SCHOOL LIBRARY RESEARCH
Research Journal of the American Association of School Librarians

Volume 19, 2016
ISSN: 2165-1019

Approved May 5, 2016
www.ala.org/aasl/slr

Applying the Quadratic Usage Framework to Research on K–12 STEM Digital Learning Resources

Jennifer R. Luetkemeyer, doctoral candidate, Florida State University's School of Information

Marcia A. Mardis, Associate Professor, Florida State University's School of Information, Louis Shores Building, Florida State University, Tallahassee, FL 32306-2100

This research was supported, in part, by NSF grants 1044315 and 1449622.

Abstract

Numerous policymakers have called for K–12 educators to increase their effectiveness by transforming science, technology, engineering, and mathematics (STEM) learning and teaching with digital resources and tools. In this study we outline the significance of studying pressing issues related to use of digital resources in the K–12 environment and use the Quadratic Usage Framework of K–12 technology adoption to contextualize the results of a qualitative synthesis of published research. While we conclude that many traditional issues relating to educators' access, skill, policy, and motivation to use digital learning resources emerged clearly from the body of literature, new areas relating to resource curation, information seeking, educational data mining, and learning personalization provide particularly promising areas for further research.

Keywords: K–12, science, technology, engineering, mathematics, learning resources, digital, educator effectiveness

Introduction

Effective learning experiences center on two variables: high-quality learning resources and high-quality pedagogy (Chingos and Whitehurst 2012; Maull, Saldivar, and Sumner 2011); deeply intertwined, neither variable alone is sufficient to improve student achievement (Morris and Hiebert 2011). The role of good educational resources in K–12 education is so necessary that an ability to locate instructional information has been found to be a significant driver of teacher

quality. Confidence in the ability to integrate available resources can be used as an accurate proxy measure of educator effectiveness (Arslan 2010; Chingos and Whitehurst 2012).

While improving the quality of teaching would seem to be an obvious way to improve the quality of learning, the importance of improving access to digital resources cannot be understated. Many researchers have shown that the majority of K–12 teachers in the United States use digital media and technology in some aspect of their classroom instruction, with most teachers reporting that they use the Internet for searching, finding, retrieving, and using digital media such as games, activities, lesson plans, and simulations frequently or every day (PBS and Grunwald Associates 2011; Project Tomorrow 2010). The common standards movements, represented by the creation and adoption of the Next Generation Science Standards and the Common Core State Standards, promote digital resource use as a way of promoting a common resource base (Chingos and Whitehurst 2012; National Science Digital Library 2013).

In New Media Consortium's future-casting K–12 edition of the NMC Horizon Report expert panelists have consistently identified digital content, learning personalization, and educational data analytics as key elements of both near-term trends and solutions to challenges that are difficult to address (New Media Consortium 2012, 2013, 2014, 2015). A major activity for contemporary teachers, then, is to turn unorganized and disparate resources, lesson plans, and student data into high-quality, organized, validated technology-rich authentic learning opportunities with linked, meaningful assessments. The explosion of information and technology poses complications to all aspects of the learning process, and the approaches to integrating information and technology define the degree to which digital resources and tools can positively affect learning.

Although digital learning resources are mentioned with increasing regularity in research involving K–12 education, a single definition is elusive. For purposes of this study, digital learning resources are any form of digital media content that is used for educational purposes, including, but not limited to, text, images, and video (Clyde 2004; Harley 2007). This definition provides a framework for understanding that the move toward the use of digital learning resources in K–12 education is inherently a move away from relying on print-based resources. Because advances in science, technology, engineering, and mathematics (STEM) are national priorities, and STEM fields have long been well-supported by digital materials (Barker 2010; Braun et al. 2009; Duschl, Shouse, and Schweingruber 2007), digital resources are often first implemented in schools to support STEM learning (Fletcher, Schaffhauser, and Levin 2012; State Educational Technology Directors Association 2010).

Guided by an overarching desire to understand the relationship between national digital learning priorities, the shift to digital resources, and changes in learning and teaching, we conducted an extensive qualitative synthesis of the preceding decade's K–12 STEM digital learning resources research and policy literature. Using the Quadratic Usage Framework (QUF) for K–12 technology adoption (Marshall 2007; Mardis, Hoffman, and Marshall 2008), we analyzed the results for common themes, overarching conceptual structures, and directions for future research.

Method

Overview

We used a qualitative research synthesis method for this review because our objectives were descriptive and critical (i.e., assessing fit between article content and the conceptual framework

QUF), rather than meta-analytic (e.g., calculating an average effect size) (Sandelowski and Barroso 2007). This method informed our data collection and analysis.

Data Collection

On March 23, 2015, we conducted an advanced Boolean keyword search using OneSearch, a research-literature search tool available in the Florida State University Libraries. Our search string is below:

> *(“digital resource*” OR “digital learning resource*” OR “electronic resource*”) AND (instruction* or education*) AND ((elementary OR secondary* OR "K-12" OR “middle school” OR “high school”)) AND (science OR math* OR engineering OR technology)*

We selected OneSearch because it executes federated searches (searches in which a search engine can find and report results located by a second search engine) and faceted searches (searches including domain-specific terms) of literature contained in all Florida State University databases and library catalogs, and on the open Web.

We searched for journal articles, books, book chapters, reports, or conference papers based on three additional criteria: peer-reviewed literature, English language, published between 2000 and 2014. We did not specify exclusion criteria in the search statement. However, from the 2,306 results, we manually selected articles based on the additional criteria listed in the appendix. Our final search result included 486 articles.

Data Analysis

From those 486 articles, we assessed, selected, and abstracted articles in a three-step process. In the first step, each author assessed the articles for topical fit with the search. Articles that did not relate to the topic of this paper were excluded. Then, each of the authors reviewed the selected articles and assigned them one or more of the conceptual framework’s (QUF) thematic categories of access, skill, policy, and motivation. In the second step, we each wrote brief narrative summaries of the articles. In all, we synthesized 173 resources for this report.

Third, for analysis, we grouped the completed articles by theme according to the categories the Quadratic Usage Framework (QUF) proposed by Marcia A. Mardis, Ellen S. Hoffman, and Todd E. Marshall (2008) based on Marshall’s 2007 work. This framework provided a useful grouping of issues that pertain to effective use of digital learning resources. The QUF was first developed to articulate dimensions of “digital divides,” gaps that affected technology integration. The QUF “is a further evolution of…models which seek to explain dynamics of usage” which “does not assume that potential users have access or that they have the necessary knowledge, skills, or motivation necessary to participate” (Marshall 2007, 10). It is important to note that, rather than measuring acceptance, usage, or success, the QUF is intended to explain why technology is used or not used by the population of interest and identify the factors that influence that usage (Marshall 2007). The QUF has been used to examine K–12 technology adoption (Mardis, Hoffman, and Marshall 2008); Web 2.0 technology use in higher education (Mtega, Benard, and Dettu 2013); online resources’ availability and accessibility in a developing country (Dulle 2015); the use of e-resources by researchers and extension staff in Tanzania (Mtega et al. 2015); and the access and use of poultry-management information by farmers in rural Tanzania (Msoffe 2015). Because the QUF allows for an explanation of factors both internal and external to the user, it is ideal for identifying the issues surrounding the current move to digital resources in K–

12 education. The flexibility and inclusivity of this framework made it an ideal choice for examining the digital learning resource adoption, use, and evaluation.

