Smarter Calculators in the Modern Classroom

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

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Spring 2020

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction:

In 2001, Marc Prensky said, “Our students have changed radically. Today’s students are no longer the people our educational system was designed to teach” (Prensky, 2001 p. 1). With the dawn of the Internet, technology and the primary education system have been mutually shaping each another for the last few decades. Nearly 20 years since Prensky’s article, the education system is still adapting to this disruption. According to Google (2017), 86% of U.S. viewers often use YouTube to learn new things and 7 in 10 YouTube viewers use the platform for help with work, study, or hobby related problem. The accessibility of information has been increasing through a diverse range of avenues – whether one is looking for a fellow student doing practice problems in video format, or a teacher posting a step-by-step tutorial to their educational blog. Another study showed that 80 percent of 8th graders had used a computer for schoolwork purposes on a weekday (U.S. Department of Education, 2017). Students today have more control than ever over how they learn and how they choose what to learn. This new control leads to the question: how are educators incorporating these technologies into their lesson plans and/or adapting to their student’s technological behavior trends? Even if the methods are still effective are the curriculums still relevant, and not teaching obsolete skills? By answering questions, we can ensure that the modern education system continues providing utility to students in an efficient manner.

Wolfram Alpha, Symbolab, and Mathway are all computational knowledge engines created in the last decade. The goal of these tools is to solve a range of queries such as simple fact-checking or complex multivariable calculus equations. They differ from traditional search engines, such as Google, because computational knowledge engines present a single result or data set as a query response, rather than a list of links. For example, if you query a vacation destination, the results would include time of day, weather, population, elevation above sea level. If you query an animal, the results would include the average size, alternate names, and taxonomy. Finally, querying an animal with multiple cities, might result in a table comparing the population of that animal across various cities. Furthermore, these engines can summarize data in multiple formats; a query to determine unknown variables in a polynomial equation can produce algebraic, graphical, and even theoretical results.

These technological innovations have the potential to significantly alter how knowledge is transferred from teachers to students; my research seeks to analyze how students and teachers perceive the abilities of these engines and how, if it all, the engines affect their behavior. Students and teachers are already using these technologies either for personal homework aid, lecture development, and in class explorations. This paper will attempt to determine whether there is a disconnect in students and teachers' beliefs on the role of computational knowledge engines in K-12 education. Furthermore, this paper will explore any existing practices that have either contributed to or bridged this disconnect. Targeting this ideological dissonance can produce a rippling effect in the multitrillion-dollar education industry and help reduce technological inefficiency, excess monetary costs, and instruction of obsolete skills. In turn this may lead to a more intelligent society of which an increasing number of students can be successful, functioning members.

Theoretical Framework:

The Social Construction of Technology (SCOT) framework will be applied in order to understand how teachers and students react to technological advancement in education. SCOT treats the development of technology as an iterative process between innovators and any relevant parties (Bijker, 2001). Relevant parties do not always hold some stake in the development of the new technology but may hold a stake in disruption innovation may cause; these distinctions allow parties involved to attribute different opinions and meanings of the development technology – a concept labeled “interpretive flexibility”. As a result, there is a back and forth dynamic between the engineers and relevant social groups that can disrupt how the engineers continue their work. Eventually the conflict weakens and a single or few solutions are accepted until the process is repeated when new innovation occurs (Lawrence, 1988).

This paper defines K-12 students, K-12 teachers, and education focused technology firms as the primary social groups and will analyze similarities and differences in how stakeholders have been disrupted from novel educational technologies. Initially, I will look into how former disruptive technologies became normalized, then I will determine whether any of these findings can be applied to the case of computational knowledge engines. This process will assume no new social groups have been introduced to the stabilization process and will instead consider how the technological needs and opinions of the existing groups (K-12 students, teachers, education firms) have changed and led to various technological stabilizations. Lastly, this paper will consider SCOT in reference to how the development and desire for computational knowledge engines began and make any relevant connections to previous innovation.

