Analysis of Learning Outcomes from Mobile Mathematics Applications

Gary Bitter, Ph.D. Allen Corral
Arizona State University
bitter@asu.edu

Abstract

The development, usage, and investigation of educational math applications for mobile devices have increased in recent years. This manuscript analyzes the current state of educational mathematics applications for K-12, higher learning, and professional needs. Specifically, we will highlight the current limitations, and provide a taxonomy of the features found in the most effective apps. Also, we specify the major components and considerations concerning math applications. Several methods of implementation are discussed within indicated learning contexts. Alignment with solid educational theory promotes the effectiveness of the apps, which has been replicated in multiple research studies. Finally, we provide an overview of the types of math apps and how to select one that fits a specific instructional need.

1. Introduction

Mobile technologies include laptops, notebooks, tablets and smartphones that share data and applications often through cloud-based computing. Illustrated lectures, online everywhere learning, cloud computing, student generated information, demonstrations and hands-on lab activities and projects are all possible with mobile technologies. Mobile-based resources are available for the innovation and entrepreneurial skills of communication, collaboration, creativity, problem solving, assessment, analysing information, development of critical analytic skills as well as decision making through the use of mobile digital technologies. School systems, particularly in America, are having difficulty meeting the burgeoning need for materials to educate 21st century students on science, technology, engineering and mathematics (STEM) skills. There needs to be a significant national commitment to developing technologically advanced materials that infuse modern STEM activities throughout the teaching and learning process. Specifically, the paper will

- Discuss use of digital mobile technologies, apps and the use of technology in the mathematics classroom.
- Emphasize the use of digital mobile technologies for productivity, communication, collaboration, creativity, data analysis, assessment, brain storming and problem solving.

In order to remain competitive in the increasingly globalized STEM industries, national educational governing institutions have increased focus on STEM education at all levels. Such institutions include the U.S. Department of Education, the National Science Foundation and the White House Educate to Innovate initiative. The end goal of the increased funding, oversight, and administrative support is to increase student learning outcomes in these areas.

Currently available are mobile mathematics applications, available for most mobile digital devices. Many of these math apps are free. A network study of all available apps found that there were about three times more free apps than paid apps (Xia, Wang, Wei, & Zhou, 2013). According to Statista.com, educational apps are the second most downloaded category of app from the Apple App Store. About ten percent of seventy-five billion downloaded apps were educational (Statista, Inc., 2014). There are about four thousand math apps in the Apple App Store alone (Bjerede, 2014).

In this manuscript we will analyze in detail the current state of math apps in terms of limitations, effectiveness, key components, and theoretical underpinnings. With advances in technology, new features are likely to become available in future math apps. Based on previous experimental research, suggestions for improvement are made. Guidance is also provided to help students, parents, and educators find math apps that are appropriate for specific types of students.

2. Mobile Device Applications in the Classroom

Although this manuscript focuses on the use of math apps, it is imperative to be familiar with how mobile devices can be used in the teaching space in general. Keep in mind that you must select a strategy that aligns with the terminal learning objectives, environmental factors, and the learners involved (Table 1).

Table 1: How to Leverage Mobile Devices in Education
Note: This table was developed by the author and not previously published.

Strategy	Description
Student Feedback	Combining a smart phone with online collaborative tools allows for instant, private feedback from students
Content Distribution	Responsive learning management systems can be used to distribute materials to devices
Group projects	More convenient with tablet devices, students can Collaborate while manipulating and synthesizing information digitally
Netiquette	Communicating with mobile devices in a formal, supervised setting allows students to learn what is professional behavior and what is not
Websites	Students can go to a central website in order to access all course materials, as opposed to a textbook, paper handouts, paper worksheets, DVDs, etc.
Empowerment	Seeing themselves and their ideas in videos, print, and online promotes the realization that learners can Creatively influence the world
Simulations	High quality virtual simulations can be accessed to bring content to life. For example, virtual ancient Egypt
International Experience	Net telephony and video conferencing programs allow for students to Collaborate with students around the world. The ability to work in diverse teams is also in demand in the modern work place
Content Recycling	Most modern learning management systems allow modules, documents, and complex activities to be reused and revised very quickly, with just a few mouse clicks saving hours of preparation and grading time
GPS	The GPS components in most mobile devices can be used for a number of educational purposes including problem solving, cartography and measurement
Embodied Learning	Some mobile devices contain accelerometers and other hardware that can track physical movement. When learners physically demonstrate a skill, it promotes learning outcomes.
Digital Backpack	Instead of carrying textbooks, calculators, calendars, watches, pencils, to do lists, and scratch paper, students can simply carry a mobile device

