Reflections on How Mathematics Education in Ohio Impacted the Nation

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Abstract

This invited paper reflects on the evolution of technology in mathematics education, with a focus on how handheld graphing tools have transformed teaching and learning since their inception in the 1980s. Drawing on personal experiences and the visionary work of educators at The Ohio State University, the author examines the profound impact of visualization technologies and the enduring challenges of integrating technology into curricula. Key themes include the shifting priorities in K-12 mathematics, advances in technology like the TI-Nspire, and the potential of digital tools to enhance equity and engagement. The paper concludes by advocating for a renewed vision in mathematics education that emphasizes relevance, creativity, and access.

Keywords: Mathematics Education Technology, Graphing Calculators, Curriculum Reform

Introduction

In reading the two articles by Schultz (2024a; 2024b), I was struck by the notion that what goes around comes around – that while things might seem to change, much remains the same. In fact, in my 1995 article on algebra, I noted that “algebra has different faces and is interpreted very differently by different people” (p. 1), and I just submitted a paper to a journal arguing for the need to change the face of high school mathematics from the current algebra centered stance to one that opens the door to other topics that are more relevant in today’s world (Burrill, submitted). I posed a question in the 1995 article that is relevant today, “How can a curricular sequence be designed to incorporate different perspectives in a way that will give students a coherent and useful understanding of algebra [mathematics]?” (where today “algebra” could be replaced by “mathematics”).

One key difference between then and now was the existence of the group of mathematicians and mathematics educators at The Ohio State University (OSU) who collaborated with each other and mathematics educators around the US to develop and share a common vision for what mathematics education should look like with respect to equity, technology, and the curriculum. I was fortunate to have met and interacted with some of those folks like Bert Waits, Frank Demana, and Wade Ellis and to have colleagues such as Glenn Stevens and Max Warshauer who were products of the Arnold Ross Program at OSU and instilled in me the Ross mantra of “think deeply about simple things,” which guided much of my own teaching, professional development design, and curriculum work. This paper will look briefly at how I became involved with handheld graphing technology, what has changed and what has not since the 1980s, and where we are today in what is taught and the role of technology in high school mathematics.

My Journey

Schultz describes Bert's 'aha' moment when he first succeeded in creating the graph of a function on an oscilloscope connected to a computer in his office. My "aha" moment came during the summer of 1986 when, as a high school teacher on the Mathematical Sciences Education Board, I was at the "highly regimented atmosphere in a corporate training center outside of Washington, DC" (Schultz, 2024b, p. 38) where the NCTM Standards committees were working. I had been teaching a high school statistics course since the late 1970s and, realizing that my students were limited in what they could investigate and do because of the computational load, made sure they all had CASIO calculators with keys to calculate statistical measures. But we did our calculus graphs by hand. As Schultz mentioned, the author teams for MSEB and NCTM met and exchanged information, and it was there—after following a yellow line through a maze of hallways and doors—I met Bert Waits, who introduced me to his Master Grapher and the power of visualization. My 'aha' moment—I was immediately captivated and took the copy Bert gave me to my high school calculus class, and, as they eagerly explored ideas such as end behavior and concavity, I was sold on the use of technology to graph functions.

I remained in touch with Bert and became a member of Teachers Teaching with Technology (T^3). Within a few years, all students in our math classes at Whitnall High School had a TI graphing calculator; students could rent one for $10, which they got back at the end of the year if they returned the calculator. One of the amazing things was how many different ways you could use technology to approach a problem and how technology empowered students. I clearly remember early on having my algebra class graph two equations and trace to find the point of intersection, when a student exclaimed, "You can do this with the intersect command! Why didn't you tell us? And I replied, "Because I didn't know!" The message was loud and clear—let students take charge of their learning when they use the technology; don't make them wait for me to catch up. I became an ambassador for the use of graphing technology in teaching and learning mathematics, and traveled with Bert to England and Greece and brought the first Texas Instruments (TI) graphing calculators to Australia. In 2008, with the sponsorship of Bert, I became a senior mathematics advisor to Texas Instruments Education Technology along with Tom Dick and Wade Ellis and serve in that capacity today.

The Curriculum

Schultz (2024a) makes the case that educators at OSU set the stage for four K-12 curriculum developments, which were embodied in the 1989 Curriculum and Evaluation Standards:

- Providing appropriate pathways for all students,
- Incorporating technology, especially graphing calculators,
- Including data analysis and probability as major components,
- Developing courses to prepare teachers to teach the curriculum.