Figure 1 illustrates the QUF and details its quadrants in the context of K–12 technology adoption.

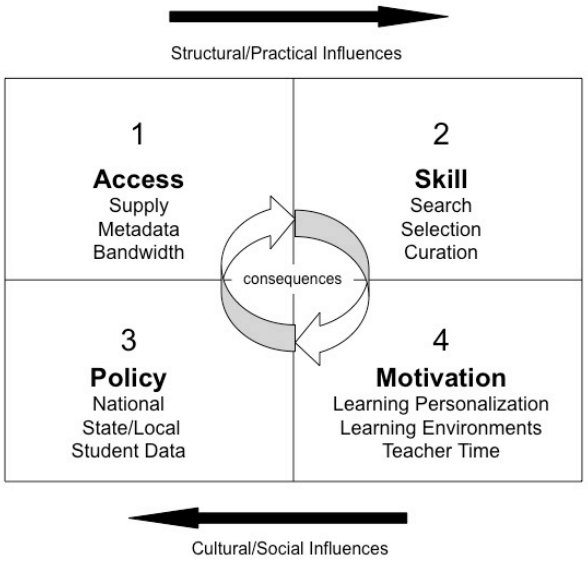

Figure 1. Quadratic Usage Framework from the perspective of K–12 technology adoption.

As Figure 1 illustrates, the framework's four quadrants of barriers include:

> **Access:** factors related to access to or use of the item itself.
>
> **Skill:** competency-related factors that affect the individual's skills, education, knowledge, and experience, which, in turn, impact whether the individual knows how to use the technology. These will vary from user to user.
>
> **Policy:** values as reflected in policy structures. Policy matters include impinging factors from the external environment, such as historic practices, organizational settings, and institutional policies, as well as cultural norms and values.
>
> **Motivation**: preferences, beliefs, traditions, and trust that are linked to the individual user's motivation and choice to use digital resources (Mardis, Hoffman, and Marshall 2008).

Each researcher independently coded each of the selected 173 resources' content for linkages to QUF quadrants and for major themes. To reach 100 percent agreement for the purposes of synthesis and reliability, the researchers compared the results of their independent coding efforts. Where item coding differed, the researchers discussed each item in order to reach a consensus.

Results

Arrangement of Section

In this section, we present a review of the major findings related to each QUF quadrant. To focus the results, we have selected dominant themes from the literature.

Access to K–12 STEM Digital Learning Resources

Overview

Access to resources, whether accomplished physically or virtually, is an essential facilitating condition of learning resource use. In this section, we address the supply of digital K–12 STEM education resources, their description, and access.

Digital Learning Resource Supply

A significant theme relating to access to digital learning resources is associated with the type of resources. Digital learning resources encompass text, videos, images, games, virtual experiences, online assessments, and other media forms. Issues relating to their access were primarily determined by whether the resources were fee-based or open educational resources (OER).

Regardless of the commercial or open nature of classroom instructional materials and textbooks, research suggests that students rely on OER for homework support and supplemental learning drivers (Davis et al. 2014). This finding suggests that, whereas large scale adoption of OER is seen as adoption of *educational resources that are open*, for many students, they are *resources for open education*, that is, the resources are freely available for self-directed learning. Figure 2 illustrates the distinction between educational resources that are open and resources for open education.

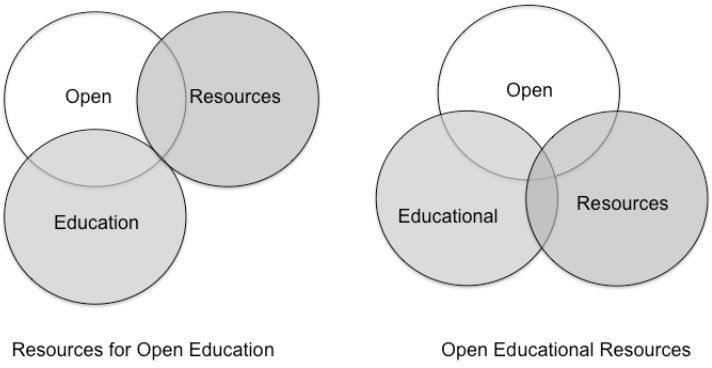

Figure 2. Territorial contrast between conceptions of OER.

As Figure 2 shows, OER can be resources specifically designed to support open education. This scenario is in line with open education environments, MOOCs, badging, and virtual schooling (Boston Consulting Group 2013; De Liddo 2010; Neary and Winn 2012). In contrast, looking at OER as educational resources that are open means that they can be used in any type of formal or informal learning environment.

Resource Granularity

A key concept related to a digital learning resource is its granularity (Littlejohn 2003). A learning object is the smallest grain (piece) of a digital learning resource. For example, a digital video clip is a learning object, which contrasts with a website containing a library of digital video clips. A digital learning object's physical parallel might be a single worksheet, textbook passage, or physical specimen. Because of their small size and targeted focus, fine-grained digital learning resources can be combined to provide activities of various lengths and purposes (Arslan, Gök, and Saltan 2010; Griffith 2003). Digital resources can be combined in a number of different ways or tailored for different audiences (Kay and Knaack 2007, 2008; Pattuelli 2006; Sing and Chew 2009).

Description

Metadata schemata for learning objects are extensions of classification and organization schemes used for physical media such as books. In addition to reflecting descriptive information about the object, metadata have been used to reflect more characteristics of effective learning objects. At a glance, teachers want to know if a digital resource:

- Is motivating to the learner;
- Is controlled by the learner;
- Is designed with appropriate media, colors, text size, sophistication, and placement of information;
- Contains clearly stated and enough questions and activities;
- Supports further learning (Arslan, Gök, and Saltan 2010; Leary et al. 2011).

However, capturing these characteristics in metadata that remain flexible enough to adapt to the changing needs of educators is a challenge and has encouraged fresh looks at approaches to resource description.

Adequate Bandwidth

Use of digital learning resources such as video clips can be difficult for teachers because of skipping, pausing, or slow buffering, problems that indicate that the device and/or infrastructure do not have the ability to handle intense Internet activity (Mardis 2009). About 78 percent of teachers have difficulties at least part of the time, and up to a quarter consistently have problems (PBS and Grunwald Associates 2011). The majority of these difficulties are due to inadequate bandwidth.

In many schools, bandwidth capacity dictates how teachers integrate online resources into their classrooms. While 99 percent of public schools in the United States report having Internet access, classroom connections are less frequent (Snyder and Dillow 2011). Even if classroom access is available, many building-level policies impede the integration of the Internet into teaching and learning. A 2010 survey revealed that many (over 80 percent) school connections were not meeting school officials' needs because the connections were overloaded and poorly

managed, leading to slow performance or restricted use (Federal Communications Commission 2010). For example, in a study done in Michigan, education officials reported having to develop and enforce bandwidth-use policies that limited video streaming and other high-capacity uses (Mardis 2009). The Michigan finding was confirmed by the overwhelming majority of respondents to a nationwide survey of school officials who reported that their networks were too slow to support video streaming. This factor influenced teachers' use of the Internet in their classrooms as much as their skills with technology integration influenced their use of digital resources (Federal Communications Commission 2012).

