A GRAPHING APPROACH TO ALGEBRA USING DESMOS

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Personal experience in the classroom has shown me the benefits of an approach to college algebra that leverages technology (in the form of the TI-83/84 graphing calculator) and graphical representations to facilitate students' conceptual understanding and engagement with a subject for which they often have little affection. On the other hand, I have also seen some of the shortcomings inherent to graphing calculators, and have sought better alternatives for my students. I first encountered the online graphing utility Desmos in a graduate geometry course, but have since spent considerable time and effort on applying it in the classroom. Desmos is an online graphing utility that is free to use and offers opportunities for facilitating students' understanding of mathematical concepts beyond those possible with a handheld graphing calculator. I believe that using Desmos as an instructional tool in a course like college algebra could lead to significant gains in student achievement and understanding, as well as improving student engagement and attitudes toward mathematics.

Since the introduction of the graphing calculator, educators and researchers have sought to determine the effect of integrating graphing technology into mathematics education. Although this research has produced some mixed results, Ellington's (2003) meta-analysis of studies on the effects of technology in pre-college mathematics indicates that graphing calculator use is correlated with improvements in students' conceptual and problem-solving skills, that students' operational skills benefit from calculator use, and that graphing calculators may positively influence student attitudes toward mathematics. Quesada & Maxwell (1994) found that graphing calculators had a significant positive effect on their precalculus students' exam performance, citing as possible sources of this improvement "the more interactive presentation of topics, the immediate feedback and the ability to check answers…, the development of visualization skills or the students' constructing of knowledge" (p. 214). Hollar & Norwood (1999) used a graphing approach to an undergraduate intermediate algebra class, and while they found no significant difference on a "traditional" final exam or in student attitudes toward mathematics, they did find that students in the experimental group demonstrated significantly improved understanding of functions, as measured by the O'Callaghan Function Test. Several sources have noted the importance of the function concept, with Carlson, Oehrtman, & Engelke

(2010) calling it the "central conceptual strand of the mathematics curriculum from algebra through calculus" (p. 115), so improvement in this area is essential.

The potential benefits of graphing calculators extend beyond achievement and conceptual understanding, as integrating technology into the curriculum can promote students' engagement with the material as well. Quesada & Cooper (2010) observed that graphing calculators and dynamic geometry software empower students to explore mathematical concepts on their own, allowing them the opportunity to take an active role in their own learning. The incorporation of technology also allows instruction, class activities, and assessments to focus less on computation and more on concepts (Esty, 2000), opening the door for students to develop lasting understanding, and in turn improving transfer and retention. Smith & Shotsberger (1997) found that students perceived that the use of graphing calculators helped them to "'understand more fully' or to see certain ideas 'better'" (p. 373), illustrating the powerful impact that visualization can have on students' construction of mathematical knowledge.

Although graphing calculators can be a powerful tool for facilitating student learning, there are also inherent qualities of the devices that create barriers. For example, the process of finding the real roots of a function can be difficult for students, particularly if they have non-integral values, do not appear in the calculator's standard viewing window, or are grouped closely together. Many of the tasks for which the graphing calculator is the most useful in the college algebra curriculum (e.g., finding real roots, identifying extrema, and solving systems of equations) also have a relatively steep learning curve. The result is often that too much attention is devoted to the mechanics of working with the calculator, confounding the mathematics at hand. At the level of logistics, there is the obvious issue of the high cost of graphing calculators (often around $100), as well as the somewhat less evident problem that skill with a handheld graphing calculator is not likely to transfer beyond the classroom. The upshot is that while graphing technology is a powerful tool that can impact student learning, handheld graphing calculators are expensive, have a steep learning curve, and require students to develop a specialized and largely non-transferable set of skills.

Desmos addresses many of the shortcomings of handheld graphing calculators. This online graphing utility is free, runs in a web browser with no additional downloads or installation required, and can be used as an app on many smartphones and tablets ("Desmos | About Us", 2015). Many of the features of Desmos are very intuitive; for example, zooming can be accomplished by mouse scrolling on a computer, or by the familiar pinch-zoom method on a tablet or smartphone. Intuitive design choices such as this make using Desmos more relatable for students, in turn greatly reducing the "learning to use technology" component of instruction and allowing for greater focus on developing skills, strategies, and mathematical concepts. In terms of the college algebra curriculum, finding real roots, extrema, and points of intersection is as simple as clicking on the relevant point(s). Desmos also provides a fertile ground for student exploration, as the list of inputs and the graph itself are shown side-by-side, the calculator updates in real-time, and students can employ sliders to "play" with the effects of changing different components of an equation. Beigie (2014) argues that these features provide "immediate visual feedback that is ideal for informal experimentation" (p. 259). Recent updates allow users to perform regression on a table of data and import an image into Desmos, then overlay a curve to match the real-world phenomenon depicted (Ebert, 2014). Ultimately, Desmos is a powerful tool for calculation that has intuitive design features, is free to use and highly accessible, and "gets out of the way" of the mathematics. For these reasons, it could represent a significant improvement over handheld graphing calculators as a tool for teaching and learning mathematics.

Research clearly indicates the potential benefits of using a graphing-intensive approach to algebra that is facilitated by graphing calculators. However, the handheld graphing calculators that are typically used are expensive, outdated, have a steep learning curve, and are seldom used beyond the classroom. Desmos is a free, web browser-based graphing utility that is powerful and intuitive, and can be used to facilitate students' construction of mathematical knowledge without needing nearly as much attention devoted explicitly to learning to use the technology. Accompanied by pedagogy and assessment that is geared toward developing conceptual understanding and problem-solving skills, integrating Desmos into the classroom has the potential to significantly impact student learning. Further research is needed to determine the extent to which using Desmos affects student achievement, conceptual understanding, and attitudes toward mathematics, but my hope is that the analysis provided here will serve as sufficient motivation to explore the possibilities.

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