Since then, we have had two more standards documents, the 2000 *Principles and Standards for School Mathematics* (NCTM) and the *Common Core State Standards for Mathematics* (2010). These brought some coherence to what is being taught K-8, but high school mathematics remained relatively unchanged despite calls for modeling and statistics. In most high schools, mathematics has remained centered on algebra with preparing students for calculus as the goal, although many are arguing for change (e.g., Leinwand & Milou, 2021; NCTM, 2024; Schoenfeld & Daro, 2024). Although conversations have shifted from content to an emphasis on the nature of instruction, with attention to issues of equity, access, and identity in who gets taught what, course-taking structures and system policies still ration opportunities and reinforce inequities for many students (Burdman, 2018). Some movement to allow students to pursue pathways relevant to their interests, once they have learned key mathematical content, happened at the post-secondary level when, in 2012, the Dana Center began work on separating developmental and college-level mathematics courses into distinct pathways to offer more students a chance at college success. This movement has spread to high schools, and as of 2022, at least twenty states had joined the Center's launch year initiative to align high school math courses with students' goals and interests (Dana Center, Communications, 2022).

However, Schultz's characterization of the 9-12 mathematics curriculum of the 1980s as a "mañana curriculum" is still true for too many students in 2024, consisting of prerequisite after prerequisite in preparation for calculus even for the majority of students on other career paths. The curriculum still emphasizes manipulation of isolated skills at the expense of understanding how to combine and apply fundamental concepts; the curriculum largely ignores other important topics like analyzing and interpreting data (Levitt & Severts, 2022; Schoenfeld & Daro, 2023). While 75% of high school students take a course called Algebra II only 17% take a course in statistics (National Center for Educational Statistics [NCES], 2022) and a statistics unit embedded in another course is likely to be at the end and omitted (Burrill, 2023). And, despite Crosswhite's warning in his 1986 NCTM President's Report, false dichotomies still lurk when educators consider the direction of mathematics education (e.g., concept vs procedure, data science vs calculus). Tensions between mathematics educators and mathematicians still exist in some institutions.

The Technology

Today, graphing technology is well entrenched in high school mathematics with access required on Advanced Placement Calculus, Precalculus, and Statistics exams as well as other high stakes tests. Personal experience doing workshops with teachers suggests that the technology still seems to be used more for advanced mathematics than for beginning courses. The power of function graphing technology to explore the effects of transformations on parent functions was a prominent theme in the Waits and Demana texts and is part of most high school mathematics curricula today. The notion of a complete graph, although not that language, is a key component of the new Advanced Placement Precalculus treatment of functions, which emphasizes rate of change, end behavior, holes and asymptotes, transformations, and language to describe the graphs of functions (College Board, 2023). T^3 has over 500 instructors internationally who provide support for teachers through a variety of webinars, workshops, and professional development options. The Texas Instruments website contains hundreds of well thought out and carefully designed activities by teachers for teachers to use in their classrooms.

Web based interactive dynamic technology has become increasingly prominent, which does give me some concern. As of 2023, approximately 92% of 15-17-year-olds had a computer at home (https://www.statista.com/statistics/475949/usage-of-desktop-latop-teens-age/), which seems positive. However, this means 2 out of every 25 students do not; given the 17 million high school students in the US, too many students do not have access to the web and without access to a handheld are deprived of a tool that can help them learn leaving them with a less than optimal mathematical experience. (Note that 5% of high school students do not have cell phones (Hatfield, 2024)).

The TI-84 has vastly improved from the earlier versions with the addition of color, pretty print, increased functionalities such as relational graphing and expanded statistics features. The latest version has more memory, faster processors, and advanced connectivity options but with the same interface and is still relatively easy to use. You can program in Python on the TI-84 Plus CE.

The release of the TI Nspire in 2007, opened up another world. This new interactive dynamic handheld brought together computation, graphing, geometry, computer algebra, spreadsheets, notes, and data and statistics, where activities from these different functionalities could be compiled on pages to produce an integrated mathematical sequence of connected ideas. Nspire brings a new meaning to visualization—linking words, symbols, and graphs on the same screen that update together when one is changed as well as update across pages in the same problem. For example, Figure 1 displays a document developing the Central Limit Theorem where random samples are generated from each of three populations and a simulated distribution of sample means for that population is visually updated in real time as new samples are generated. Figure 2 (left) shows how the simultaneous display of the graphs of a function, (easily changed) and of its derivative can be used to understand the relationship between the two, while Figure 2 (right) illustrates how dragging a point can make the concept of a Riemann sum and of an over or an underestimate approximation meaningful.

Figure 1: Collecting data in real time, investigating the Central Limit Theorem for (left) skewed; (middle) uniform; and (right) bimodal populations.

