Acceptance of Technology in STEM Secondary Education

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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 the 21st century, the technological revolution radically shifted the way people interact with each other. Technology is increasingly intertwined with our daily lives, including its presence in education. As we grow up, we spend a significant amount of time in a classroom setting. The academic disciplines of science, technology, engineering, and mathematics are frequently grouped together and known by the abbreviation of STEM. Snyder (2018) observes that engineering education is a way to "integrate disciplines, such as math and science, using hands-on learning activities to solve problems", bridging "foundational knowledge and technological development through thoughtful planning and design." The beauty of an engineering education is that it "can help make science and mathematics come to life through application" (p. 46). However, STEM instructors in U.S. secondary education systems disagree about how and for what purposes educational technology is useful, and under what circumstances it is a detriment. Some STEM instructors caution that educational technology can introduce problems of security and equity.

Social Construction of Technology

The goal of this paper is to discuss the role of technology in education using the Social Construction of Technology (SCOT) framework. I will begin by describing the integration of technology into the classroom over the last decade. A relevant social group is defined as those who "share the same set of meanings, attached to a specific artefact" (Pinch and Bijker, 1984). One of the core concepts behind SCOT is the idea that relevant social groups, also known as stakeholders, can utilize artifacts differently to best suit their individual needs. Interpretive flexibility describes how a given artifact can have different meanings and interpretations for different social groups. The design of a given technology "is an open process that can produce different outcomes depending on the social circumstances of development"(Klein & Kleinman, 2002). Technology is neither inherently good nor bad nor neutral. Just like any other tool, its usage is determined by the ones who wield it. The same tool can serve different purposes and stand for different ideas. The tools shape the users just as the users shape the tool. Social groups serve as the agents behind the negotiation process of technology's incorporation into society. Clashing agendas will lead to shifts in design and the negotiation of the artifact's proper place in society.

These negotiations conclude with what is known as "closure and stabilization". According to Pinch and Bijker, there are two main forms of closure: rhetorical closure and closure by redefinition of the problem. Rhetorical closure refers to the convergence of interpretive flexibility by different social groups. When different stakeholders begin to view the artifact with similar interpretations, the barriers between the stakeholders dissolve and the groups are in agreement over its usage. On the other hand, redefinition of the problem results in closure when the technological artifact is used to solve a different, new problem. The benefits of solving this new issue outweigh any previous concerns and help settle the debate. By understanding how this process works, we can make better-informed decisions on the role technology should play in education.

Background

The debate around the inclusion of newly developed educational technologies and tools is not new. During the early 1970s, "the scientific calculator generated a worldwide and intensive debate on whether these calculators should be allowed in mathematics classrooms" and to what extent they can be used by students (Drijvers & Weigand, 2010). The level of integration depends on the curriculum and the instructor's beliefs.

On one side, a calculator almost behaves like a black box and deprives the students of practice and hides the mathematical concepts that are happening behind the scenes. With modern computer algebra system (CAS) calculators such as the TI-Nspire CAS, it is trivial to enter "solve($x^2+4x+4=0$, x)" and figure out the answer with just a few presses of the buttons. However, a student using a calculator learns the abstracted interface and syntax of the device and misses out on all of the middle steps. These middle steps are crucial to the learning process especially when being done for the first time by hand.

Different educators in different classes will have different expectations for students. As an example, teachers in an introductory algebra class would not want students to have access to CAS calculators because it circumvents key aspects of the curriculum such as learning how to factor polynomial equations and finding their roots. In contrast, calculus instructors are less concerned with simple algebra and more interested in ensuring that students understand integrals and derivatives. Using a CAS calculator to speed up calculations in homework is not an issue because it is not the key concept being tested and practiced.

In a world where we all carry a calculator in our back pockets in the form of a mobile phone, some might argue that working out a simple multiplication problem by hand is an obsolete skill. Using a calculator is simply adapting to advances in technology. Neglecting its use would be a waste of potential. As a counterargument, issues such as the digital divide and matters of accessibility point out the flaws with this line of thinking. To state that everyone has access to a smartphone would be an overgeneralization.

External regulations can also run into conflict with internal technology policies. For example, mathematics instructors were told by government qualification exam boards that calculators are becoming so powerful that students cannot use them on certain exams. As an analogy, one instructor declared “when you do your driving test, they don't test you in your horse and cart, it's what you can make of this modern machine” (Hennessy et al., 2005, p. 172). Another instructor from the same department stated “so however important it personally may be to educate a child to use this wonderful piece of machinery [known as a calculator]… I must concentrate… on getting them that [standardized] qualification.”