Research	A mobile device can access scholarly information resources, such as peer-reviewed journals, data analytics and document problem solving.
Increased Efficiency	When students aren't actively engaged, class time is wasted. Multiple supplementary learning activities are available on mobile devices, which are useful during free time.
Guest Speakers	Career day with parents and/or guest speakers for the class can be done using video conferencing on a mobile device. This saves time and energy for all involved, and allows speakers located far away from the class to participate.
Note Taking	Students can use the audio recording and camera features in mobile devices to record every word and every chalkboard diagram
Augmented Reality	Mobile devices can support software that overlays digital information over live images of the real world, in real time. Education potential is far reaching, including mechanics, biology and design
Photography	The digital cameras in modern mobile devices are better than the most advanced hand held cameras available ten years ago. It is a tool that can be used by students and teachers in many Creative problem solving situations.
News Media	Mobile devices can access many forms of local, national and international news instantly. This saves storage space, time and money compared to bringing in physical newspapers and articles.
Sustainability	Course materials can be distributed digitally instead of physically reduces waste of precious resources. Green technologies and renewable energy that conserve natural resources can be Creatively analyzed in cooperative world-wide settings.
Webquests	Exploratory learning can be achieved by having students to research for their own answers online in a controlled fashion
Computer Literacy	Being able to work with digital files, word processing software and file structures is essential in the 21st century workplace. Mobile technologies enhance computer literacy.
Field Work	Mobile devices remove the restriction of being at home or at school while work is being done. Anytime-anywhere learning is possible.
File Sharing	File transfer protocol apps allow for instantaneous syncing of project folders and files for enhanced Cooperative Collaborative learning.
Flipped Classroom	Mobile technologies provide recorded lectures and guidance for students to study at home with problem solving completed in the classroom.
Higher Order Learning	Creativity is among the highest levels of learning. Mobile technologies can provide many applications (many of which are free) that allow learners to Create most any type of digitally based project content.
QR Codes	Similar to the bar code, but more advanced, QR Codes allow for a large amount of information to be accessible about a physical object, without taking up a lot of physical space. Teachers can Create and read their own codes with free software.
Visualization	The processing power of mobile devices allows for the instant visualization of data and information to produce scatterplots, tables, charts, diagrams, 3D models etc... Skill with these tools is an advantage in the work place.

Special Needs	Videos presented on mobile devices can be subtitled for the hearing impaired, and dubbed for ESL students. Imagery in course materials can be linked to audio descriptions for the visually impaired.
Learning Styles	Social activities, text, face-to-face interaction, visual materials and audio can be included in every activity using mobile devices. Students are known to have preferences for certain types of learning. Being able to pick and choose can increase student motivation.

3. Limitations

There are limitations of math apps in multiple aspects. From a business perspective, well designed math apps do not get marketed in the mainstream media. There are limited librarians around to help recommend the best or most insightful apps. Educational apps are still a niche in online reviewing, not often mentioned in the largest of online media outlets. These circumstances make it harder to stay informed of the latest and greatest math apps.