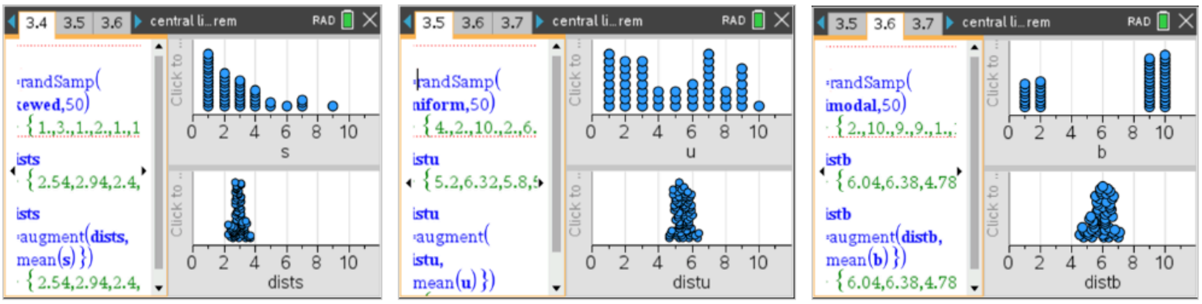
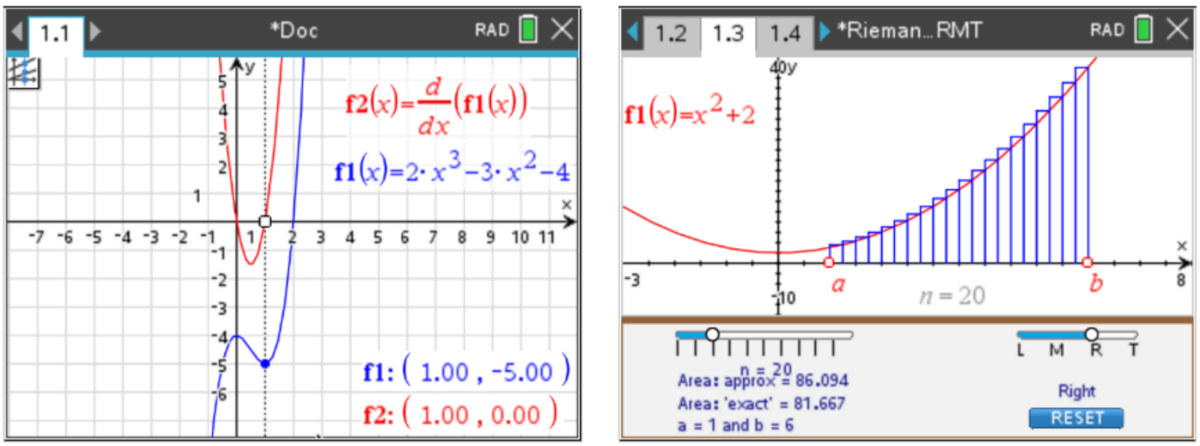


Figure 2: Interactive connections. (Left) Connecting functions and their derivatives through multiple representations; (Right) Dragging points to explore Riemann sum approximations using different methods.



While I can still do everything mentioned by Schultz (2024b, p. 32) quoting from Waits & Demana (1998, p.3), I now have a much wider array of tools to use in exploring mathematical ideas; I can develop an activity and store it in a "tns file" for easy access and sharing. I can create mini "apps" that allow me to investigate concepts such as the difference between an expression and an equation using an action consequence move (Burrill, 2015)— grabbing and dragging a point on a number line displays the changing value of an expression; clicking a bar changes the expression to an equation, and the focus becomes what point will make the statement true (Figure 3, left and middle). I can see a dot plot morph into a box plot and move points in the dot plot to see the effect on the box plot (Figure 3, right), display many multiple representations simultaneously, such as the monthly CO2 levels (ppm) in the air over a series of years (Figure 4, left); or make and test conjectures about points of inflection by dragging points to change the shape of an object (Figure 4, right). Nspire allows me to track and collect trace data in real time to see the behavior of the derivative of a function; move a point in the plane and change the entries in a list; and work with multivariate data sets with thousands of entries. Students can go to mathematical places they have never been—exploring three dimensional shapes or tracking climate change data. They have many more options and can quickly "undo" a step that seems unproductive, giving them confidence to experiment with mathematical ideas.

Figure 3: New ways of visualizing math. (Left and Middle) Investigating expressions and equations; (Right) The structure of box plots.