With the right balance, the scientific calculator can serve as a tool to expand one’s knowledge and increase learning efficiency. In higher-level courses, using calculators will prevent simple computational mistakes. A student can focus on learning the core concepts of their statistics, calculus, chemistry, etc classes instead of spending time dealing with computation using skills they have already been tested on. In a calculus class, simple algebraic errors are penalized less than mistakes that demonstrate a student’s lack of understanding of core calculus concepts. As a calculus teaching assistant, I’ve often been instructed to not grade just the final answer, but to put the bulk of the points on their conceptual understanding of the calculus aspects of the solution.

Relevant Social Groups

To assist with the technology integration process, Ruben Puentedura developed the SAMR Model. SAMR is an acronym for Substitution, Augmentation, Modification, and Redefinition. Each word is on a different part of the integration spectrum. Educators can slowly begin to incorporate technology into their curriculum by moving up one stage at a time.

As an example, the student assignment is to assemble a model airplane from a kit to learn about physics and aerodynamics. At the lowest level, *substitution* replaces one form of the task with another but does not provide additional benefits. Instead of using physical paper instructions, students are provided with virtual copies. *Augmentation* uses technology to improve the task and lead to enhancements of the student experience. Interactive animations are embedded within the virtual instructions to reduce the chance of assembly errors. *Modification* redesigns the task with the technology in mind. Students can try to replicate effective airfoil designs using 3D models found online. *Redefinition* allows for the creation of tasks that are otherwise impossible without the tech. Using open-source software, students can design and launch virtual planes with parameters that cannot be replicated at the model level such as jet engines and complex airfoil shapes.

Educators attempting to integrate technology into their classrooms will find themselves at different stages of this spectrum. In general, educators are not arguing that technology is bad, but there are disagreements about how it should be used and to what extent. Each SAMR stage serves as its own relevant social group. While educators are unified in their desire to improve student learning, they are divided in their beliefs of how technology should be incorporated. Certain educators are content with the mere substitution of technology into certain aspects of teaching and learning while others are pushing for the complete redefinition of the classroom. That being said, there are specific concerns regarding roadblocks to technology integration shared by all of these different relevant social groups. One of these major roadblocks is known as the Digital Divide.

The Digital Divide

The Digital Divide refers to the growing gap between underprivileged members of society who struggle with access to computers or the internet and those who do not. This divide is one of the issues that prevent technology in education from reaching rhetorical closure. In a review of educational technology research trends, Billings et al. (2012) found growing attention to technology integration and distance learning. Before bridging the gap between tech-savvy educators and their peers, Kelly (2015) states that "issues of access, time, professional development, support, consistent policies, and sustainability of programs need to be addressed prior to the implementation of any technology."

Mupinga (2017) concludes that mobile devices serving as education tools can be adapted and utilized to help students prepare for the workplace. Socrative, an educational technology (edtech) application, "engages students in the classroom using their own devices, regardless of platform, with the interactive, real-time, web-based student response system tool" (Wash, 2014). A significant proportion of secondary school students own mobile phones or laptops but there are still students being left behind (fig. 1). The students who lack access to laptops and computers face severe disadvantages when compared to their peers.

