Creating an Evidence-Based Framework for Selecting and Evaluating Mathematics Apps

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Abstract: Given that there are over 80,000 educational apps in the Apple store alone (Apple, 2017), teachers need clear guidance on choosing the most useful tools possible. The purpose of this paper is to provide an evidence-based framework for selecting and evaluating math apps used in elementary school settings. Based on a comprehensive review of the literature, five app types (instructive, practice-based, constructive, productive, game-based) will be discussed in detail. Next, eight characteristics (learning value, content quality, learning goals, usability, engagement, challenge level, feedback, and collaboration) for evaluating the quality of math apps will be described. Finally, the role of the teacher in integrating math apps into the classroom will be explained.

Introduction

The National Council of Teachers of Mathematics (NCTM) maintains that technology is essential to math curricula (NCTM, 2000). However, research the impact of technology on improving mathematics education has been mixed (Cheung & Slavin, 2013; Hattie, 2012; Murray & Olcese, 2011). Part of the problem is that a number of studies focus on the technology used, as opposed to the software or pedagogy employed. For example, recent studies on the use of technology in mathematics have focussed primarily on tablet use and not the type or quality of math apps employed (e.g., An et al., 2015; Milman et al., 2014; van Deursen et al., 2014). Alon et al. (2015) argue that the proper selection of mathematics apps is critical for integrating tablets into the classroom. Currently, there are thousands of math apps available, most are not formally regulated, and few focus on how students actually learn (Alon et al., 2015; Hirsh-Pasek et al., 2015). Therefore, an evidence-based framework for selecting and evaluating math apps is required.

To develop an effective framework, over 25 peer-reviewed articles targeting the use of math apps in elementary school environments were assessed. Thirteen of these articles focussed on either characteristics (Cayton-Hodge et al., 2015; Falloon, 2013; Falloon, 2014; Handal et al., 2015; Hawkins, Collins, & Flowers, 2017) or type (Alon et al., 2015; Ebner, 2015; Grandgenett et al. 2011; Handal et al., 2015) of math apps. In addition, 15 empirically-based studies on the use of tablets and math apps in elementary school classrooms were critiqued. Based on the review of the literature, five types of math apps were identified and are described in Table 1. Next, an amalgamation of eight characteristics was created to evaluate the quality and effectiveness of math apps (Table 2).

Results

Type of Apps

When selecting math app, the first step is to establish the desired learning outcomes. If the goal is to have students learn a new concept, then an instructive app might be appropriate. On the other hand, if the intent is to review concepts recently learned, practice or game-based apps would be a good choice. Constructive apps might be more advantageous when higher level skills are targeted, and productive apps could be particularly useful for a culminating task. In addition, some apps may represent multiple types. For example, game-based math apps can involve considerable practice. Productive apps may incorporate the construction of knowledge and higher-level skills. Once the type of math app is selected, the teacher can then evaluate it based on the eight characteristics discussed below. All apps should provide clear learning goals, accurate content based on solid mathematical principles, and an easy-to-use format. The influence of the other characteristics, though, will vary by app type.

Instructive. The primary purpose of this type of app is to teach a student a new concept or provide tutoring/training (Ebner, 2015). These apps tend to guide students by providing organized, step-by-step, systematic scaffolding (Falloon, 2013). In terms of app characteristics, an ideal instructive app would provide emotional and cognitive engagement, explicit feedback, tracking and progress reports, and a sufficient range of challenge levels (Handal et al., 2015). While active learning is generally promoted in mathematics (NCTM, 2000), direct instruction using math apps to learn essential facts, concepts and skills can significantly improve student achievement (Hattie, 2012; Keengwe, 2013; Pitchford, 2014; Riconscente, 2013; Zhang et al., 2015).

Practice-based. Practice-based apps are designed to help students practice new content, concepts, and skills (Grandgenett et al.,2011). While many teachers are encouraged to promote critical and reflective thinking, a basic knowledge of content and concepts is required to engage in higher levels of thinking, especially at the primary school level. Practice-based apps are used to support the acquisition of foundational mathematics knowledge (Hirsh-Pasek et al., 2015). Important characteristics in a practice app might include high emotional engagement, timely, corrective feedback, a range of challenge levels, and progress reports.

