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

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

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Abstract

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

Keywords: K-12, science, technology, engineering, mathematics, learning resources, digital

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Effective learning experiences center on two variables: high quality learning resources and high quality pedagogy (Chingos & Whitehurst, 2012; Maull, Saldivar, & Sumner, 2011); deeply intertwined, neither variable alone is sufficient to improve student achievement (Morris & 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, and confidence in the ability to integrate available resources can be used as an accurate proxy measure of educator effectiveness (Arslan, 2010; Chingos & 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. The number of teachers who do not integrate digital instructional material is dwindling (Project Tomorrow, 2010). Studies 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 & Grunwald Associates, 2011). The common standards movements, instantiated through 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 & Whitehurst, 2012; National Science Digital Library [NSDL], 2013)

In their future-casting for education, the New Media Consortium's *K-12 Horizon Report*'s expert panelists have consistently identified digital content, learning personalization, and educational data analytics as key to both near term trends as well as to difficult challenges to address (New Media Consortium [NMC], 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 affect learning.

Although digital learning resources are mentioned with increasing regularity in research involving K-12 education, a definition is difficult to find. The working definition for the purposes of this work is as follows: 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 one away from a reliance on print-based resources. Because STEM is a national priority and has long been well supported by digital materials, (Barker, 2010; Braun, Coley, Jia, & Trapani, 2009; Duschl, Shouse, & Schweingruber, 2008), digital resources tend to be implemented in schools first to support STEM learning (Fletcher, Schaffhauser, & Levin, 2012; State Educational Technology Directors Association [SETDA], 2010).

An understanding of the relationship between a shift to digital resources and changes in learning and teaching is essential for researchers and practitioners to truly support national digital learning priorities. To begin to define and explore this relationship, we conducted a extensive qualitative synthesis of the preceding decade's K-12 STEM digital learning resources research and policy literature and, using the Quadratic Usage Framework (QUF) (Mardis, Hoffman, & Marshall, 2008) analyzed the results for common themes, overarching conceptual structures, and directions for future research.

Method

We used a qualitative research synthesis method for this review because our objectives were descriptive and critical (i.e., appraising fit between article content and the conceptual framework), rather than meta-analytic (e.g., calculating an average effect size) (Sandelowski & 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 Florida State University Libraries' research literature search tool:

("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 and faceted searches of literature contained in all FSU databases, library catalogs, and the open web.

We searched for journal articles, books, book chapters, reports, or conference papers based on three additional a priori criteria: peer-reviewed literature, English language, published between 2000 and 2014. From the 2306 results, we manually selected articles based on the additional a priori criteria listed in Appendix 1. We did not specify a priori exclusion criteria in the search statement, but manually eliminated any results that did not fit the above criteria. Our final search result included 486 articles.

Data Analysis

From those 486 articles, we appraised, selected, and abstracted articles in a three step process. First, each author selected and reviewed articles for fit with the conceptual framework and wrote narrative synopses. Second, the completed synopses were integrated for narrative presentation.

Third, for analysis, we applied the Quadratic Usage Framework (QUF) proposed by Mardis, Hoffman, and Marshall (2008) based on the work of Marshall (2005). First developed to articulate dimensions of "digital divides," or gaps that affected technology integration, this framework provides a useful grouping of issues that pertain to digital learning resource use. Figure 1 illustrates the QUF and details its quadrants.

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

Access: factors related to access to or use of the artifact itself.

Skill: competency-related factors that affect the individual's skills, education, knowledge, and experience which 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 encompassing 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 et al., 2008)

In all, we synthesized 173 resources for this report with each researcher independently coding the documents' content for QUF quadrant linkage and major themes.

Results

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

Access to K-12 STEM Digitial Learning Resources

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

Digital Learning Resource Supply. A significant theme relating to access to digital learning resources is related to 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 they were fee-based and open educational resources.

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 (J. D. Davis, Drake, Choppin, & McDuffie, 2014), this suggesting 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;* these are related, but different spaces, as Figure 2 illustrates.

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 & Winn, 2012). In contract, 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 notion of a digital learning resource is granularity (Littlejohn, 2003). The smallest grain of digital learning resource size is that of learning object, like a digital video clip as opposed to a website containing a library of digital video clips. Their physical analogs 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, & Saltan, 2010; Griffith, 2003). Digital resources can be combined in a number of different ways or tailored for different audiences (Kay & Knaack, 2007, 2008; Pattuelli, 2006; Sing & Chew, 2009).