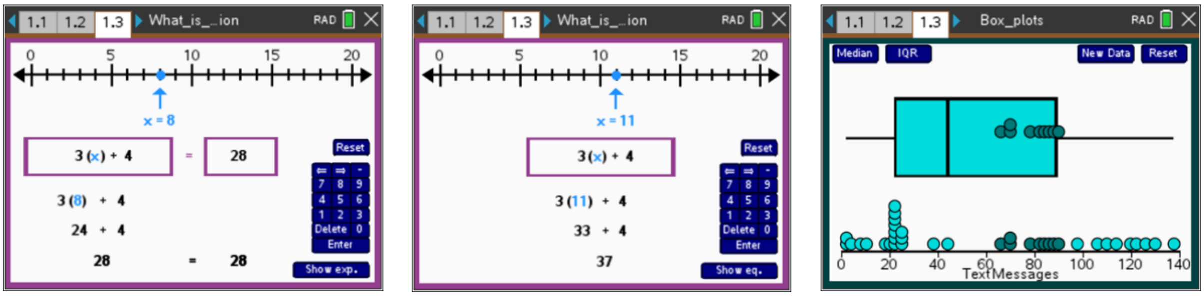
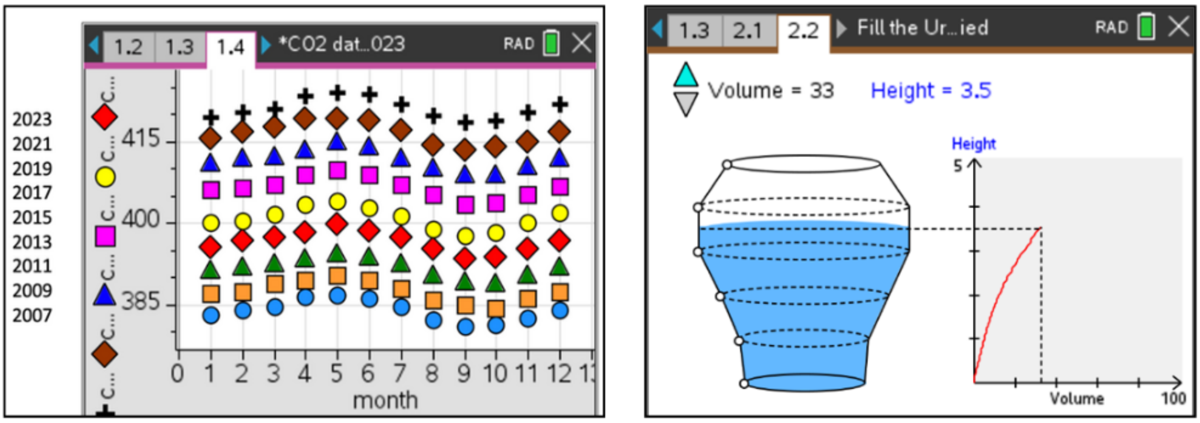


Figure 4: New ways of visualizing math. (Left) Monthly CO_2 levels for 2007-2023; (Right) Connecting the share of the urn to the graph of the height vs volume.



However, the possibilities offered by the technology have not really been fulfilled: CAS is merely tolerated by some and not well accepted by many. Too often, the use of handheld graphing technology or digital technology is restricted in college courses. Current research on the role and use of interactive dynamic technology seems to be scarce. One exception is Sacristan (2021), who summarized observed predominant uses of technology in classrooms from a variety of countries and concluded, "Digital technologies are generally used to teach and serve the old; that is, they serve to cater the existing curricula, with much of their potential overlooked" (Sacristan, 2021, p. 92).

Final Thoughts

By 1989, technology had mathematized the world and permeated society (MSEB), but yet in 2024, the OSU educators' vision of mathematics education has not quite been realized. As noted in the introduction, I am still arguing for what we teach and how in high school mathematics and algebra in particular. And technology continues to advance; the advent of AI such as ChatGPT is upending the education world much as the graphing calculator did to mathematics education in the 1980s. The mathematics education community needs leaders such as those described by Schultz (2024a, 2024b) to step up and confront those bound by the inertia of tradition, which can value processes and procedures that are no longer relevant. This stance should not undermine mathematics nor replace it but instead delineate and emphasize what is important about the mathematics all students need to learn, enabling more students to see the value of mathematics, to utilize new mathematical learning technologies that can create new ways of seeing and doing mathematics, and to work with relevant and engaging mathematics.

A call to action: Do you as a mathematics educator emphasize “thinking deeply about simple things” in your courses? Do you “push the envelope” as Waits and Demana did in arguing for the use of technology as an everyday tool to do mathematics? Do you find ways to make the technology accessible to all students? And for mathematics education researchers, we need research that is accessible to teachers and others in mathematics education on how to maximize the technology to enhance learning in the spirit of Suydam (Schultz, 2024a). As they did at OSU, mathematicians, mathematics educators, and teachers working together can realize the OSU vision where changes are driven by what is important for all students to understand for their professional and personal lives, all students are given the opportunity to experience the joy and beauty of mathematics, and each and every student can engage in experiences that illustrate how mathematics can help us understand and critique the world in which they live (NCTM, 2018).

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