There are multiple fields of specialization involved in the development of an effective math app. Cognitive psychology, instructional design, pedagogy, web development, programming, graphic design, user experience design, media development, music production and scoring, voice talent, and software engineering can all be required. It is difficult to budget and plan for all of these experts and stages of development. As a result many math apps are strong in one area but weak in others. For example, you may have a math app that teaches 4th grade fractions, with a large amount of problems and activities. Meanwhile the app has no characters, no themes, no music and no built in interactivity. Many errors are encountered while touching the screen and difficulty seems to vary at random. Some apps will have all the recommended components, but some components are done poorly, because for example the programmer was asked to add game elements to an activity. Or perhaps the math subject matter expert was asked to create the music, on free software, due to lack of budget. There are no shortcuts to creating a truly effective, engaging math app.

There is also the matter of being able to purchase a mobile device, for a student. Justifying the expense of a smartphone, tablet, or hybrid device for a working professional is one thing. Justifying the purchase of a new iPhone for an elementary school student is another. Regardless of priority, many families in the US simply are not able to afford either the device or high speed internet access.

4. Effectiveness

Studies have found learning outcomes to be positively affected by the use of math apps. The studies have been conducted using multiple different combinations of types of mobile device, type of math app, learning context, and type of student. Mobile technologies are powerful and effective for communication, collaboration, creativity and problem solving in the math classroom. Digital tools used in the mathematics classroom will be identified in time, and a variety of other web-based tools will be demonstrated in problem-based environments for the teaching and learning of math. Math apps were found to not only improve learning outcomes, but also to increase student engagement among students with emotional disturbances (Haydon, et al., 2012) (Devlin, 2013) (Bitter & Meylani, 2013). Students with emotional disturbances have difficulty with self-control and staying engaged long enough to complete school assignments (Blood, 2010). Much of the utility and effectiveness of math apps had been envisioned by prominent educators long before it became a booming industry (Bitter G. , 1978).

In a study of third grade students of the Oconomowoc school district, the use of a math app during a nine week intervention lead to statistically significant increases in learning outcomes with an effect size of d = .45 (Kiger, Herro, & Prunty, 2012). The experimental study controlled for relevant covariate variables, including prior knowledge and home usage of students. Eighty-seven students were given access to ten math apps on iPod touch devices. The researchers noted that in order to achieve these high increases in outcomes, a commitment from school administrators is required.