Literature Review:

Teachers’ Perspectives

From a teacher’s perspective, there are three major factors when adopting new technologies for the classroom: complexity of technology, purpose of innovation, and social support system. The specific arrangement of these factors determines how quickly a novel technology will be brought into the classroom, or why it is rejected.

Complexity of technology is defined as the learning curve that teachers and/or students will face when integrating new tech into their current environment. It can be measured in terms of how much time it takes for individuals to reach pre-adoption levels of performance with new technologies. It can also be stated as time required to build knowledge of when and how to utilize a new technology. Complexity is mentioned less often than relative advantage or compatibility, but for new innovations, complexity can be a significant barrier to adoption (Rogers as cited in Boothe, 2017). It can be summarized that a technology with a lower barrier to entry is more likely to be adopted than a technology that requires a robust understanding. In a study by Elizabeth Boothe (2017) on the adoption of a "Learning Management System (LMS)" in a school district, she found that "user friendliness" was attributed to seventeen percent of her participants as the main reason in the adoption/rejection of the LMS. Boothe defined "user friendliness" as what Rogers stated in 2003: "Some innovations are more easily understood than others, which leads to a more rapid adoption than more complex innovations." Another study by Elaine Simmt (1997), "Graphing Calculators in High School Mathematics," further explores how a disruptive technology was adopted in the classroom. Simmt stressed the importance of "user friendliness" by assuming that the burden of technological adoption falls on educators; if teachers do not at least become familiar with the innovation then there would be no way for that technology to enter the classroom without external inputs. There would be need to be outside influence such as administration mandating technological education. In the six teachers Simmt studied, complexity of graphical calculators was not treated as an inhibiting factor, and since this barrier was overcome, the other factors were weighed more heavily. Furthermore, most teachers were able to easily modify their curriculum in order to utilize graphical calculators by adjusting/expanding their examples to generalize and/or foreshadow concepts (Simmt, 1997). The ease of integration can be attributed to the fact a graphing calculator has a low complexity and high flexibility such that it can be interpreted numerous ways to solve broad goals such as saving time and checking work. From this former research, we can conclude when a novel technology provides sufficient and/or flexible utility relative to its complexity, it is likely to be adopted in educational environments with less influence from external factors.

The next key factor in how technology is adopted in the classroom is "purpose of technology" – this is tied into the complexity factor and is defined as how innovation modifies existing curricula. A key point from Simmt's findings showed that graphical calculators were not a means of replacement for any instruction content, instead this tool was used to optimize a teacher's time towards students (Simmt, 1997). For example, a common theme was using the calculator so a student to could verify work themselves – allowing teachers to spend more time on questions more difficult for students to answer outside the classroom. On the other hand, purpose of the Learning Management System in Boothe's Study was to reduce the time teachers spent outside the classroom on logistical and organizational activities (i.e. making copies, updating grades, assigning make-up work, etc.). This allowed teachers to spend more time tailoring teaching strategies to the evolving needs of their students. In another example, the purpose of graphical calculators was to generate excitement and improve students' scores; it was found "Because calculations are easy with graphing calculators, students can deal with numbers in real life problems rather than small numbers, so students can be more interested in problem solving instead of numbers (Kandemir & Demirbag-Keskin, 2019 p. 206). Furthermore, they improved scores because "Calculators can also be used when there is computation in the problem but the purpose is not computation" (Kandemir & Demirbag-Keskin, 2019 p. 206). Basically, students would spend more time on the crux of the subject. All of these various reasons contribute to how a technology is accepted by teachers; LMSs and graphing calculators had different purposes but were both utilized by teachers.