Constructive. Constructive apps focus on exploration (Handal et al., 2016; Murray, 2011), making sense of new information, reflection, conjecture (Grandgenett et al., 2011), skill acquisition, data management (Domingo & Gargante, 2016) and the active manipulation of ideas and concepts (Keenwge, 2013). This type of app could be particularly useful for applying and extending concepts or skills. The main goal for this type of app is to help student construct understanding. The structure of a constructive app is more open-ended than practice-based or instruction apps, and students can experiment with different scenarios. Useful characteristics for these apps would be authentic content leading to cognitive engagement, along with sufficient control to manipulate a wide range of parameters.

Table 1 – Types of Math Apps

Type	Description	Examples	Evidence/Research
Instructive	• Direct instruction, acquiring information, stand-alone, self-directed, step-by-step progression, tutoring	Math42 Number Line	Ebner, 2015; Falloon, 2013; Grandgenett et al., 2011; Hattie, 2012;
Practice-Based	• Drill and practice, test-taking, quizzes, practicing fact or skill-based knowledge	IXL Quick Math	Grandgenett et al., 2011; Hattie, 2012; Risconscente et al., 2013
Constructive	• Exploration, elements of ambiguity, posing a conjecture, develop argument, categorize, interpret result, estimate, compare and contrast, testing and evaluating solutions, making sense of new information, questioning, reflection	Desmos Math Gizmos	Grandgenett et al., 2011; Handal et al., 2015; Hattie, 2011; Murray & Olcese, 2011
Productive	• Demonstrating knowledge, producing artefacts, creating representations (graphs, mind maps, videos)	Coggle (Mind Maps) SnagIt (Videos)	Grandgenett et al., 2011; Handal et al., 2015; Hattie, 2011; Murray & Olcese, 2011
Game-Based	• Background story, aesthetically engaging, progressive challenge, fantasy, curiosity, active interactive participation, continuous feedback loop	Mystery Math Town Prodigy	Ebner, 2015; Falloon, 2013; Kiili et al., 2014; Risconscente et al., 2013; Whitton, 2014

Productive. Productive or tool-based apps (Murray & Olcese, 2011) are used to demonstrate and use knowledge by creating math artefacts and representations (e.g., graphs, mind maps, videos) (Grandgenett et al., 2011; Handal et al., 2016). This type of app could be useful in a culminating activity and may involve collaboration. Typical attributes of a productive app would include an open-ended, tool-based design that is relatively easy to use and provides numerous options for creating artefacts. Learning goals, cognitive engagement, and collaboration would be established outside the app by the teacher and students.

Game-based. Game-based apps involve learning and practicing concepts while playing games (Ebner, 2015; Kiili et al., 2014; Riconscente, 2013). In a typical education-based game, students are exposed to challenging activities structured with a narrative, rules, goals, progression and rewards (Whitton, 2014). One advantage of a game-based app is regular interaction and engagement (Kiili et al., 2014). Another benefit is a strong narrative that can deeply engage students, possibly leading to a state of "flow" (Hirsh-Pasek et al., 2015). However, with some apps, educational content is artificially introduced into a game creating a quiz-like atmosphere with extrinsic rewards (Riconscente, 2013). Compelling game-based apps are relatively easy to use and engaging, both emotionally and cognitively. These apps provide quick corrective feedback and a wide range of challenge levels. Preferred game-based math apps naturally bring about communication and collaboration regarding strategy (Risconscente et al., 2013).

Characteristics of Apps

The following eight characteristics emerged from a detailed review of the literature. When evaluating an app, not all of these characteristics are required for a math app to be useful. For example, learning goals and collaboration may not be present, but a teacher can augment the process outside of the app by communicating the learning outcomes and arranging for students to work in teams. Additionally, there is no exact formula for assessing each characteristic because the learning goals and type of app can vary. Practice-based apps may score high on usability and engagement but help students to acquire foundational knowledge. Apps for constructing knowledge may be harder to use and less engaging but offer more extrinsic rewards and a higher challenge-level.

Learning value. The primary goal of any app is to support and promote learning. Not surprisingly, then, one of the most researched characteristics of math apps is learning value, often measured by assessing teacher or student perceptions. Key areas of focus are control over learning (Clark & Luckin, 2013), promoting knowledge building and information searching skills (Chou et al., 2014; Domingo & Gargante, 2016), improving learning outcomes and achievement (An et al., 2015; Milman et al., 2014; van Deuersen, 2014), and have a positive impact on student achievement. Promising areas of learning value, not yet formally studied for math apps, include developing arguments, categorizing, interpretation, comparing and contrasting, making sense of new information and generalizing relationships (Grandgenett et al., 2011).