Skills

For many teachers, using digital learning resources provided an entry point into technology integration when physical resources were replaced by free, high-quality digital resources. If the teacher's goal was to improve students' skills by means of practice with interactive digital resources, then the act of swapping out and updating resources was often a first step. The creation and sharing of resources in the context of teaching and learning should be seen as a cornerstone skill for educators (Mardis, Hoffman, and Marshall 2008). Although replacing physical resources in existing lessons with digital resources is often a teacher's first step in technology integration (Haughey and Muirhead 2005), this step is influenced by the teacher's ability to locate, select, and manage resources (Sappey and Relf 2010). Continued use of digital resources is highly dependent on teachers' abilities to reuse and adapt the digital learning resources they trust (Pattuelli 2007).

Search

As designers of learning activities, teachers are enabled and constrained by the digital resources available to them (Recker et al. 2007). Teachers who lack sufficient skill to integrate digital learning materials continue to use non-digital resources and, thus, have fewer technology-enhanced teaching opportunities (Perrault 2007b). Currently, limited research results are available to describe teachers' online information-searching behaviors (Maull, Saldivar, and Sumner 2010). In the studies that *have* been conducted and published, teachers reported that they are increasingly overwhelmed by the process of locating, aligning, and adapting materials amidst the abundance of online resources that could potentially support their curriculum planning (Maull, Saldivar, and Sumner 2010; Perrault 2007b).

Indeed, many teachers are not prepared to enter the classroom with the information skills they need to locate, evaluate, and effectively use resources that would enhance their instruction. Consequently, many teachers are not prepared to teach information and research strategies to their own students (Duke and Ward 2009). For example, one study of pre-service teachers showed that 36 percent did not have the necessary knowledge to use search engines effectively; 77 percent did not understand the principles of Web technology that created the indexes used by search engines; and the pre-service teachers used a limited selection of operators to narrow search results (Laverty, Reed, and Lee 2008). The lack of ability to locate, select, or manage resources has a constraining effect on instruction. When planning curriculum and instruction, pre-service teachers who were not only unfamiliar with content but were also not confident in finding or selecting resources referred to textbooks and web-based teaching resources created by publishers when making critical decisions about materials and resources (Lai and Lam 2011).

Although in-service teachers perceived themselves as proficient in finding online materials for curriculum planning, many teachers surveyed did not report that they were comfortable finding information in specific tools like periodical databases or educational digital libraries, especially

in the area of finding applicable digital learning resources within larger collections (Perrault 2007a). Like their pre-service counterparts, in-service teachers' information seeking tended to be a recursive process of integrating a quickly located online resource into practice, discovering its shortcomings, and going back to search again (Perrault 2007a). Teachers frequently reported using a Web search engine for a quick look for age-appropriate resources on a specific topic rather than exploring databases or digital libraries that the teachers recognize as more reliable (Perrault 2007b). Teachers stated that they felt that the time they saved by performing a quick Web search outweighed the "satisficing" nature of their compromises about resources to use.[1] Perhaps because teachers typically rely upon their files and ideas from colleagues for their curriculum planning (Perrault 2007b; Williams and Coles 2007), few teachers reported believing that mastery of search skills is an integral part of their practice (Duke and Ward 2009).

Selection

The Web can be characterized as a double-edged sword for teachers: a wealth of educational content is available, but searches return many results, and separating good resources from bad resources can be a time-consuming challenge. Even when teachers have excellent search skills, they can struggle with resource selection because of wide-ranging ideas of what defines resource quality and the complexities of aligning resources with STEM curriculum standards (Mervis 2009). For example, Lecia Barker (2010) found that science teachers considered the most important qualities of digital resources to be: available for free, contains information about grade level and reading level, includes descriptions of the time and resources needed, and incorporates graphics and video. While studies of science teachers showed that many teachers shared these preferences, subsequent questioning revealed that their preference statements were not based on feeling that aspects like standards linkages and reputable creators were unimportant, but that the teachers felt that they did not have the time or expertise to evaluate resources for these qualities (Perrault 2007a). Most online materials encountered in a Web search are not aligned with the curricula of a school or with state standards, a circumstance that makes these resources harder for teachers to use (Mervis 2009).

Curation

Due to the sheer quantity of digital learning resources available, curation is crucial to ensure that evolving definitions of quality are reflected in the collection (State Educational Technology Directors Association and EducationCounsel LLC 2014). Some in the educational community refer to the "great piles of stuff" that are composed of accessible learning resources that should be transformed into "piles of great stuff" (Zia 2009, 121) that is current, content-rich, authoritative, and effective in communicating learning concepts. This idea of not just collecting the resources, but of actively seeking them out in response to curriculum needs, stakeholder priorities, and learning personalization concerns, puts school librarians in the dynamic role of curator. Resources must be described and organized in ways that maximize access (State Educational Technology Directors Association 2010).

Organization and management also pose issues for many educators. While teachers who lack information-seeking skills are less likely to seek new materials, for many, their most significant and frustrating challenge is how to organize the materials they *do* have for use in future instructional events (Diekema and Olsen 2011).

[1] In this context, "satisficing" refers to settling for a satisfactory item rather than trying to find the very best item.

Even when teachers are exposed to information skills in their pre-service training and through professional development, this exposure tends to follow generic process-oriented models that do not address teachers' unique needs for ready identification of resources that are context-specific, grade-appropriate, proven to be effective, curriculum-aligned, reputable, customizable, and supportive of authentic learning tasks (Markless and Streatfield 2009; Sing and Chew 2009). Classroom context is another important consideration for the effective use of digital resources in instruction (Pattuelli 2006). However, the ability to locate these resources again is just as important as finding them in the first place.

Teachers' lack of confidence in their own information-management skills affects more than just their instruction. Some researchers (e.g., Puustinen and Rouet 2009) pointed to barriers and enablers to teaching and learning created by unskilled resource management. Anna L. Ball, Neil A. Knobloch, and Sue Hoop explored the link between teachers' access to resources and planning practices in which digital learning "materials influence instructional capacity by constraining or enabling students' and teachers' opportunities to learn and teach" (2007, 4). Andrew Gitlin (2001) reported that teachers in a case study who could not quickly call upon interesting STEM digital learning resources for their teaching followed the state core curriculum very precisely and relied on textbooks and pre-packaged curricula. This adherence led to instruction that did not engage students and was ineffective for transferring concepts. This behavior not only affects instruction, but also affects learning on many levels because STEM teachers, school librarians, and other educators are expected to act as models and mentors for students' development of information strategies (Project Tomorrow and PASCO Scientific 2008), and personal organization is an important aspect of academic success.

Policy

Issues Overview

The State Educational Technology Directors Association (SETDA) provided a comprehensive list of policy issues for the implementation of digital learning resources. The list included examining policies and practices around technology use, intellectual property and reuse rights, student data access, and national and state policies (Fletcher, Schaffhauser, and Levin 2012).

National Educational Policies

Promoting adoption of digital textbooks or collections of high-quality interactive digital multimedia learning content has been a high-priority goal for United States federal education initiatives (Digital Textbook Collaborative 2012). Federal agencies have issued three directives:

1. Create an "integrated approach for capturing, aggregating, mining, and sharing content...for multiple purposes...across many learning platforms" (Office of Educational Technology 2010, 78),
2. "Take steps to create a pool of digital educational resources" (Federal Communications Commission 2010, 246), and
3. "Information created or commissioned by the Government for educational use by teachers or students and made available online should clearly demarcate the public's right to use, modify, and distribute the information" (Orszag 2009, 8).

These directives were in response to recent national forces that have dramatically changed the internal structure and function of information and technology in K–12 organizations in the United States. These forces are: the Department of Education's Race to the Top (RT3) funding; and the common standards movement that includes creation and implementation of the Common Core State Standards (CCSS), the Next Generation Science Standards (NGSS), and college and career readiness standards (Project Tomorrow 2012).