Figure 1: Screenshot from Go Math! Academy

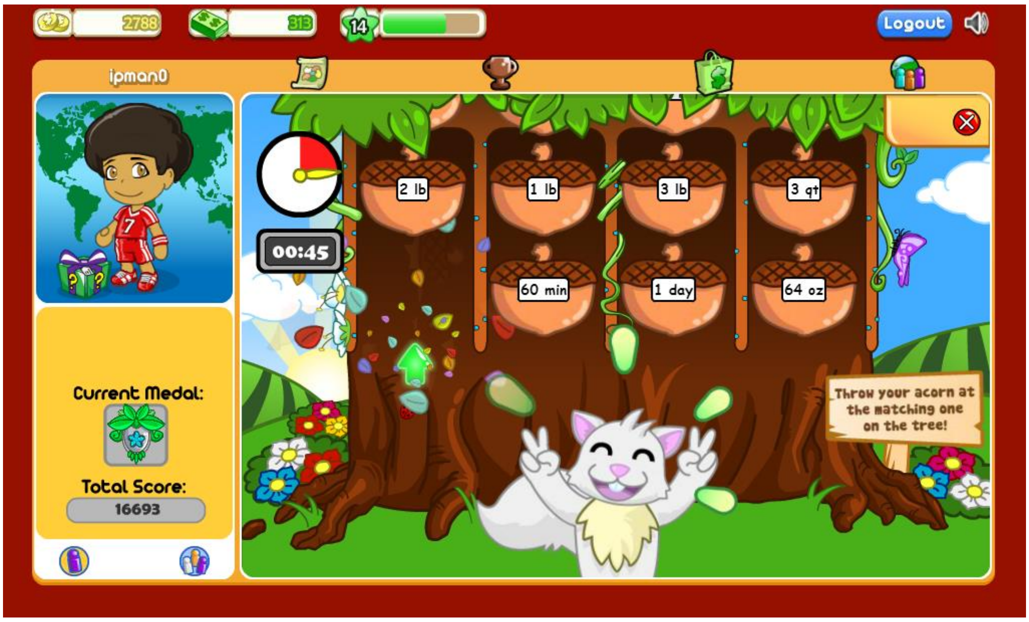


Figure 2: Screenshot from Sokikom

Math apps are not only capable of teaching math principles; they can also provide reinforcement and review. Go Math! (Figure 1) is a math app developed by researchers at Stanford University for people of all ages to use in real life situations that require math skills (Alexander, Blair, Goldman, & Jimenez, 2010). The app was designed using interviews of people to find out specifically which math skills they needed to use in their daily lives. MathStudio is a math app that allows for over 300 math functions to be run and is also usable in real world situations requiring math (Pomegranate Software , 2012). In a 2013 controlled study of the math app Motion Math, 122 students improved fraction skills by 15% (Riconscente, 2013). The students, American fifth graders, also improved self-efficacy as measured by 10%. Math apps have also been suggested at every stage of teaching mathematical algorithms in college, including the modeling, practice, transition, and independence phases (Hoang & Caverly, 2013). The app Sokikom (Figure 2) provides math education in alignment with common core standards (Sokikom, 2015). Sokikom provides an example of good math app design and an effective gamification strategy.

5. Components and Considerations

Conceptualizing, creating, and marketing math apps are complex processes. An average investment could include 9 months of development time and $300,000 US dollars. Developers need to maximize usability and design using wireframes, prototypes and mockups. Many theories and frameworks are involved including Fitt's Law of Human Computer Interaction, navigation patterns and skeuomorphic design trends. In addition the programming, coding, and database work has to be done which all require specific expertise.

Communication, Collaboration, Creativity and Problem Solving Digital tools should be the top consideration when searching for instructionally sound math apps. There are multiple types of math apps available, which range in levels of complexity (Table 2). There are basic calculator apps for learning advanced mathematics, mobile interfaces for robust math software packages, geometry apps, programming apps, simulations, games, and interfaces for electronic textbooks (Croucher, Rowlett, & Lewis, 2012). In order for a teacher, parent, tutor or student to find the right math app, certain steps can be taken to make the search easier. You should identify the grade level and age of the learner. You could also identify what curriculum standards need to be met by the learner. Examples of curriculum standards include U.S. CCSSO Common Core standards, and the Cambridge International General Certificate for Secondary Education standards. Some math apps are specifically developed to align with specific standards (Powell, 2014). It also helps to identify which type of mobile device is going to be used. Examples include Apple iOS, Google Play (Android), Microsoft Surface and Sony Computer Entertainment devices. Finally, it helps to determine if there needs to be a budget for purchasing an app. While there are many free math apps available, some have a considerable purchase price. With all this information in hand, you can perform a meaningful search. You can search within proprietary digital marketplaces, like Apple's App Store, Google Play or within standard internet search engines like Google and Bing. There is also a large community of online education experts that share lists, reviews, and test results of math apps. Many American school districts have technology integration offices that can recommend specific math apps for each grade level (Powell, 2014).

Currently, the most effective math apps have been found to include some specific features. Some important features relate to the instructional design of the app. Good instructional design requires developers to systematically analyze the intended user, the content, and the learning objectives of the app. General knowledge of how people learn can also be used to improve learning outcomes.

Another development consideration is to program the app to process user input in meaningful ways. This can include recording the time it takes a user to complete a task, matching input with databases of correct responses and compiling the information into records. Math apps should inform users whether answers are correct. Once a certain number of correct, or incorrect, responses have been made an app can be programmed to increase or decrease the difficulty level of the following activities. This is sometimes referred to as an adaptive app. Some math apps are designed around adaptive features, such as Adaptive Curriculum apps (Adaptive Curriculum, 2014). Another important feature is when incorrect responses can cause performance correction materials to be displayed.

The interface of a math app can also affect learning outcomes. Each activity, screen and resource in an app should be able to be accessed within 3 to 5 clicks or gestures by the user. In addition, these clicks or gestures should be made in logical areas of the screen, with buttons or icons that are visually relevant. The size of interactive screen elements should be large enough to allow interactivity with few input errors. In general, visual elements and effects on the screen should be related to either the skill being learned, or the theme of the activity; they should not be a distraction.