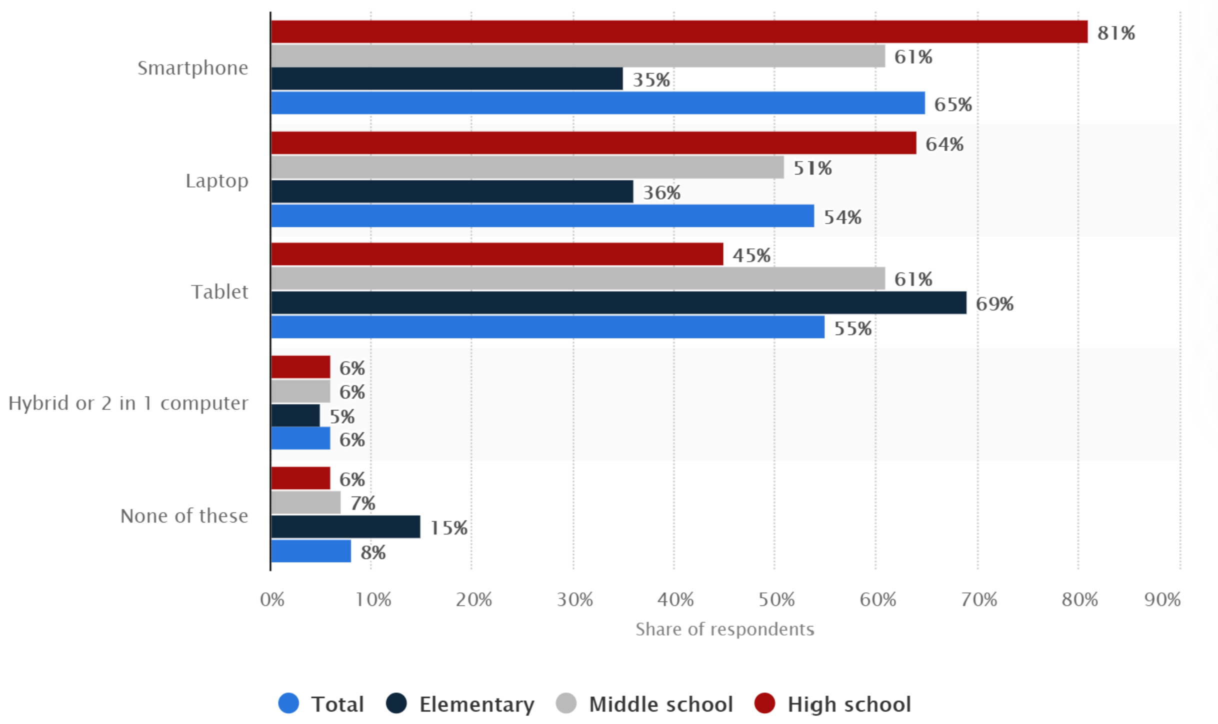

Figure 1. Device ownership by U.S. students, 2015 (Statista, 2016)

To help close the gap, school districts are turning to one-to-one programs to provide one computer for every student. The rationale behind these programs includes the idea that technological literacy skills are essential in the modern workplace and that teachers can only fully take advantage of new learning technologies when every student has access to a device (One-to-One Definition, 2013). Alternatives to one-to-one programs include dedicated computer lab classrooms and mobile laptop carts (computers on wheels or COWs as my secondary school referred to them). However, these alternatives still face issues such as competition for time slots, limited access to software installations, and the missing ability to work outside of school hours at home.

Certain school districts have the budgets to supply technology to low-income students who need it (FCPS, n.d.), but many school districts cannot afford to do so. Over ⅓ of U.S. teens sometimes have to do their homework on cell phones instead of computers that they have access to (Anderson & Perrin, 2018). The gap between the wealthiest and poorest school districts is massive. According to the president of Integrated Education Strategies: "I've seen huge disparities, where I've gone into classrooms in urban districts and the paint is peeling and there's not a computer in sight, to very high-end districts where every kid has an iPad they can bring home" (Pandolfo, 2020).

Simply supplying students with physical devices is not a complete solution. Devices require reliable internet connectivity to access many software and school resources. The abrupt shift to online learning due to COVID-19 has forced education officials to confront the reality that 15% of U.S. school-age children live in a household without high-speed internet (Anderson & Perrin, 2018). Low-income and rural students suffer disproportionately from this issue. Using public Wi-Fi hot spots is a stopgap measure for certain students, but inherently puts them at a disadvantage. For rural students, satellite internet programs such as SpaceX's growing Starlink initiative are "unbounded by traditional ground infrastructure" but still raises the issue of cost (Order Starlink, n.d.). Issues with consistency and internet outages affect student attendance levels and the quality of video calls.

As the social groups seek to integrate technology to reach their respective SAMR stages, the Digital Divide serves to impact them all. By virtue of definition, technology is a core discipline of STEM education. The remaining three disciples have much to gain by integrating technology to create new experiences and augment existing ones. However, it is impossible to do so in an equitable manner without first addressing the great inequality that exists between those who have easy access to the digital world and those who do not.

Substitution

According to SAMR, the first stage of introducing technology into the curriculum is substitution. When using substitution, technology is used to replace an existing structure without significant changes to functionality. Participants of this social group must be careful to not be using technology solely for the sake of having technology. The substitution phase is useful as a stepping stone to transition towards higher stages.

One form of substitution would be replacing class handouts with digital files accessible on student tablets. If no additional benefits are derived from these digital files, the additional risk of improperly supervised technology and easily accessible distractions becomes a net negative for fulfilling the agenda of improved learning experiences for students. In order to start gaining tangible benefits from technology integration, one needs to move onto the next stage of SAMR.

When technology is used as a substitute, interpretive flexibility is helpful in explaining why school administrators and educators can clash over technology's role. Teachers in half of the departments interviewed by Hennessy et al. (2005) felt pressured to introduce edtech into contrived learning exercises where its addition was unnecessary. The administrative pressure can stem from outside sources such as parents and state curriculum requirements. Technological integration can be viewed as a metric for the performance of a school district and serve as an attractor for new students. In this case, technology itself is interpreted by administrators as a checkmark for success. The actual utilization of said technology is less important. The use of technology is interpreted similarly to a status symbol.