RT3 applications require state and local education agencies to establish instructional improvement systems (IIS) through which student data, teacher profiles, learning resources, and assessment results are integrated to generate rapid, personalized feedback that allows teachers to individualize and differentiate instruction (Saldivar 2012). These IIS datapoints create a closed loop among teaching and learning resources, instruction, and assessment that allows teachers to personalize learning content, process, product, and environment for each student (Manderson 2012). Fundamental to this process are policies that require schools to provide a repository of vetted common standards-linked learning and assessment resources upon which to base instruction (U.S. Dept. of Education 2013). Also essential are IIS data, instructional technology, a virtual learning platform, digital textbooks, and other learning systems interoperability. Unfortunately, there is little research on the extent to which K–12 schools will be able to incorporate data and tools to affect real change and meet common standards (Project Tomorrow 2012).

The Common Core State Standards movement is generating a common curriculum framework to be used by all states that adopt the standards. This large national effort is prompting developers of digital libraries to consider new applications that support teachers' use of the new standards. These new applications bring together metadata, paradata (data about usage combined with information about context of the uses), and curated collections in ways that enable consistent instructional products with little reliance on educators' information skills. Instructional resources and products of consistent quality are a core component of effective instruction and strong student learning. Consistent instructional products can more easily be built in a system that is based on a shared purpose and when multiple sources of innovation are included in the process (Davis and Krajcik 2005).

State Instructional Materials Policies

State laws, many of which have been rewritten to include digital content as an acceptable use of state funding intended for textbook purchases, are catalysts that spur the transition to digital learning resources. Already, major advancements in—and support for—digital textbooks have occurred in Indiana, Virginia, West Virginia, California, and Texas (State Educational Technology Directors Association 2010). Florida has enacted the Digital Learning Now Act that mandates that public schools use at least 50 percent digital instructional materials by the 2015–16 school year. This move is significant not only because Florida is a textbook-adoption benchmark state, but also because the law is the first of its kind. Two other states now have similar laws. California's legislation encourages, but does not mandate, digital textbooks in public schools by 2020. In 2010 Illinois passed legislation redefining textbooks to include digital formats. The Florida law is the most ambitious measure, but many states are soon to follow (Mickey and Meaney 2014; Mickey et al. 2012). However, digital textbooks are not necessarily spurring a move to states' promotion of digital learning content. Rather, textbook publishers are still controlling content and even populating supplementary materials lists with their fee-based content (Mickey and Meaney 2010).

A SETDA report outlined some recommendations for states and districts to make the switch from print to digital resources as soon as their next adoption cycle occurred, but not later than the 2017–2018 school year. The development of a clear plan for making the switch and communication of that plan were deemed imperative. Such a plan would include a revision of policies, significant investment in the technology to support the move to use digital resources, and an implementation of procedures that support key stakeholders during the move. SETDA encouraged collaborative efforts "to create alternative, flexible models for the creation, acquisition, distribution, and use of digital content" (Fletcher, Schaffhauser, and Levin 2012).

Student Data Policies

In isolation, the connection between learning resources and student outcomes can be difficult to trace (Saljo 2010). However, public education in the United States is tied to accountability measures designed to ensure that only innovations that yield strong student achievement are implemented (Valli and Buese 2007). Teachers have little access to information about the past performance of their students, what other teachers noted, and each learner's strengths, weaknesses, and individual needs. New personalization technologies and the demand for differentiated instruction as a Common Core strategy will place further strains on the ecosystem of data systems and paper-based records that form the patchwork of student records (Bailey et al. 2012). Learner profiles can ensure a continuous gathering of evidence of student learning. When teachers have access to student achievement data on an ongoing basis, they are willing to make instructional changes in response to these data (PBS and Grunwald Associates 2011) and to seek digital learning resources that best fit the learning task and individual learner. However, privacy concerns relating to student data have spurred a number of court cases and hearings relating to current policies about student records and their possible lack of compliance with the Family Educational Rights and Privacy Act (FERPA) and state privacy laws (Bailey et al. 2012). Still, resolving the tension between privacy and achievement may be the only way to understand the roles digital resources play in each students' learning (Manderson 2012).

Motivation

Expanding the Scope of Use

Teachers are not only using digital resources in their planning, management, and assessment processes. Educators are also changing the culture of teaching and learning by participating in technology-mediated professional exchanges, making use of and creating annotations and feedback for learning objects, and having students center their activities on digital resource location, use, creation, and sharing in learning (Leary et al. 2009, 2011).

Learning Personalization

With a variety of instructional media available to educators, selecting the appropriate instructional format to stimulate a learner's motivation is a critical decision. One study evaluated learners' perceptions of motivation in response to a range of digital learning resources and found that the 96 participants had definite preferences for resource types that motivated them to engage in a learning task (Rodgers and Withrow-Thorton 2005). Proponents of the growing trend toward personalization advocate that teachers should more deeply explore the possibilities of the

electronic media and technology for tailoring learning experiences. Despite the numerous potential advantages of digital materials, teachers often lack the time, technical skill, and pedagogical knowledge range to respond to the challenges of personalizing learning and differentiating instruction (Konings et al. 2007). To empower children to become active participants in their own learning and ensure the desirable effects of digital learning materials, teachers should cultivate strategic knowledge about resource curation and use.

Despite the money and time spent on training primary and secondary teachers to customize learning experiences by integrating technology into their practice, researchers have observed few results in instruction and learning (Spaulding 2010). As policymakers' expectations of teachers have intensified in the areas of personalization, these expectations often had negative consequences for teachers' relationships with their students, pedagogical innovation, and sense of professional well-being (Valli and Buese 2007). Myriad challenges affect use and integration of digital learning resources in personalization, primarily due to many teachers' difficulties in finding and vetting quality resources as well as their ongoing curation of those resources (Fletcher, Schaffhauser, and Levin 2012; LEAD Commission 2013).

This wide variation in approaches to personalizing learning results in a wide disparity in student achievement. In addition to great variations in the ways teachers seek and select resources for learning, the ways in which they plan and assess learning also undermine consistent student experiences from teacher to teacher, school to school, and academic year to academic year.

The number of students now receiving learning support services in the traditional classroom is the highest in U.S. history (Mervis 2009), and many teachers struggle to support them, especially in learning STEM topics (van Garderen et al. 2009; Lee 2005). Using material from the Web is difficult for teachers who need to be able to tailor the material to the needs of individual students, yet digital resources have the potential to diversify the way teachers represent concepts and processes with images, simulations, tutorials, and other resources tailored to the learner's needs. For students to build upon and connect concepts requires a supportive learning environment dependent upon the teacher's skills in selecting appropriate resources and structure for activities to bridge the gap between classroom content and informal knowledge, that is, knowledge gained through active participation and knowledge creation (Hennessy et al. 2007).

Teacher Time

In almost every study of teachers' use of technology integration and instructional innovation, the issue of time is identified as a barrier to optimal use of digital resources. Teachers average about ten hours of planning a week (Ball, Knobloch, and Hoop 2007), and the majority of the time they spend online looking for curriculum materials occurs during the school day (Mardis 2009). Teachers have said that they do not have enough time to incorporate digital resources into instruction because of the time it takes to locate learning objects and preview websites, and the hours it would take to define and engage in professional development to upgrade their skills (Cuban, Kirkpatrick, and Peck 2001; Warschauer and Matuchniak 2010).