Math apps with game elements are able to teach various subjects through practice, play and learner embodiment. Math apps are also able to add a narrative to the learning experience in which the learner must accomplish goals by increasing skills in the subject-matter. Impacts on learning include socialization, challenge, accomplishment, fantasy, stress relief, alleviation of boredom, escapism, and exploration. Elements can be added to increase learner motivation including emotional investment, excellent storytelling, and heroes that can be identified with. Math apps can use a special non-verbal communication to communicate with and motivate users. Personal investment into an app draws players into the activity and its goals. Math apps are able to overcome the stigma of "learning" and "doing schoolwork" that some students experience.

Table 2: Components of Effective Math Apps
Note: This table was developed by the author and not previously published.

Component	Type	Description
Achievement Records	Input Processing	User performance on one or more variables are recorded, compiled, and displayed at set intervals. The reports may be savable and/or transferrable outside of the app.
Adaptability	Input Processing	Increases or decreases assessment difficulty based on prior user performance. May also change to a new subject matter once a skill has been mastered.
Age Appropriate	Design	The vocabulary, complexity, and attention span required are appropriate for the target users' age and education level.
Performance Correction	Input Processing	Reinforcement of correct performance when users make mistakes.
Logical Structure	User Interface	The individual pages, screens, and elements in the app are accessed in a logical manner. Input errors are rare.
Standards of Mastery	Design	User performance is measured against concrete standards.
Alternative Materials	Design	Specific materials are accessible that provide information on skills. May be used for learning, review, or as a reference.

Repetition	Design	Users are asked to practice a skill multiple times, and on multiple occasions. This can help transfer knowledge to long term memory.
Meaningful Learning	Design	Users are asked to make connections between new information and information that had been learned earlier.
Effective Multimedia	User Interface	Images, graphic effects, sounds and other media are related to the user activities being conducted.
Learning Objectives	Design	A learning outcome has been clearly identified. May also include the conditions of performance and a measurement criterion.
Feedback	Input Processing	Assessment of correct performance. Can be provided by imagery, audio, text or a combination.
Gamification	Design	Users are challenged with an entertaining theme, complex interaction, and goals to accomplish. May include storytelling elements, characters, and a reward system.
Creativity	Design	Encourage the user to exhibit modeling ideas
Collaboration	Design	Requires involvement of others such as multi-player games
Problem Solving	Design	App provides problem situations for user to solve
Communication	Design	App has specific communication abilities

6. Implementation

As with any educational technology, math apps can be implemented in various ways, for voluminous purposes. For higher education, math apps can be used in conjunction with "flipped classroom" teaching methods. Students are told to review instructional materials, like a chapter in a text book, before arriving at class. Students then spend the class period practicing the skills described in the materials, or collaborating on a project using one or more math apps. Math apps can also be blended with institutions that have one-to-one computing. Some schools have been able to provide each student in specific classes with a computing device. This allows for better standardization of activities, increased ability to streamline lesson plans, reduce IT related issues, and increase networking among students. If these electronic devices are imaged remotely, it would be easy to add one or more math apps to each device during setup. Many companies offer reduced pricing for schools, especially schools ordering licenses for multiple devices.

There are many types of Math Apps--see www.garybitter.com (Arizona State University, 2011)