Description. Metadata schema for learning objects is an extension of classification and organization schemes used for physical media like books. In addition to reflecting descriptive information about the object, metadata have been used to reflect the characteristics of effective learning objects. At a glance, teachers want to know if a digital resource is:

- Motivating to the learner;

- Controlled by the learner;
- Designed with appropriate media, colors, text size and sophistication, and placement of information;
- Contains clearly stated and enough questions and activities;
- Supports further learning (Arslan et al., 2010; Leary, Giersch, Walker, & Recker, 2011)

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

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

In many schools, bandwidth capacity dictates how teachers integrate the Internet into their classrooms. While 99% of public schools in the United States report having Internet access, classroom connections are less frequent (National Center for Education Statistics [NCES], 2011). Even if classroom access is available, many building-level policies impeded the integration of the Internet into teaching and learning. Many (over 80%) of school connections were not meeting school officials' needs because they were overloaded and poorly managed, leading to slow performance or restricted use (Federal Communications Commission [FCC], 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 (Federal Communications Commission [FCC], 2012).

Skill

For many teachers, using digital learning resources provides an entry point into technology integration when they integrate technology by replacing physical resources with free, high quality digital resources. The teacher's goal is to improve student skills using interactive digital resources. The act of swapping out and updating resources is often a first step, but the creation and sharing of resources in the context of teaching and learning can be seen as a cornerstone skill for educators (Mardis et al., 2008). Often, replacing physical resources used in existing lessons with digital resources is a teacher's first step in technology integration (Haughey & Muirhead, 2005), but this step is influenced by the teacher's ability to locate, select, and manage resources (Sappey & Relf, 2010). Continued use 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). Though there is limited current research addressing teacher online information searching behaviors (Maull, Saldivar, & Sumner, 2010), in extant studies, teachers report 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 et al., 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 (Duke & Ward, 2009). For example, one study of preservice teachers showed that 36% did not have the necessary knowledge to use search engines effectively; 77% did not understand the principles of web technology that created the indexes used by search engines; and that they used a limited selection of operators in order to narrow search results (Laverty, Reed, & Lee, 2008). The lack of ability to locate, select, or manage resources has a constraining effect on instruction. Preservice

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 for critical decisions about materials and resources in planning curriculum and instruction (Lai & Lam, 2011).

Although in-service teachers perceive 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 discerning applicable digital learning resources from larger collections (Perrault, 2007a). Like their preservice counterparts, teachers' information seeking tends to be a recursive process of integrating a quickly located online resources into practice, discovering its shortcomings, and going back to search again (Perrault, 2007a). Teachers frequently reported using a web search engine in a quick look for age-appropriate resources on a specific topic rather than databases or digital libraries that they 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 resource compromises. Perhaps because teachers typically rely upon their files and ideas from colleagues for their curriculum planning (Perrault, 2007b; Williams & Coles, 2007), few teachers feel that mastery of search skills is an integral part of their practice (Duke & Ward, 2009).

Selection. The Web can be characterized as a double edged sword for teachers: a plethora 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 the wide-ranging ideas of resource quality and the complex nature of resource alignment to STEM curriculum standards (Mervis, 2009). For example, Barker (2010) found that science teachers rated free sites, resources that indicated grade level and reading level, and descriptions of the time and resources needed, as well as sites that had graphics and video, as the most important resource qualities. 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, which makes them 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 (SETDA & EducationCounsel LLC, 2014). Some in the educational community cite the "great piles of stuff" that are composed of accessible learning resources that should be transformed into "piles of great stuff" (Zia, 2009, p. 121) that is current, content rich, authoritative, and effective in communicating learning concepts. This notion 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 (SETDA, 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 & Olsen, 2011).

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

Teachers' lack of confidence in information management affects more than just their instruction. Some researchers (e.g., Puustinen & Rouet, 2009) pointed to barriers and enablers to teaching and learning created by unskilled resource management as Ball, Knobloch, and Hoop and (2007, p. 4) did in their study's link between teacher access to resources with planning practices in

which digital learning "materials influence instructional capacity by constraining or enabling students' and teachers' opportunities to learn and teach." 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 prepackaged curricula. This adherence led to instruction that did not engage students and was ineffective for transferring concepts. This behavior not only affects instruction, but it 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 & PASCO Scientific, 2008), and personal organization is an important aspect of academic success.

Policy

SETDA provided a comprehensive list of policy issues for the implementation of digital learning resources, many of which include examining policies and practices around technology use, intellectual property and reuse rights, student data access, and national and state policies (Fletcher et al., 2012)

National Educational Policies. Promoting adoption of digital textbooks, or collections of high quality interactive digital multimedia learning content, has been at the fore of 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, p. 78)
2. "Take steps to create a pool of digital educational resources" (Federal Communications Commission [FCC], 2010, p. 246), and
3. "[I]nformation 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, p. 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: the Department of Education's Race to the Top (RT3) funding; and the Common Standards Movement that includes the Common Core State Standards (CCSS), the Next Generation Science Standards (NGSS), and the college and career readiness standards (Evans, 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 data points 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. Department of Education, 2013) and IIS data, instructional technology, virtual learning platform, digital textbook, 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 realize common standards (Evans, 2012).