It is very likely that priorities for using precious time are also a matter of confidence and perceived value. Teachers are unlikely to invest time in activities they do not feel confident about doing (Recker et al. 2007) and for which they do not see a benefit (van den Berg 2002). Therefore, to change teachers' behavior in digital resource use and curriculum planning, a digital tool would have to be easy to use and demonstrate immediate differences in student time on task and achievement (Maull, Saldivar, and Sumner 2010).

Discussion

QUF

In this paper, we integrated an extensive body of research and literature to provide an overview of challenges relating to use of digital learning resources in K–12 STEM education. We premised this study on the importance of studying K–12 environments as complex information organizations that must respond to a range of external influences, such as the current national focus on STEM learning.

As we inventoried and integrated the literature, it was clear that the research topics mapped well to the K–12 tailoring of the QUF proposed by Mardis, Hoffman, and Marshall (2008) relating to access, skill, policy, and motivation. As Figure 1 suggested, there are four main areas in the results of this synthesis. The top two quadrants, labeled Access and Skill, are structural and practical aspects of digital resource use, while the bottom two quadrants, Policy and Motivation, are manifestations of social and cultural priorities and trends.

Access

In the area of access, we considered affordances for accessing K–12 STEM digital learning resources. Concerns about the number of available resources (both fee-based and open) emerged, as did the importance of tailored educational metadata to enhance the findability of resources. Bandwidth also emerged as a necessary conveyance of video, large data sets, simulations, and other resource types that are best used over high-speed Internet connections.

Skill

Digital resource use also appeared to depend on a suite of skills. Because this synthesis focused on formal K–12 STEM learning, the literature in this quadrant focused mainly on teachers' abilities to search for, select, organize, and manage resources to effectively involve the resources in the educators' workflow and instructional events.

Policy

Policy matters were also a major feature of digital resource use, not only in national movements toward common standards and instructional improvement, but also in state-level moves to rethink instructional materials funded and to use student data to more closely link instruction, learning materials use, and student outcomes.

Motivation

Motivation is, of course, an essential component of digital resource use, and the desire to personalize learning, create appropriate learning environments, and save time affect teachers' willingness to use digital learning resources.

Interdependencies

As the curved arrows in the center of the Figure 1 suggested, the topics in each of the quadrants have relationships, or consequences, for the other quadrants; no quadrant is independent. However, as Mardis, Hoffman, and Marshall (2008) suggested, motivation is the most powerful quadrant because the desire to engage in digital learning resource use, regardless of challenges present in other quadrants, is essential.

Conclusion

In this research synthesis, we examined the factors surrounding digital resource use in K–12 STEM learning. As with any exploration that is designed to be both descriptive and critical, the results of this synthesis are limited by the research available as well as by the author-imposed bounds on the topic. Nevertheless, as with the adoption of other information-mediated changes in schools, in the context of digital learning resources the challenges, research opportunities, and necessary conditions for use of these resources fall in four areas: access, skill, policy, and motivation.

Contemporary learning resources are increasingly digital, and their use requires not just keen information skills, but also knowledge of ways to integrate digital resources in ways that enable all learners (Mardis et al. 2012). Educators' confidence in resource selection is a precursor to their confidence in the use of a wider range of tools that enable higher-quality feedback and deeper student engagement (National Academy of Sciences 2010; Project Tomorrow 2014; Rotherham and Willingham 2009; Silva 2008).

Implications for Practice and Research

The framework provided by QUF offers researchers and practitioners a starting point to engage with digital resources in K-12 STEM digital learning. A natural next step would be to operationalize the framework with needs assessment and evaluation instruments that allow stakeholders to measure the extent to which the framework is present within a learning environment. Our research results provide an initial checklist of features that researchers and school library practitioners may wish to inventory to determine the fit between their school conditions and the framework.

As policymakers and school administrators increasingly embrace learning personalization through the deployment of OER, researchers can work with school librarian practitioners to evaluate implementation environments and determine which quadrants of barrier are particularly present. Knowledge of potential pitfalls can be very useful in planning implementation and professional development efforts. Similarly, since in many ways, these quadrants also provide a continuum, researchers and evaluators can work together to determine whether a school is progressing through barriers or getting stuck in one particular area of hindrance.

Finally, the results presented here suggest that school librarians must vigorously engage in the curatorial enterprise by integrating digital resources, particularly OER, with their physical collections. This broadening of collection scope will require new decisions about which information to capture about a resource and how to create a central repository through which all resources are accessible in and beyond the school day. Accumulation, description, and access must be accompanied by a thoughtful effort to promote resources to educators and learners;

evaluation of the extent to which they are meeting learners' needs; and constant attendance to resources' quality and fit with the curriculum.

Seamless and extensive meaningful integration of technology in all aspects of teaching and learning is essential if the various organizations' visions of 21st-century skills articulated are to be realized. Regardless of the QUF quadrant in which an educator's issues with using digital learning resources fall, reforms that focus on improving the act of instruction without examining how educators are motivated to select and use the information and technology that undergirds instruction are incomplete.

Works Cited

Arslan, K. 2010. "Evaluation of Learning Objects from Different Aspects of Effectiveness: Learning, Learning Object Benefit, and Learning Object Quality." In *Proceedings of Society for Information Technology and Teacher Education International Conference 2010*, edited by D. Gibson and B. Dodge, 2143–49. Chesapeake, VA: Association for the Advancement of Computing in Education.

Arslan, K., A. Gök, and F. Saltan. 2010. "Motivating Teachers to Use Learning Objects." In *Proceedings of Society for Information Technology and Teacher Education International Conference 2010*, edited by D. Gibson and B. Dodge, 2637–44. Chesapeake, VA: Association for the Advancement of Computing in Education.

Bailey, J., et al. T. 2012. *Data Backpacks: Portable Records and Learner Profiles*. <http://digitallearningnow.com/site/uploads/2012/10/DLN-Smart-Series-Databack-Final1.pdf> (accessed May 21, 2016).

Ball, A. L., N. A. Knobloch, and S. Hoop. 2007. "The Instructional Planning Experiences of Beginning Teachers." *Journal of Agricultural Education* 48 (2): 56–65. <www.jae-online.org/attachments/article/176/Ball_etal_48_2_56-65.pdf> (accessed May 21, 2016).

Barker, L. 2010. "Science Teachers' Search Behaviors, Resource Preferences, and Classroom Technology." In *Proceedings of Society for Information Technology and Teacher Education International Conference 2010*, edited by D. Gibson and B. Dodge, 1340–1345. Chesapeake, VA: Association for the Advancement of Computing in Education.

Boston Consulting Group. 2013. *The Open Education Resources Ecosystem: An Evaluation of the OER Movement's Current State and Its Progress toward Mainstream Adoption*. <www.hewlett.org/sites/default/files/The Open Educational Resources Ecosystem.pdf> (accessed May 21, 2016).

Braun, H., et al. 2009. *Exploring What Works in Science Instruction: A Look at the Eighth-Grade Science Classroom*. Princeton, NJ: Educational Testing Service. <www.ets.org/Media/Research/pdf/PICSCIENCE.pdf> (accessed May 21, 2016).