In the hands of an educator hoping to help their students learn, technology serves the role of a valuable tool. However, due to contrived learning exercises mentioned earlier, educators will find it difficult to perform as well as before. In one interview, a mathematics teacher stated that they wanted “more in terms of [information and communication technology] as the servant of the curriculum rather than the other way round” (Hennessy et al., 2005). The forced and unnecessary introduction of technology would actually reduce the usefulness of these tools and turn them into detriments in the classroom. Educational technology use must be balanced with “developmental psychology, the psychology of addiction and educational psychology” (Arnold-Schwartz, 2019). There are concerns that “certain ways of using technology could curtail [students’] thinking processes and obscure underlying ideas" (Wexler, 2019).

Augmentation

Within the “Augmentation” social group, educators view the end goal of technology to serve as extensions to the current curriculum. When these technological resources are introduced, they are able to enhance how lessons are taught and lead to better student engagement. The core lessons are unchanged, but there are improvements over the original form.

STEM courses tend to cover large amounts of material in a short period that can be difficult for students to follow. To help with absorbing this information, electronic devices can provide for an enhanced note-taking experience. For example, Reins (2007) found that there were “positive perceptions regarding the benefits of the use of digital ink technology”. Researchers found that “writing with a digital pen may improve learning relative to the use of an ink pen” (Osugi et al., 2019, p. 275). Digital note-taking using software such as Google Documents and Microsoft OneNote have distinct advantages over the traditional pen-and-paper approach such as cloud backups, shareable notes, and the ability to copy complex images/diagrams with ease. However, utilizing thix software requires the cooperation of both teachers and administrators as well as continued access to electronic devices.

School administrators develop technology policies that often supersede the personal policies of instructors. At the forefront of the decision-making process, administrators weigh the pros and cons of various educational technology tools. School systems are bound by software contracts and bear a legal obligation to secure students' information, limiting instructors' and students' technology choices (Waseem, 2020).

Other forms of augmentation include changing activities to resemble games to encourage student engagement (Terada, 2020b). For example, Kahoot! is a game-based educational quiz tool. Students can connect to the web application by phone through an invitation code and participate in classroom activities. Players compete with each other to earn the highest number of points and names are displayed on the leaderboard. The point value of an answer corresponds to the correctness as well as the speed of the response relative to other players.

As with any type of technology, edtech can be the target of cyberattacks and malicious actors. The use of online learning platforms like Kahoot! opens the door to both external and internal abuse. In one incident, students flooded their own Kahoot! session with disruptive bots (Barcelona, 2020). Zoom, the video-conferencing software that was widely used during the COVID-19 pandemic, was abused when online class meetings were hijacked with inappropriate messages and images from malicious actors (Donnell, 2020). As technology becomes further embedded within our education systems, concerns about data misuse and privacy are becoming increasingly relevant as the amount of collectible information grows in scope.

Modification

Technologically modified tasks are able to provide experiences beyond the boundaries of a traditional classroom. Educators belonging to the "Modification" social group seek to design dynamic tasks that are beyond the scope of physical activities.

Graphical representations of equations are common sights within STEM curriculum tasks. This is typically either graphed by hand or with a calculator. A modified version of this task could involve the use of digital graphing tools like the web-browser-based Desmos site. One usage of Desmos is the ability to dynamically change how graphs look by using a slider to modify constants in equations. When compared to traditional methods, Desmos is much more flexible and will help students better visually understand the effects of changing constant parameters of their function.

However, students should not be given free rein over their usage of technology in the classroom. When abused, technology serves as the gateway to distractions. Studies have shown that divided attention between electronic devices and classroom lectures affected the long-term retention of knowledge and reduced subsequent exam performances (Glass & Kang, 2018, p. 405). Additionally, these studies showed that the device distractions negatively affected the performance of not only those who were multitasking on devices but also other students who were merely near them.

Logistics are also vital aspects of any classroom. Educators can consider using management systems such as Google Classroom, Collab, or Blackboard to assist in running their classroom. These digital tools consolidate tasks such as grading and resource distribution into a single location for easy access. If organized well, these systems will provide students with a centralized platform to submit assignments and view class resources. Depending on the level of automation, this could also serve to provide immediate and individualized feedback.