The last factor in determining technological adoption is the social support system in teachers' educational environments. Many new technologies require an adjustment period in which their ins and outs are learnt; afterwards this technology can be best applied and modified to changing classroom needs. However, this adjustment period can be reduced by incorporation of programs such as onboarding classes for teachers and points of contact who have experience with the technology. In Boothe's study, many teachers with varying experience levels were all comfortable adopting the learning management system "the HUB" when there were other teachers in their school utilizing the technology. A study on incorporating "mobile learning" also found that teachers were hesitant to incorporate technology when it was intimidating to balance the possibilities and constraints (Parrot & Leong, 2018). However, in Simmt's study, a support system was not a concern as in most cases calculator use was first demonstrated by the teacher and then students simply mimicked the steps (for different examples); there was limited use of graphing calculators in exploration or investigative activities. In other words, graphing calculators were used as a secondary device to confirm, reassure, or verify existing knowledge and not as a primary technology modifying a teacher's style (Simmt, 1997). In Chinese K-12 education, there is also an emphasis on the support system as there was criticism on the One Child per Laptop policy for "not providing teachers' training and ongoing support" (Warschauer & Ames as cited in Taotao Long et al., 2013). A strong social support system is an important factor for technological adoption and it can influence what type of technologies are brought into schools. However, the importance of this factor can also be mitigated in situations where the technology is operated as a secondary device that is not a functional dependency in the system.

From a teacher's perspective, these three factors: technological complexity, purpose, and support, are significant in telling how technological innovation is adopted into the classroom. However, it is important to consider that there are various other factors in different educational environments that can change the outcome. One of which is the opinions and behaviors of students.

Students' Perspectives

Although the burden of technological adoption may primary rely on teachers, it is still important to consider students' perspectives as they can create a dynamic that persuades or dissuades how teachers introduce technology. The two main factors that are analyzed in past literature are whether students are comfortable using the novel technology and whether they think it helps them learn.

The first study by Long, Liang, and Yu (2013) explores how tablet computers were applied in K-12 schools in China; they found that "the users in the educational system, including the students, teachers and educational administrators, lacked a deep and comprehensive understanding about the application of tablet computers in education" (Taotao Long et al., 2013 p. 68). Their findings also revealed that when students lacked understanding of the tablet's education utility, they used the device for entertainment even though they agreed and showed interest in using the tablets for learning. It was concluded that students prefer to use "old technology" due to improper onboarding and complexity the innovation would introduce (Taotao Long et al., 2013). Another study conducted at the University of Waterloo, analyzed perspectives on self-initiated technology use and determined that students found technology use to be more helpful that detrimental overall. Both students and teachers did agree that “off-task” technology usage hinders learning. Furthermore, students said that off-task technology use was extremely distracting in many cases but many were still undecided on the whether teachers should regulate usage (Zaza & Neiterman, 2019). From these findings we can conclude that students’ comfort with technology actually depends on how the technology is being used and not necessarily the technology itself. In these scenarios it becomes important for more research to be published so that the knowledge is passed down and both students and teachers can form educated opinions on these issues.

In many cases, SCOT analysis shows that educational technology achieves closure as an avenue to provide students with additional motivation and control of their learning. In a study by Parrot and Leong (2018) in Malaysia, they found that students who utilized graphing calculators in problem solving had a better attitude and greater mean score than a group who used a traditional “chalk and talk” methods. Simmt also determined that the key factor for calculator usage was that students found it motivating and it aided in keeping students engaged when teachers were busy with another student (Simmt, 1997). Zaza and Neiterman (2019) had comments from students that when other students were using technology in a productive manner, it helped them be alert and identify important content. In addition to technology being motivating, students found that it provided them with additional representations of information and “enhanced clarity and understanding” (Parrot & Leong, 2018). Overall students had a positive and accepting view of bringing technology into the classroom but still held reservations when asked to make judgements on related policy. These reservations could possibly be alleviated by technological advocacy via K-12 faculty.

From past literature we can see that any technological adoption in educational settings will have some level of organizational user discomfort. That is, there will be challenges that one group or another will have to overcome in order to integrate new inventions. In the educational environment this burden is assumed to be on the teachers. Different levels of adoption are a result of how teachers and their classroom environments can interpret the new technology and once a critical mass is reached, adoption increases rapidly.