Chingos, M. M., and G. J. Whitehurst. 2012. "Choosing Blindly: Instructional Materials, Teacher Effectiveness, and the Common Core." Washington, DC: Brown Center on Education Policy, Brookings Institution. <www.brookings.edu/~/media/research/files/reports/2012/4/10-curriculum-chingos-whitehurst/0410_curriculum_chingos_whitehurst.pdf> (accessed May 21, 2016).

Clyde, L. A. 2004. "Digital Learning Objects." *Teacher Librarian* 31 (4): 55–57.

Cuban, L., H. Kirkpatrick, and C. Peck. 2001. "High Access and Low Use of Technologies in High School Classrooms: Explaining an Apparent Paradox." *American Educational Research Journal* 38 (4)*:* 813–34.

Davis, E. A., and J. S. Krajcik. 2005. "Designing Educative Curriculum Materials to Promote Teacher Learning." *Educational Researcher* 34 (3): 3–14.

<www.project2061.org/research/ccms/site.archive/documents/Promote_Teacher_Learning.pdf> (accessed May 21, 2016).

Davis, J. D., et al. 2014. "Factors Underlying Middle School Mathematics Teachers' Perceptions about the CCSSM and the Instructional Environment." *Middle Grades Research Journal* 9 (3): 11+.

De Liddo, A. 2010. "From Open Content to Open Thinking." In *World Conference on Educational Multimedia, Hypermedia and Telecommunications (Ed-Media 2010)*, Toronto, Canada, 3178–83. <http://oro.open.ac.uk/22283/1/De-Liddo-Ed-Media2010.pdf> (accessed May 21, 2016).

Diekema, A., and M. W. Olsen. 2011. "Personal Information Management Practices of Teachers." *Proceedings of the American Society for Information Science and Technology* 48 (1). <http://onlinelibrary.wiley.com/doi/10.1002/meet.2011.14504801189/pdf> (accessed May 21, 2016).

Digital Textbook Collaborative. 2012. *The Digital Textbook Playbook.* <http://transition.fcc.gov/files/Digital_Textbook_Playbook.pdf> (accessed May 21, 2016).

Duke, T. S., and J. D. Ward. 2009. "Preparing Information Literate Teachers: A Metasynthesis." *Library and Information Science Research* 31 (4): 247–56. <doi:10.1016/j.lisr.2009.04.003>.

Dulle, F. W. 2015. "Online Information Resources Availability and Accessibility: A Developing Countries' Scenario." *African Journal of Library, Archives and Information Science* 25 (1).

Duschl, R. A., A. W. Shouse, and H. A. Schweingruber. 2007. "What Research Says about K–8 Science Learning And Teaching." *Principal* 87 (2): 46–50.

Federal Communications Commission. 2010. *2010 E-Rate Program and Broadband Usage Survey: Report.* (DA 10-2414). <https://transition.fcc.gov/010511_Eratereport.pdf> (accessed May 21, 2016).

———. 2012. *Eighth Broadband Progress Report.* (FCC 12-90). <http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-12-90A1.pdf> (accessed May 21, 2016).

Fletcher, G., D. Schaffhauser, and D. Levin. 2012. *Out of Print: Reimagining the K–12 Textbook in a Digital Age*. Washington, DC: State Educational Technology Directors Association. <http://files.eric.ed.gov/fulltext/ED536747.pdf> (accessed May 21, 2016).

Gitlin, A. 2001. "Bounding Teacher Decision Making: The Threat of Intensification." *Educational Policy* 15 (2): 227–57. <doi:10.1177/0895904801015002001>.

Griffith, R. 2003. *Learning Objects in Higher Education*. Madison, WI: Academic Advanced Distributed Learning Co-Lab. <www.academiccolab.org/resources/webct_learningobjects.pdf> (accessed May 24, 2016).

Harley, D. 2007. "Use and Users of Digital Resources." *Educause Quarterly* (4): 12–20. <https://net.educause.edu/ir/library/pdf/EQM0742.pdf> (accessed May 24, 2016).

Haughey, M., and B. Muirhead. 2005. "Evaluating Learning Objects for Schools." *E-Journal of Instructional Sciences and Technology* 8 (1). <http://files.eric.ed.gov/fulltext/EJ850358.pdf> (accessed May 24, 2016).

Hennessy, S., et al. 2007. "Pedagogical Approaches for Technology-Integrated Science Teaching." *Computers & Education* 48 (1): 137–52. <doi:10.1016/j.compedu.2006.02.004>.

Kay, R., and L. Knaack. 2007. "Evaluating the Use of Learning Objects for Secondary School Science." *The Journal of Computers in Mathematics and Science Teaching* 26 (4): 261.

Kay, R. H., and L. Knaack. 2008. "A Formative Analysis of Individual Differences in the Effectiveness of Learning Objects in Secondary School." *Computers & Education* 51 (3): 1304–20.

Konings, K. D., et al. 2007. "Participatory Design in Secondary Education: Is It a Good Idea? Students' and Teachers' Opinions on Its Desirability and Feasibility." *Educational Studies* 33 (4): 445–65.

Lai, E., and C.-C. Lam. 2011. "Learning to Teach in a Context of Education Reform: Liberal Studies Student Teachers' Decision-Making in Lesson Planning." *Journal of Education for Teaching* 37 (2): 219–36. <doi:10.1080/02607476.2011.558287>.

Laverty, C., B. Reed, and E. Lee. 2008. "The 'I'm Feeling Lucky Syndrome': Teacher-Candidates' Knowledge of Web Searching Strategies." *Partnership: The Canadian Journal of Library and Information Practice and Research* 3 (1): 1–19. <https://journal.lib.uoguelph.ca/index.php/perj/article/view/329/743#.V0SJrfkrK70> (accessed May 24, 2016).

Leading Education by Advancing Digital (LEAD) Commission. 2013. "Paving a Path Forward for Digital Learning in the United States." <https://etcjournal.files.wordpress.com/2013/06/lead-commission-blueprint-final.pdf> (accessed May 24, 2016).

Leary, H., et al. 2009. "Developing a Review Rubric for Learning Resources in Digital Libraries." In *Proceedings of the 9th ACM/IEEE-CS Joint Conference on Digital Libraries*, 421–22. New York: Association for Computing Machinery.

Leary, H., et al. 2011. "Developing and Using a Guide to Assess Learning Resource Quality in Educational Digital Libraries." In *Digital Libraries—Methods and Applications*, edited by K. H. Huang. Rijeka, Croatia: InTech. <http://www.intechopen.com/books/digital-libraries-methods-and-applications/developing-and-using-a-guide-to-assess-learning-resource-quality-in-educational-digital-libraries> (accessed May 24, 2016).

Lee, O. 2005. "Science Education with English Language Learners: Synthesis and Research Agenda." *Review of Educational Research* 75 (4): 491–530.

Littlejohn, A. 2003. *Reusing Online Resources: A Sustainable Approach to E-Learning*. Sterling, VA: Kogan Page.

Manderson, D. 2012. *Evolving Personalized Learning: Maximizing K12 Expenditures To Support Instructional Reform*. <www.imsglobal.org/sites/default/files/i3lc/201211-EvolvingK12PersonalizedLearning-FNL.pdf > (accessed May 24, 2016).

Mardis, M. A. 2009. "Viewing Michigan's Digital Future: Results of a Survey of Educators' Use of Digital Video in the USA." *Learning, Media and Technology* 34 (3): 243–57. <doi:10.1080/17439880903141539>.

Mardis, M. A., and K. Howe. 2010. "STEM for Our Students: Content or Co-conspiracy?" *Knowledge Quest 39* (2): 8–11.