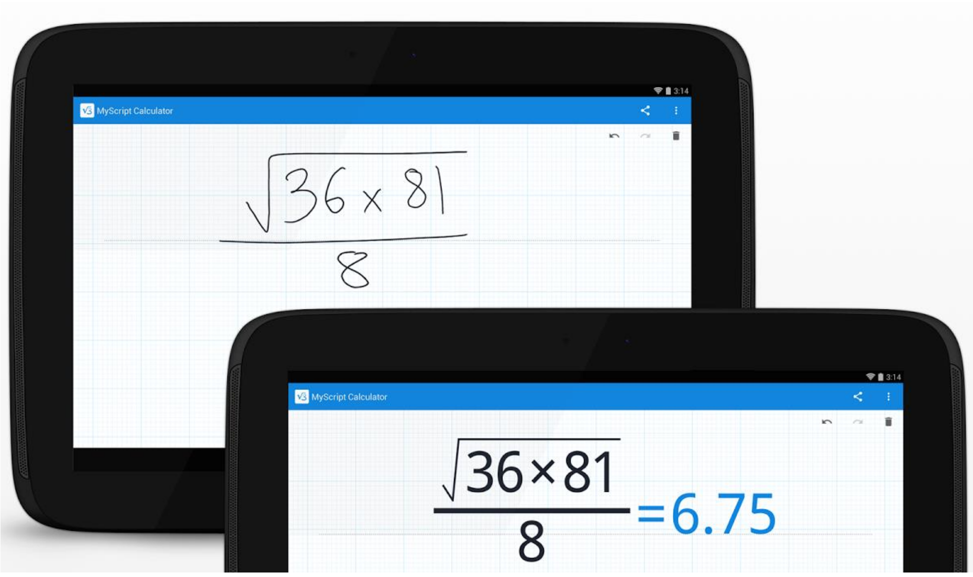
- Drill and practice
- Computational tool-- http://www.wolframalpha.com/pro/ (Wolfram Alpha LLC, 2015)
- Gaming
- Problem Solving
- Augmented learning
- GPS

- Photo
- Tutorial
- Decision Making
- Critical Thinking
- Digital tool
- Simulations
- Assessment
- Lesson planner

Often there are times in class where individual students need some type of individual attention, leaving the rest of the class unoccupied. Math apps are an impeccable tool to provide supplemental activities to the unattended students in these situations. The Bring your own device (BYOD) strategy is sometimes used in schools with limited budgets, limited IT expertise, and/or limited staff. Students are encouraged to bring and use their personally-owned computing devices in class. Educators in such schools could also use math apps as a supplemental activity by identifying a list of apps for android and iOS that students are allowed to use. It is recommended that teachers first demonstrate how to find and install each type of app onto a device before the first use. One of the simplest ways to take advantage of math apps is to use a calculator app. These apps can replace, and even improve upon, standard hand-held calculators. For example MyScript Calculator (Figure 3), available for iPads and iPhones, solves problems that are hand-written and is rated 4.5 out of 5 by about 2000 users (App Annie, 2014). This is significantly faster than entering problems key by key, especially for advanced problems like logarithmic functions. Yet another innovation in automated calculation is PhotoMath by Microblink (Microblink, 2015). With this app, you can simply hover the camera of a smart device over a mathematical problem, and the app solves the problem. PhotoMath can calculate arithmetic expressions, fractions, decimals, powers, roots, simple linear equations, quadratic equations, inequalities, simple equations systems, absolute value inequalities and absolute value equations.

Figure 3: Screen shot of My Script Calculator (MyScript, 2014)

Teachers should clearly determine how and when students will be allowed to use math apps and communicate



the standards. Questions that need to be answered include:

1. Will the students only be allowed to use math apps after completing tests, during the remainder of the class, or will they be allowed any time a student is not actively engaged?
2. How will the student's use of the devices be monitored in a consistent and fair manner?
3. How much student training and IT support will be required?
4. Will the training and support interfere with the progress of the lesson?
5. What restrictions need to be placed on web browsers to avoid risk of access to inappropriate materials?
6. While preparing a lesson plan, identify the overall learning objectives first, and then devise a math app activity that aligns with those objectives (and doesn't preclude other aspects of the lesson).
7. How can I assure digital access for all?
8. Is the app free? If not funds?
9. Does the app match the math standards (Figure 4)?
10. Is this a good app for blended learning?
11. Is this a good app for a project based learning approach?
12. How can I include worldwide collaboration with the app?
13. How can creativity be part of the learning approach?
14. How can digital features such as GPS and photo capabilities be built into the lesson?
15. The app must be matched to the math strands and topics in the current lessons see Table 2 for some apps matched by math strand.