Evidence and Analysis:

In the current academic climate, there has been a slew of technological innovation that has increased the accessibility of information. With the development of the internet, the last few decades have seen a boom in the number of tutorials, guides, and help videos that allow individuals to learn topics without having to physically seek out an expert (Fahmy, 2004). Furthermore, computer-based computational engines, such as Wolfram Alpha, are gaining the ability to answer a range of questions that may reduce the need for certain skills. These engines can also present information inquired in a format mimicking a human's solution, further increasing these programs capability. One review summarizes Alpha as: a knowledge engine to answer free-form user queries that does computations from its own internal knowledge, rather than searching the web and trying to match a result (Hindin, 2010). Despite the growing use of these programs, the questions remain: Do students, teachers, and corporations possess a shared understanding of how these fit into the education system? Are educators incorporating these technologies into their lesson plans and/or adapting to their student's technological behavior trends?

There exists some foundational research into how to incorporate these engines into lesson plans and teaching methods. Furthermore, there has been some analysis on whether these engines have a net positive or negative result on student's success. One study by a group of researchers in Mexico had educators and Wolfram Alpha developers implement specific widgets for the course content so that the students could input physics problems into a smaller version of Alpha tailored for their problems. The findings showed that these widgets resulted in a "better understanding of abstract concepts" through visualization and revelation of hidden connections among related ideas (Cepeda & Acosta, 2014, p. 269). However, another study suggested that the use of engines such as Alpha to learn probability, required a "deep understanding of mathematics" and the advantage of them was the minimal programming skills required rather than utility towards teaching (Abramovich & Nikitin, 2017). It is possible that these deviating views on knowledge engines are a result of variance in subject matter they were used with, differences in the overall curriculum structure, or from factors mentioned in the literature review (complexity of technology, social support system, primary/secondary utility).

Looking further into Cepeda and Acosta's study it is important to note that the knowledge engine (Wolfram Alpha) was different from former technologies (i.e. Mathematica) because of its "simpler and more specific" nature. Going back to the teacher's perspectives and key factors for technological adoption, this case demonstrated reduced complexity and a smaller timeline to implement the technology. Their study also hypothesized benefits from incorporating the knowledge engine into the curriculum because students' learning processes would occur at additional levels in the Bloom Taxonomy (Zichermann and Cunningham as found in Cepeda & Acosta, 2014). This was the primary "purpose for technology" – demonstrate content in new manners to encourage understanding as evaluated via existing assessment protocols (homework, quizzes, tests). Their study also facilitated a training period for teachers to make them familiar with the knowledge engine – this shows better results in whether the technology provided utility when introduced to an adequately prepared environment. However, other studies are needed to see the results of computational knowledge engines in unprepared settings. In Thrasher and Perry’s (2015) work, it is further expanded that computation knowledge engines can be used to discover mathematical concepts through student experimentation. Wolfram Alpha queries can be structured and combined in a variety of formats further allowing students to recognize nuances in concepts (Thrasher & Perry, 2015). The key takeaways from these studies are that when students generate their own widgets, experiment with queries, or study multiple representations it assists higher level comprehension and forces students to think critically about the course concepts and variables involved. Knowledge of how to use these engines can continue to provide value as an avenue for students to explore future curiosity.

Most professional studies dealing with computational knowledge engines (or similar technologies) found sufficient benefits to expect their increased adoption. Still, this technology is evolving and a professional research not always being up to date with the technology means we must analyze marketing material and individual accounts for the applicable information. As described by Wolfram Research themselves, Wolfram Alpha was developed “not only to search for answers but also to involve embedded calculations” and display relevant data, charts, and derivations (Hindin, 2010 p. 77). The idea was to provide a direct answer rather than have users sift through a list of web pages.