Mardis, M. A., E. S. Hoffman, and T. E. Marshall. 2008. "A New Framework for Understanding Educational Digital Library Use: Re-Examining Digital Divides in U.S. Schools." *International Journal on Digital Libraries* 9 (1): 19–27. <doi:10.1007/s00799-008-0035-z>.

Mardis, M. A., et al. 2012. "The Digital Lives of U.S. Teachers: A Research Synthesis and Trends to Watch." *School Libraries Worldwide* 18 (1): 70–86.

Markless, S., and D. Streatfield. 2009. "Reconceptualising Information Literacy for a Web 2.0 Environment?" In *Handbook of Research on Social Software and Developing Community Ontologies*, edited by S. Hatzipanagos and S. Warburton, 316–34. Hershey, PA: Information Science Reference.

Marshall, T. E. 2007. "A New Model For Explaining Technology Usage: The Quadratic Usage Model." <www.researchgate.net/publication/296112510_A_New_Model_for_Explaining_Technology_Usage_The_Quadratic_Usage_Model> (accessed May 25, 2016).

Maull, K. E., M. G. Saldivar, and T. Sumner. 2010. "Online Curriculum Planning Behavior of Teachers." Paper presented at the Third International Conference on Educational Data Mining, Pittsburgh, PA. <http://educationaldatamining.org/EDM2010/uploads/proc/edm2010_submission_54.pdf > (accessed May 24, 2016).

———. 2011. "Understanding Digital Library Adoption: A Use Diffusion Approach." Paper presented at the Joint Conference on Digital Libraries, Ottawa, Canada. <www.cs.colorado.edu/~lizb/phd/sumner1.pdf> (accessed May 25, 2016).

Mervis, J. 2009. "NSF Rethinks Its Digital Library." *Science* 323 (5910): 54–58. <doi:10.1126/science.323.5910.54>.

Mickey, K., and K. Meaney. 2010. *Simba Information's 2010 National Textbook Adoption Scorecard and 2011 Outlook*. Stamford, CT: Market Research Group.

———. 2014. *Publishing for the PreK–12 Market 2014–2015*. Stamford, CT: Market Research Group.

Mickey, K., et al. 2012. *K–12 Technology Tools and Trends 2012*. Stamford, CT: Market Research Group.

Morris, A. K., and J. Hiebert. 2011. "Creating Shared Instructional Products: An Alternative Approach To Improving Teaching." *Educational Researcher* 40 (1): 5–14. <doi:10.3102/0013189x10393501>.

Msoffe, G. E. 2015. "Access and Use of Poultry Management Information in Selected Rural Areas of Tanzania." PhD diss., University of South Africa. <http://uir.unisa.ac.za/bitstream/handle/10500/19021/dissertation_msoffe_gep.pdf?sequence=1> (accessed May 25, 2016).

Mtega, W. P., R. Benard, and M. Dettu. 2013. "The Prospects of Web 2.0 Technologies in Teaching and Learning in Higher Learning Institutes: The Case Study of the Sokoine University of Agriculture in Tanzania." *Knowledge Management and E-Learning: An International Journal (KM&EL)* 5 (4): 404–18. <www.kmel-journal.org/ojs/index.php/online-publication/article/view/295/200> (accessed May 24, 2016).

Mtega, W. P., et al. 2015. "The Usage of E-Resources among Agricultural Researchers and Extension Staff in Tanzania." *Library and Information Research* 38 (119): 47–66.

National Academy of Sciences. 2010. *Exploring the Intersection of Science Education and 21st Century Skills: A Workshop Summary*. Washington, DC: National Academies Press. <www.nap.edu/catalog/12771/exploring-the-intersection-of-science-education-and-21st-century-skills> (accessed May 21, 2016).

National Science Digital Library. 2013. *OER Digital Content: A Combined Voices Meeting, June 27–30, 2013*. University Corporation for Atmospheric Research. Boulder, CO.

Neary, M., and J. Winn. 2012. "Open Education: Common(S), Commonism and the New Common Wealth." *Ephemera* 12 (4): 406–22. <www.ephemerajournal.org/sites/default/files/12-4nearywinn.pdf> (accessed May 25, 2016).

New Media Consortium. 2012. *NMC Horizon Report 2012 K–12 Edition*. <http://nmc.org/pdf/2012-horizon-report-K12.pdf> (accessed May 23, 2016).

———. 2013. *NMC Horizon Report 2013 K–12 Edition*. <www.nmc.org/pdf/2013-horizon-report-k12.pdf> (accessed May 23, 2016).

———. 2014. *NMC Horizon Report 2014 K–12 Edition*. <http://cdn.nmc.org/media/2014-nmc-horizon-report-k12-EN.pdf> (accessed May 23, 2016).

———. 2015. *NMC Horizon Report 2015 K–12 Edition*. <http://cdn.nmc.org/media/2015-nmc-horizon-report-k12-EN.pdf> (accessed May 23, 2016)

Office of Educational Technology. 2010. *Transforming American Education: Learning Powered by Technology. National Educational Technology Plan 2010*. Washington, DC: Office of Educational Technology, U.S. Dept. of Education. <www.ed.gov/sites/default/files/netp2010.pdf> (accessed May 25, 2016).

Orszag, P. R. 2009. "Open Government Directive M-10-06." <www.whitehouse.gov/omb/assets/memoranda_2010/m10-06.pdf> (accessed May 25, 2016).

Pattuelli, M. C. 2006. "Content for Context: Shaping Learning Objects and Modeling a Domain Ontology from the Teacher's Perspective." In *Digital Libraries in the Context of Users' Broader Activities. First International Workship, DL-CUBA 2006, Chapel Hill, USA, June 15, 2006*, edited by A. Blanford and J. Gow, 23–27. <http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=013A546EF169B2ED9FCBF63B7F7AB773?doi=10.1.1.96.8745&rep=rep1&type=pdf> (accessed May 25, 2016).

———. 2007. "Teachers' Perspectives and Contextual Dimensions to Guide the Design of N.C. History Learning Objects and Ontology." *Information Processing and Management* 44 (2): 635–46. <doi:10.1016/j.ipm.2007.05.008>.

PBS, and Grunwald Associates. 2011. "Deepening Connections: Teachers Increasingly Rely On Media and Technology." <www.grunwald.com/pdfs/PBS-GRUNWALD_2011_ANNUAL_ED_TECH_STUDY.pdf> (accessed May 25, 2016).

Perrault, A. M. 2007a. "An Exploratory Study of Biology Teachers' Online Information Seeking Practices." *School Library Research* 10. <www.ala.org/aasl/sites/ala.org.aasl/files/content/aaslpubsandjournals/slr/vol10/SLMR_ExploratoryStudy_V10.pdf> (accessed May 25, 2016).

———. 2007b. "The School as an Information Ecology: A Framework for Studying Changes in Information Use." *School Libraries Worldwide* 13 (2): 49–62.

Project Tomorrow. 2010. *Unleashing the Future: Educators "Speak Up" about the Use of Emerging Technologies for Learning: Speak Up 2009 National Findings [from] Teachers, Aspiring Teachers, and Administrators.* <www.tomorrow.org/speakup/pdfs/SU09UnleashingTheFuture.pdf> (accessed May 25, 2016).

———. 2012. "Mapping a Personalized Learning Journey – K-12 Students and Parents Connect the Dots with Digital Learning." <www.tomorrow.org/speakup/pdfs/SU11_PersonalizedLearning_Students.pdf> (accessed June 3, 2016).