The Common Core standards movement is generating a common curriculum framework to be used by all states. This large national effort is prompting digital library developers to consider new applications that support teachers' use of the new standards. These new applications bring together metadata, paradata, 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 based on a shared purpose and when multiple sources of innovation are included in the process (E. A. Davis & Krajcik, 2005)

State Instructional Materials Policies. State laws, many of which have been rewritten to include digital content as an acceptable use of state textbook funding, 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 (SETDA, 2010).

Florida has enacted the Digital Learning Now Act that mandates that public schools will use at least 50% digital instructional materials by the 2015-16 school year. This move was 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 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, requiring full implementation of digital textbooks by 2015, but many states are soon to follow (Mickey & Meaney, 2014; Mickey, Meaney, Montinat, & Pierre, 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 & 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 beyond the 2017-2018 school year. The development of a clear plan in order to make the switch, and communication of that plan, was deemed imperative. Such a plan would include a revision of policies, significant investment in the technology to support the move, and an implementation of procedures that support key stakeholders during the move. Finally, SETDA encouraged collaborative efforts "to create alternative, flexible models for the creation, acquisition, distribution, and use of digital content" (Fletcher et al., 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 & Buese, 2007). Teachers have little visibility into the past performance of their students, what other teachers noted, or each learner's strengths, weaknesses, and individual needs. New personalization technologies and the demand for differentiated instruction as a Common Core strategy will only place further strains on the ecosystem of data systems and paper based records that form the patchwork of student records (Bailey, Carter, Schneider, & Vander Ark,

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 & Grunwald Associates, 2011), and to become aware of 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 student records policies related to 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

Teachers are not only using digital resources in their planning, management, and assessment processes, but they 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, Giersch, Walker, & Recker, 2009; Leary et al., 2011).

Learning Personalization. With a variety of instructional media available to educators, selecting the appropriate instructional format is a critical decision to stimulate learner motivation. 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 & Withrow-Thorton, 2005). A growing trend advocates that teachers should more benefit from the possibilities of the electronic media and technology for their instruction. Despite the numerous advantages of materials, their design and selection process may be demanding for teachers due to their limited technological knowledge and the difficulties (i.e. complexity, time consuming) of design (Konings, van Zundert, Brand-Gruwel, & van Merrienboer, 2007). In order to facilitate children's learning, empower them to become active participants in their own learning, spark their curiosity, and ensure the desirable effects of the materials, teachers should benefit from their strategic knowledge.

Despite the money and time spent on training primary and secondary teachers to integrate technology, few results have been observed in instruction and learning (Spaulding, 2010). As the role expectations of teachers have intensified in the areas of instruction, technology, and reform, these expectations often had negative consequences for teachers' relationships with their students, pedagogical innovation, and sense of professional well-being (Valli & Buese, 2007). Myriad challenges affect use and integration of learning objects in planning and teaching.

The wide variation in instructional planning, delivery, management, and assessment processes in the classrooms results in a wide disparity in student achievement. In addition to a great variation 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.

Learning Environment. The number of students 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 (Garderen, Scheuermann, Jackson, & Hampton, 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 (Hennessy et al., 2007).

Teacher Time. In just about every study of teachers' use of technology integration and instructional innovation, the issue of time is cited. Teachers average about 10 hours of planning a week (Ball et al., 2007) and the majority of the time they spend online looking for curriculum materials occurs during the school day (Mardis, 2009a). 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, & Peck, 2001; Warschauer & Matuchniak, 2010).

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

Discussion

In this paper, we integrated an extensive body of research and literature to provide an overview of challenges concerning 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.

The Quadratic Usage Framework

As we inventoried and integrated the literature, it was clear that the research topics mapped well to the QUF proposed by Mardis et al (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.

In the area of access, we considered affordances of 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. 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 them in their workflow and instructional events.

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 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.

As the curved arrows in the center of the figure suggest, the topics in each of the quadrants have relationships, or consequences, for the other quadrants; no quadrant is independent. However, as Mardis et al (2008) suggested, Motivation is the most powerful quadrant since 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 and suggested paths for information science research. As with any exploration that is designed to be both descriptive and critical, the results of this synthesis are both limited by the research available as well as by the author-imposed bounds on the topic. Still, as with the adoption of other information-mediated changes in schools, challenges and research opportunities, necessary conditions, or categories reside in four areas: access, skill, policy, and motivation. In many ways, these categories also provide a continuum. Contemporary learning resources are increasingly digital and require not just keen information skills, but knowledge of ways to integrate digital resources in ways that enable all learners (Mardis, ElBasri, Norton, & Newsum, 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 (Board on Science Education, 2010; Project Tomorrow, 2014; Rotherham & Willingham, 2009 ; Silva, 2008). Finally, seamless and extensive meaningful integration of technology in all aspects of teaching and learning is essential if the visions of 21st century skills articulated by various organizations are to be realized. Regardless of the point on

the continuum on which an educator resides, reforms that focus on improving the act of instruction without examining how teachers select and use the information and technology that undergirds it are incomplete.

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