiry-based learning, problem-based learning, and other specific methodologies are robust and require experience and time.

We offer experiential learning theory to provide a framework to not only begin transforming educational practices with digital tools, but to also provide an easier to follow introduction to IBLLs. By definition, ELT and IBLLs all offer a connection of background knowledge to new learning tasks, as a way to vary learning experiences through an assortment of actions and reflections related to a lesson. However, lessons and interventions based on IBLLs and the stages of ELT may not be feasible or sufficiently effective for all students. To benefit from ever-changing experiential learning expectations of today's classrooms, AR and other digital tools may provide all learners a solution where experiences and interactions can offer explicit instruction with varied opportunities to engage in learning rather than a singular learning approach (Chen et al., 2016). In this way, additional digital content may afford students with disabilities and those who struggle in the classroom, the support they need to learn new content through an IBLL.

We presented AR as a way to illustrate how an innovative digital tool can practically address the ELT stages of IBLL experiences. While AR seems to offer a promising support for struggling students, it is not the only option available to teachers. However, many technologies will take additional time to program, create, and implement. Fortunately for the time-pressed teacher, many applications are available at a low or free cost with content already created. This saves time by allowing teachers to download an application and begin use immediately. For example, Halo AR or Adobe Aero, readily available applications, have pre-created content but also a program to allow a user to take a picture of an object and upload any content to appear when that object is scanned. Ultimately, teachers can utilize pre-made content in combination with their own creations.

Implications for Students and Teachers

AR represents one of many digital tools that can be delivered in various formats, available via mobile devices as well as standard desktop and laptop computers, which most students already utilize. With this increased access and the potential of what these digital tools offer to learning, teachers need to understand the impact they can have on instructional practices. By utilizing digital tools to enhance instructional methods such as IBLL, teachers now have the ability to tailor learning situations with familiar mobile devices. Using devices that have large application stores, such as Google Play or Apple Appstore, can further offer teachers innovative digital tools to meet the needs of the increasingly diverse learners in their classroom, but it does not end in the classroom. Due to the mobile nature of tools such as AR, explicit and replicable instruction can be utilized outside of the classroom. This means that a student who may need support at home now has access to a number of digital support tools. If teachers plan instruction and thoroughly incorporate digitals tools to support their students, learning skills and generalizing those skills to new contexts can enhance, augment, and potentially expedite student competency.

Conclusion

This article sought to offer defining features of common experiential IBLL environments and examples of how AR can support struggling students through the independent completion of IBLLs. A variety of AR applications and other digital tools exist and will continue to grow in their ability to support struggling students, and all students in the classroom. As educators continue to adjust to the new normal associated with Covid-19, it is important that teachers understand the underlying components of IBLLs, and we hope the framework of ELT simplifies the complex nature surrounding the initial implementation of IBLLs. This understanding, coupled with knowledge of how digital tools (i.e., AR) promote implementation of IBLLs, can better support the diverse needs of all learners to be more independent, regardless of where they are physically, in school, at home, or in the community.

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