Discussion boards such as Piazza can provide students with new communication channels with both their instructors and peers. Shy students may feel more comfortable reaching out to their instructor in a private discussion post rather than raising a question during class. Additionally, the peer-to-peer support from answering each other's questions has been demonstrated to improve performance and retention of information (Drane et al., 2014).

Redefinition

Finally, the last stage of SAMR is redefinition. Participants who seek to redefine the classroom will be able to create experiences that were previously unheard of. The fundamentals of teaching are changed through the introduction of ground-breaking technologies and different lenses to view traditional teaching methods (Best, 2021).

In a traditional "chalk and talk" classroom, students follow along with instructor lectures and class activities. Homework and textbook readings are to be completed outside of class. However, the advent of online learning has led to the rise of "flipped classrooms". In a flipped classroom, students are introduced to new content at home usually through video recordings, and complete homework and other projects during class time. Flipped learning allows students to learn at their own pace while receiving more individualized help during class instead of keeping pace with an in-class lecture. Students can also rewatch sections of the lecture without holding back other members of the class or skip sections that they are already comfortable with. With videos that they can replay on their own devices and other multimedia formats, students can typically learn more than they learn from non-interactive video presentations (Schwan &

Riempp, 2004, p. 294). Shabiralyani (2015) reports that "using visuals aids as a teaching method stimulates thinking and improves [the] learning environment in a classroom."

As defined by Abrahams and Millar, practical work is "any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials." (pg 8) Practical work is "useful in establishing linkages among STEM-related disciplines as well as the connections between knowledge and the real-life problems" and is regarded as critical to scientific reasoning and understanding (Fung, 2020, p. 505). The flipped classroom model allows for additional practical work time without the need to extend class time. Advances in computer and information technology accessibility have allowed flipped classrooms to become a more viable teaching model.

Closure

In recent years, educators were participants in various SAMR social groups. On a personal level, I've had class periods relying on film projectors and chalkboards immediately followed by other classes utilizing digital whiteboards and virtual simulations. Even within a single school, educators differ dramatically in the levels of technology that they wish to incorporate into lessons.

As of March 10, 2021, we are exactly one day short of the one-year anniversary of the University of Virginia's announcement that all students are to be sent home and that the remainder of the semester will be exclusively virtual. It was a sudden announcement in the midst of a rapidly expanding global crisis. The vast majority of secondary schools and higher education were also forced to transition in a similarly abrupt fashion. The U.S. Census Bureau (2020) found that “nearly 93% of people in households with school-age children reported their children engaged in some form of ‘distance learning’ from home” during the pandemic period.

In the blink of an eye, educators across the country were forced to transition. COVID-19 did not care about which SAMR group educators were part of. To the virus, people were simply hosts for replication and vectors to other potential victims. The requirement to socially distance meant that it was impossible to conduct large-scale in-person education. There were simply too many students and too little room.

Halting the education of millions of students in the U.S. for an unknown, but lengthy period of time was simply not an option. This pandemic posed a brand-new problem to society that required a rapid response. The only way forward was to go virtual. Against the common enemy of the virus, educators united in their need to use technology to continue teaching their students in these trying times. The issue of how educators approached technology in the classroom was redefined as the solution to safe teaching in a global pandemic. The alternative of not embracing technology was too costly in terms of damage to the education system.

Nevertheless, this is not complete closure through redefinition of the problem. Even with the transition to virtual, educators still retain bits and pieces of their initial SAMR identification and it is reflected in their remote learning techniques. During the forced transition period, educators range from meeting the bare minimums of remote learning to digging deep into the core of what educational technology has to offer.

Conclusion

Technological advances are being made each day at an ever-increasing rate. As mass production and miniaturization drive down the cost of technology, mobile devices, and computers, the internet is becoming increasingly accessible. Its treasure trove of information and knowledge is very beneficial for extending the reach of STEM education. The scope of web and mobile applications will only increase as time goes on and our devices become more and more powerful. However, issues such as the digital divide stand in the way of fully embracing technology in the classroom.

Educators and their usage of technology can be classified into the four SAMR stages: Substitution, Augmentation, Modification, and Redefinition. Each of these stages corresponds to relevant social groups that share beliefs on to what extent technology should be accepted into the curriculum. The widespread impact of the COVID-19 pandemic and desperate transition to remote learning helped technology in STEM reach closure through redefinition of the problem when debates were dropped in favor of a quick resolution.

The shaping of technology acceptance in education is not unlike a fire. It should not be left alone to its own devices. As a tool, it has great potential but comes with significant risk of abuse. Veletsianos and Moe (2017) warn that edtech ”envisions technology as a solution in and of itself” and should be evaluated with empirical evidence. When you have a hammer, everything else looks like a nail.

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