Content quality. Limited research has been conducted on the quality of content addressed in math apps (Cayton-Hodge et al., 2015). Moyer-Packenham et al. (2016) recommend that the concepts and knowledge included in an app must be faithful to the underlying mathematical properties. Other issues, not yet addressed by researchers of math apps, include gender, cultural and ethnic bias (Papadakis et al., 2017), authenticity (Boone & Higgins, 2012), and accuracy (Alon et at., 2015).

Learning goals. A number of theorists have noted the need for clear learning goals to be communicated to students when they are using math apps (Falloon, 2013, 2014; Wiggins & McTighe, 2005). The absence of learning goals can discourage students, lead to off-task behaviour or the pursuit of entertainment and gamification (Falloon, 2014). It is worth noting that a teacher can articulate the learning goals of an app if these goals are not explicitly stated in an app.

Usability. Usability is necessary but not sufficient for a math app to promote meaningful learning. Critical features identified include using the appropriate language level, user-friendliness, clear instructions, and navigation (An et al., 2015; Clark & Luckin, 2013; Ebner, 2015; Falloon, 2013, 2014; Handal et al., 2015). The primary goal of usability is to reduce cognitive load while using math apps, so full attention can be directed toward learning the targeted knowledge or skills.

Engagement. This characteristic is a highly valued and extensively researched with respect to tablet use. Key descriptors focus on fun, entertainment, excitement, aesthetics, richness of interactions, pacing, and persistence (An et al., 2015; Cayton-Hodge et al., 2015; Domingo & Gargante, 2016; Handal et al., 2015; Hattie, 2012; Hawkins et al., 2017; Keenwge, 2013; Milman et al., 2014; Risconscente et al., 2013). Most studies ask students and teachers whether working with a tablet and math apps is motivating or engaging, overall (An et al., 2015; Clark and Luckin, 2013; Keenwge, 2013; Kiili et al., 2014; Riconscente, 2014). However, engagement is a more complex concept consisting of at least three components: behavioural (involved in activities), emotional (positive and negative reactions), and cognitive (investment in learning) (Fredricks et al., 2004). Math apps may be emotionally engaging and highly interactive, for example, but they need to be cognitively engaging to support learning (Cayton-Hodges et al., 2015; Hirsh-Pasek et al., 2015). Even if students appear to be engaged, it is hard to ascertain without direct observation what they are focusing on (Falloon, 2014).

Table 2 – Characteristics for Evaluating Math Apps

Characteristic	Descriptors	Evidence/Research
Learning Value	• Structures, trial and error, gamification, remembering, understanding, applying, analysing, evaluating, creating, achieving fluency, academic improvement	An et al., 2015; Clark & Luckin, 2013; Falloon, 2013, 2014; Handal et al., 2015; Hawkins et al., 2017; Milman et al., 2014; van Deuersen, 2014
Content Quality	• Accuracy, faithful to underlying math principles,	Alon et al., 2015; Cayton-Hodge et al., 2015; Moyer-Packenham et al., 2016
Learning Goals	• Clear objectives, personal	Falloon, 2013, 2014; Keenwge, 2013; Wiggins & McTighe, 2005
Usability	• User-friendly, appropriate language, distraction-free, clear instructions, easy to follow, intuitive, navigation	An et al., 2015; Clark & Luckin, 2013; Ebner, 2015; Falloon, 2013, 2014; Handal et al., 2015; van Deuersen, 2014
Engagement	• Emotional (look and feel, entertainment value, fun, exciting) • Behavioural (rich interactions, persistence) • Cognitive (pacing, control over settings, desire to participate)	An et al., 2015; Cayton-Hodge et al., 2015; Domingo & Gargante, 2016; Falloon, 2014; Fredricks et al., 2004; Handal et al., 2015; Hattie, 2012; Hawkins et al., 2017; Keenwge, 2013; Kiili et al., 2014; Milman et al., 2014; Risconscente et al., 2013; Whitton, 2011; Van Deursen et al., 2014
Challenge Level	• Adaptability, differentiation, levelling, independent learning, selecting content parameters, instructional pacing	An et al., 2015; Cayton-Hodge et al., 2015; Falloon, 2013, 2014; Handal et al., 2015; Hawkins et al., 2017; Milman et al., 2014
Feedback	• Scaffolding, hints/corrective, formative, accommodations, tracking, progress reports, text vs visual feedback, intrinsic vs, extrinsic	Cayton-Hodge et al., 2015; Ebner, 2015; Falloon, 2013, 2014; Hawkins et al., 2017; Handal et al., 2015; Keengwe, 2013; Kiili et al., 2014; Riconscente
Collaboration	• Social interaction, sharing	Ebner, 2015; Handal et al., 2015; Hattie, 2012; Keenwge, 2013