Taking a look at one early product review in 2009, Wolfram Alpha was heavily criticized for lacking the breadth of information traditional web crawlers had (i.e. Google) (Harris, 2011). Furthermore, it was argued that Wolfram Alpha did not provide any interactivity; if there was an issue in how the query was structured or the user wanted to further explore, the user would need to do all the analysis and interpretation themselves in order to generate the next query. This aspect would increase the complexity of the technology for both teachers and students. Google and Ask.com on the other hand provide cross-references and related links that allow users to continue researching. However, even with these complaints, the positive aspects addressed included Wolfram Alpha's expertise with calculations and being able to piece together multiple "fact-focused" queries (O'Leary, 2009). Another review in 2011 had a much more positive take on Wolfram Alpha's abilities; Christopher Harris's (2011) opinion was that Wolfram Alpha was a turning point in learning innovation because it significantly extended the type of queries one could ask the internet without additional training. One metaphor Harris used was that Wolfram Alpha could not only display the data points provided by search engines such as Google, but now those data points could be manipulated or computed as desired. Harris also is impressed by the tools ability to transform day-to-day queries in natural language input to mathematical equations back to a natural language output. Another positive review comes from a researcher at the University of Omaha and his recommendations to use Wolfram Alpha in high school mathematics, computer science, and other disciplines where mathematical connections are common. This reviewer was more impressed by how quickly one could load various representations of a math concept and less so by the query understanding (Hindin, 2010). From these reviews we can see there was no clear or single interpretation of this technology's functionality. This can be attributed to why nearly a decade since its release there is yet to be technological stabilization and even within the social group of K-12 teachers there is not a common, shared understanding of this innovation; one common perspective views this technology as a primary tool for exploratory learning, another perspective sees this as a secondary tool to perform various types of fact checking.

Overall, I believe Wolfram Alpha and other computational knowledge engines were initially seen as an innovation that could assist researchers and relevant educational parties, but the novelty had worn off and the technology was not functionally beneficial to relevant to the disruption caused to introduce permanent change. As time goes on, it is likely that the disruption caused from adopting this technology will decrease and at some point, the benefits will be worth making these engines a permanent primary or secondary tool. Some factors contributing to this include the limitation of queries and how one could structure them (unlike traditional web crawlers) and lack of data fact-checking and query recommendation. As quoted by Nicholas Carr (cited by Giles, 2009), a technology writer at Encyclopedia Britannica, he warned that "Any level of frustration sends people away".

Since then computational knowledge engines have been evolving and relevant parties have been exercising SCOT's "interpretive flexibility." In an article by WIRED.com (2017), they claim students have begun to use computational knowledge engines to aid in their homework. Some teachers however have held onto their reservations with the technology and claim use of this technology is cheating – specifically citing how it could can provide multiple perfect solutions (Biddle, 2017). Other opinions argue that Wolfram Alpha is a "study aid, not a way of avoiding work." Computational knowledge engines will continue to become more advance and if there is a point where the utility provided outweighs the adoption cost then we will see technological stabilization of these engines in K-12 education.

Conclusion and Recommendations:

In the United States, the education market is expected to reach 2.04 trillion dollars by 2026, up from 1.35 trillion in 2017. In such a large industry it the impact of technology can be immense; individual optimizations derived from research have paved how education has improved over the past hundreds of years. Computational knowledge engines are still at a point where there is an ideological dissonance preventing their adoption. Part of this occurs because the teachers and students affected do not have enough empirical evidence or time on their hands to formulated an educated opinion. Another reason for the ideological dissonance is because the technological landscape and capability is changing so fast it is impossible for the various social groups to attain closure. One example of this is mentioned by Croucher, Rowlett, and Lewis (2012) that today, mobile devices have a variety of calculator applications aimed to serve even the most niche needs. In order for computational knowledge engines to stabilize inside and outside of classroom situations, their use cases in K-12 education need to become extremely clear and outweigh the complexity and need for social support systems.

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