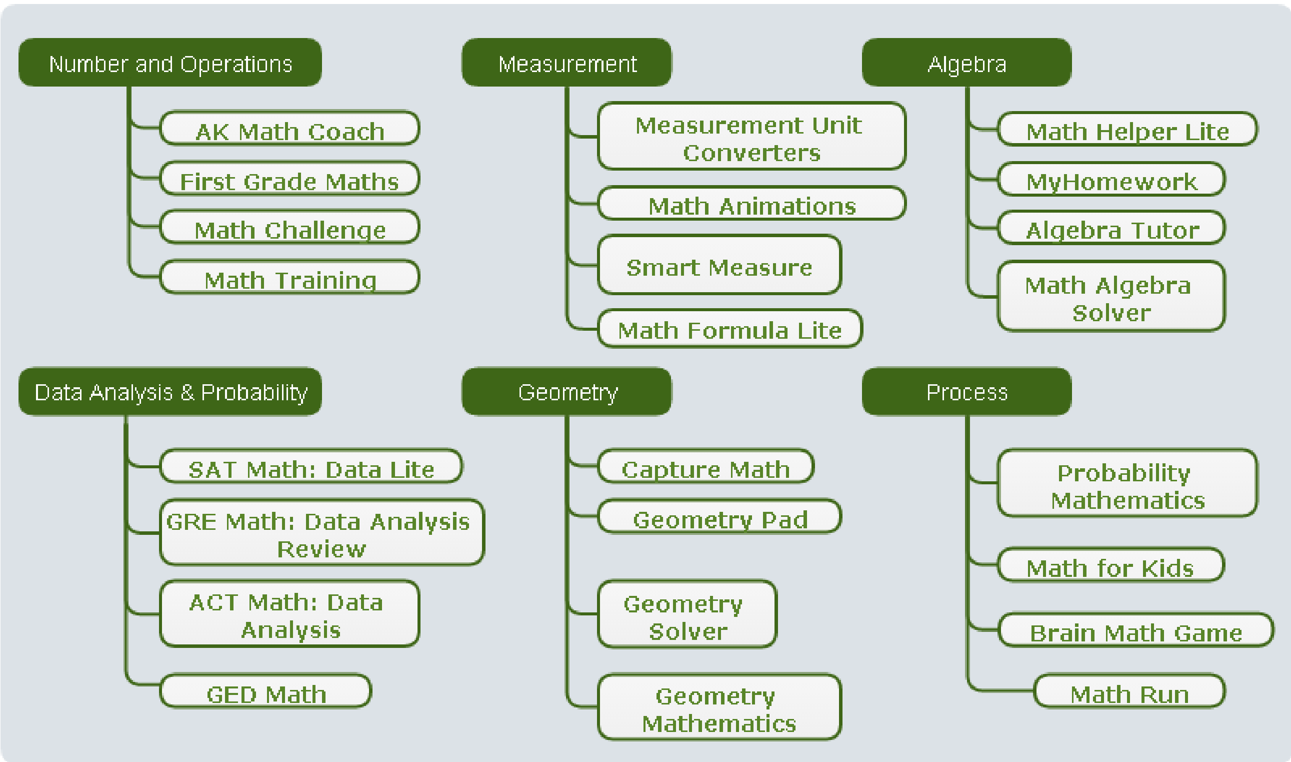


Figure 4: Effective Math Apps by Common Core Strand

Note: This figure was developed by the author and not previously published.

Implementing a new technology without proper planning and preparation can have disastrous results, which may negatively affect future attempts. However, it is worth the effort. Preferably many of these and issues be addressed with the help of administrators at the school, district, department or college level.

Procedural documents and policies can reduce the amount of time and effort required of individual teachers. Even so, teachers are strongly encouraged to become familiar with any app to be used. Math apps can be used for individual practice, as well as team competitions. For team competition, the teacher needs to identify meaningful, yet achievable goals. Goals to be achieved may include the highest score, highest game level, or quickest completion time. In group activities, the teacher should migrate between teams regularly and act as a coach. The attractive visuals can help keep learners motivated in math; an un-motivating subject for many students.