Challenge level. Challenge level, sometimes referred to as differentiation or the adaptability of an app to adjust to and meet the learning needs of individual users, is another significant app characteristic (An et al., 2015; Cayton-Hodges et al., 2015; Milman et al., 2014). Descriptors used by researchers to describe challenge level include adaptability, differentiation, levelling, independent learning, selecting content parameters, and instructional pacing (An et al., 2015; Cayton-Hodge et al., 2015; Falloon, 2013, 2014; Handal et al., 2015; Hawkins et al., 2017; Milman et al., 2014). The fundamental premise is that a responsive math app needs to match students' personal preferences (e.g., look and feel, avatars) and/or ability level. Falloon (2104) cautions that if the challenge level does not align with cognitive ability, elementary school students will experience app fatigue, disengage, or seek entertainment.

Feedback. Different kinds of math app feedback, including rewards and visual progress markers, the status of the problem being solved, corrective guidance, and conceptual correction can help students understand concepts better (Cayton-Hodges et al., 2015; Falloon, 2013; Hirsh-Pasek et al., 2015). Tracking student behaviour in the form of a report can provide useful information for both students and the teacher regarding progress toward learning goals (Ebner, 2015; Falloon, 2014). Intrinsic rewards can motivate students to learn rote skills that require considerable practice (Ebner, 2015). However, extrinsic rewards in the form of authentic learning goals with corrective guidance may be preferable for older students learning higher level concepts.

Collaboration. Hattie (2012) presents several meta-analyses suggesting that discussion, cooperative activities, and peer tutoring significantly improve student achievement. Hirsh-Pasek et al. (2015) add that working together toward common learning goals and explaining one's reasoning to a peer deepens mathematical understanding. Math apps that allow students to collaborate with, share and co-create knowledge are rare at the elementary school level (Ebner, 2015). However, the potential of general tools like Google Apps, to aid in the co-construction of mathematical ideas and artefacts is considerable (Lee et al., 2015; Papadakis et al., 2017). Even though an app may not be designed to be collaborative, teachers can frame the use of math apps within a co-operative environment where students share their ideas, thoughts and responses.

Role of the Teacher

The teacher is absolutely fundamental in determining the success or failure of a math app (Risconscente et al., 2013). For example, many apps do not provide explicit learning goals, nor do they connect the math app to specific course curricula. Teachers can supplement this process by communicating learning goals to the class and selecting apps that meet course learning objectives. Additionally, as stated earlier, teachers can optimize the use of constructive and productive apps using a collaborative, team-based approach. Furthermore, teachers can select a wide range of math apps to accommodate the ability and interest levels of students (Bouck et al., 2016). Teachers must also monitor app use during class to ensure the intended learning goals are pursued. It is particularly challenging to determine whether actual learning is occurring without observing and interacting with students using the math apps (Falloon, 2014). Finally, it is critical to integrate math apps with the correct teaching strategy. Matching the right math app to the desired learning goals and appropriate learning approach is a challenging but necessary process to achieve meaningful learning gains (Handal et al., 2015).

Future Research

The purpose of this paper was to provide an evidence-based framework for selecting and evaluating math apps used in elementary school settings. Five application types and eight characteristics were presented as a starting point, based on a detailed review of the current literature on math apps. The next step is to create a metric based on this framework and test it with small, formative case studies. This type of qualitative analysis can help refine parameters with practical and real-world feedback. Once the scale is refined, it can then be tested on a larger sample of students and teachers to establish reliability and validity. Finally, the scale can be employed to evaluate promising and document math apps for elementary school.

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