———. 2014. "The Digital Learning Playbook: Advancing College and Career Ready Skill Development in K–12 Schools." <www.tomorrow.org/speakup/SU13_EducatorsReportTEXT.html> (accessed May 25, 2016).

Project Tomorrow, and PASCO Scientific. 2008. "Inspiring the Next Generation of Innovators: Students, Parents, and Educators Speak Up about Science Education." <www.tomorrow.org/speakup/pdfs/Inspiring_the_next_generation_of_innovators.pdf> (accessed May 23, 2016).

Puustinen, M., and J.-F. Rouet. 2009. "Learning with New Technologies: Help Seeking and Information Searching Revisited." *Computers and Education* 53 (4): 1014–19. <doi:10.1016/j.compedu.2008.07.002>.

Recker, M., et al. 2007. "A Study of Teachers' Use of Online Learning Resources to Design Classroom Activities." *New Review of Hypermedia and Multimethods* 13 (2): 117–34. <doi:10.1080/13614560701709846>.

Rodgers, D. L., and B. J. Withrow-Thorton. 2005. "The Effect of Instructional Media on Learner Motivation." *International Journal of Instructional Media* 32 (4): 333–42.

Rotherham, A. J., and Willingham, D. 2009. "21st Century Skills: The Challenges Ahead." *Educational Leadership* 67 (1): 16–21.

Saldivar, M. G. 2012. "Teacher Adoption of a Web-Based Instructional Planning System." PhD diss. University of Colorado at Boulder. (UMI 3508034).

Saljo, R. 2010. "Digital Tools and Challenges to Institutional Traditions of Learning: Technologies, Social Memory and the Performative Nature of Learning." *Journal of Computer Assisted Learning* 26, 53–64. <doi:10.1111/j.1365-2729.2009.00341.x>.

Sandelowski, M., and J. Barroso. 2007. *Handbook for Synthesizing Qualitative Research*. New York: Springer.

Sappey, J., and S. Relf. 2010. "Digital Technology Education and Its Impact on Traditional Academic Roles and Practice." *Journal of University Teaching & Learning Practice* 7 (1): 1–17. <http://ro.uow.edu.au/cgi/viewcontent.cgi?article=1162&context=jutlp> (accessed May 25, 2016).

Silva, E. 2008. *Measuring Skills for the 21st Century.* Washington, DC: Education Sector.

Sing, K.-M., and M.-K. Chew. 2009. "Learning Science with Learner-Centered and Pedagogically-Driven Engaging Web-Based Interactive Resources." In *Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications 2009, Honolulu, HI, USA*, edited by G. Siemens and C. Fulford, 3789–94. Chesapeake, VA: Association for the Advancement of Computing in Education.

Snyder, T. D., and S. A. Dillow. 2011. *Digest of Education Statistics 2010.* (NCES 2011-015). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U. S. Dept. of Education. <https://nces.ed.gov/pubs2011/2011015.pdf> (accessed May 25, 2016).

Spaulding, M. 2010. "The Influence of Technology Skills on Preservice and Inservice Teachers' Perceived Ability to Integrate Technology." In *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2010*, edited by J. Sanchez and K. Zhang, 2193–202. Chesapeake, VA: Association for the Advancement of Computing in Education.

State Educational Technology Directors Association. 2010. *National Educational Technology Trends: 2010*. <www.setda.org/wp-content/uploads/2013/12/NationalTrendsReport2010Final_042110-4.pdf> (accessed May 25, 2016).

State Educational Technology Directors Association, and EducationCounsel LLC. 2014. "The Accessibility of Learning Content for All Students, Including Students with Disabilities, Must Be Addressed in the Shift to Digital Instructional Materials." <www.setda.org/wp-content/uploads/2014/03/SETDA_PolicyBrief_Accessibility_FNL.5.29.pdf> (accessed May 23, 2016).

U.S. Department of Education. 2013. "FY 2013 Race to the Top–District Competition Background." <www2.ed.gov/programs/racetothetop-district/2013-background.pdf> (accessed June 3, 2016).

Valli, L., and D. Buese. 2007. "The Changing Roles of Teachers in an Era of High-Stakes Accountability." *American Educational Research Journal* 44 (3): 519–58. <doi:10.3102/0002831207306859>.

van den Berg, R. 2002. "Teachers' Meanings Regarding Educational Practice." *Review of Educational Research* 72 (4): 577–625. <doi:10.3102/00346543072004577>.

van Garderen, D., et al. 2009. "Supporting the Collaboration of Special Educators and General Educators to Teach Students Who Struggle with Mathematics: An Overview of the Research." *Psychology in the Schools* 46 (1): 56–78. <doi:10.1002/pits.20354>.

Warschauer, M., and T. Matuchniak. 2010. "New Technology and Digital Worlds: Analyzing Evidence of Equity in Access, Use, and Outcomes." *Review of Research in Education* 34 (1): 179–225. <doi:10.3102/0091732X09349791>.

Williams, D. A., and L. Coles. 2007. "Evidence-Based Practice in Teaching: An Information Perspective." *Journal of Documentation* 63 (6): 812–35. <doi:10.1108/00220410710836376>.

Zia, L. L. 2009. "NSF's NSDL Program: An Overview of Its History, Progress, And Promise." *Journal of Chemical Education* 86 (1): 121–30. <doi:10.1021/ed086p121>.

Appendix

Additional Criteria for Article Selection

Our OneSearch search previously described in the "Data Collection" subsection returned 2,306 results. We did not specify exclusion criteria in the search statement, but we did manually eliminate any results that did *not* fit all the criteria below.

1. Studies with direct relevance to the topic, i.e., those involving digital learning resources in K–12 STEM education. To the extent that resources, learning, and educational technology are interrelated, this review included studies that examined the complexities of technology integration and the effects digital materials have on learning processes.
2. Studies published between 2000 and 2014. The National Science Foundation's National Science Digital Library was founded in 2000 and is recognized as the major source of K–12 STEM digital learning content in the United States. The evolution of the study of STEM digital learning resources can be anchored to this point of departure (Mardis and Howe 2010).
3. Studies conducted within the United States and abroad, but limited to those published in English and focusing on settings where English is the main medium used in the digital learning resource.
4. Studies focusing on digital learning resources at the elementary and secondary levels, i.e., K–12 formal schooling. Studies involving post-secondary, adult learners, or informal learning contexts were not included.
5. Empirical studies from different methodological traditions including: experimental and quasi-experimental studies; correlational studies; surveys; descriptive studies; interpretative, ethnographic, qualitative, or case studies; and impact studies of large-scale intervention projects.
6. Literature reviews and conceptual pieces.

Cite This Article

Luetkemeyer, Jennifer, and Marcia Mardis. "Applying the Quadratic Usage Framework to Research on K–12 STEM Digital Learning Resources." <http://www.ala.org/aasl/slr/volume19/leutkemeyer-mardis>

School Library Research (ISSN: *2165-1019*) *is an official journal of the American Association of School Librarians*. It is the successor to *School Library Media Quarterly Online and School Library Media Research. The purpose of School Library Research is to promote and publish high quality original research concerning the management, implementation, and evaluation of school library media programs. The journal will also emphasize research on instructional theory, teaching methods, and critical issues relevant to school library media. Visit the **SLR website** for more information.*

*The American Association of School Librarians empowers leaders to transform teaching and learning. Visit the **AASL website** for more information.*