Math Apps are effectively leveraged in problem-based environments. A properly prepared math lesson, incorporating math apps into the instructional strategy, can serve as a model for partner educators. Lessons can be delivered throughout grade spans PreK-2, 3-4, 6-8 and 9-12 in science, technology, math and engineering (STEM) while at the same time providing exposure to digital tools. Recently the education industry has placed a great emphasis on STEM education. STEM interest among students has emerged as a critical issue in the United States. It is similar to the impact on math and science education caused by the launch of Sputnik in 1957. Federal, state, and local agencies are investing billions of dollars to equip schools with iPads and Tablets, computers, and telecommunication networks enabling Wi-Fi. But these investments will not pay off unless teachers, and future teachers, become proficient with implementing math apps.

Math apps, and in general, mobile technologies provide enhanced communication, collaboration, creativity, and problem solving in classrooms. Teachers can meet the burgeoning need for technology-proficient graduates with a significant national commitment to infusing modern STEM activities throughout the teaching and learning process. The U.S. Department of Education, the National Science Foundation and the White House "Educate to Innovate" initiative have all provided institutional momentum. Effective teachers are known to often increase student learning outcomes (Aaronson, Barrow, & W., 2007) (Rivkin, Hanushek, & Kain, 2005) (Rockoff, 2004) (Slater, Davies, & Burgess, 2012).

Math apps can also provide a virtual out-of-school experience helping K-12 students to prepare for careers in STEM. In addition, using web applications on a mobile device to view high quality digital videos is a technology-rich experience likely to help prepare them for the workplace. In regards to working professionals, adult learners prefer video demonstrations over live demonstrations, and prefer them to be available online (Smith, Rafeek, Marchan, & Paryag, 2011). Math apps developed in the future are likely to contain digital video demonstrations. Alternately, digital video libraries developed for mobile devices containing math content will be distributed via the World Wide Web and available twenty four hours a day, sometimes free of charge.

Progressive research and development teams can maximize accessibility and impact by making math apps free of regional restrictions, application interface barriers and usable across platforms. A math app can be developed for Android and iOS based devices at the same time. They can also be developed for error-free functionality on most major web browsers to include Mozilla Firefox, Internet Explorer, and Google Chrome.

7. Theoretical Underpinnings

A sound theory can provide deeper understandings of phenomena, causal relationships, and practices in regards to developing and implementing new technologies in education. Theories of metasystems learning describe an advanced form of learning supported by online collaborative apps, such as Google Apps and many math apps. This is a more advanced type of learning compared to linear thinking and standard retention of knowledge, skills, and abilities.

In addition, the pedagogical features in math apps support the theoretical components of meaningful learning, including personalized feedback, self–regulation, and personalization (Railean, 2012). Meaningful learning, as opposed to rote memorization, results in an understanding of knowledge, concepts, and principles. Secondly, material that is learned meaningfully can then be applied to more advanced topics that follow from it; topics that require the material as a prerequisite. Tertiary positive effects can also result, as the learning can transfer to diverse, real-world, unscripted problem solving activities.

8. Conclusion

Tech savvy teachers and educational researchers have paved the way for math apps to be integrated into most, if not all, math curriculum. The result tends to be increased learning outcomes, increased motivation, and increased self-efficacy. While not every math app to be found is capable of achieving such results, there are many that can. Educators must analyze their specific learning context, the learners, and the technological environment. Multiple established theories of learning and education support the use of math apps, and elucidate the mechanism of how benefits are realized from a cognition perspective. With thousands of free math apps currently available, and increasingly more effective apps in development, dutiful educators will work to integrate them into the math classroom. As professionals we must strive to teach as effectively and efficiently as we can, and not settle for what been done in the past. Emphasis needs to be placed on Digital tools that support Communication, Collaboration, Creativity and Problem Solving in a problem-based math learning environment.

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