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Abstract

Mandates to improve curriculum and instruction and incorporate technology in teaching U.S. K-12 students have failed to improve math proficiency as measured by standardized assessments. Still, 40–60% need remedial coursework in college. Past efforts have focused on incorporating specific technologies. The SAMR approach redirects the effort to focus on how technology is used, aligning with Bloom's taxonomy. Hierarchical multiple linear regression analysis was used to quantify the contribution of Substitution, Augmentation, Modification, and Redefinition to MAP Growth in math for 644 students taught by eight teachers across 36 class sections at a single Indiana middle school. A wide range in teacher use of technology corresponded to significant ($p < .05$) differences in MAP Growth. Hierarchical multiple linear regression revealed that incorporation of SAMR elements above Substitution explained a small, 2.0%, yet significant ($p = .001$) part of variation in MAP Growth. At least Most Weeks use of Augmentation added 1.06 points ($p = .008$), Modification an additional 2.12 points ($p = .002$), and Redefinition an additional 1.19 points ($p = .003$) for a combined significant net 4.37-point increase. With all teachers from the same school and only some using technology at high learning levels, the findings led to a recommendation for investment in professional development training rather than focusing on adding specific technology tools.

Introduction

The United States has a history of trying to improve K-12 education, enacting multiple legislative reforms (Improving America's Schools Act, 1994; No Child Left Behind Act, 2002) and developing the Common Core in 2009 (Common Core State Standards Initiative [CCSSI], 2016). The *Nation's Report Card* (National Assessment of Educational Progress, [NAEP], 2015) identified no significant improvement in math from 2005 to 2015, with only 25% of 12^{th} grade students performing at or above proficiency level, U.S. students lagging further behind their international counterparts (Daun-Barnett & St. John, 2012; National Center for Education Statistics [NCES], 2015; Rothman, 2012), and 40–60% of high school graduates needing remediation coursework prior to taking college-level math (ACT, 2015; Bahr, 2012; Davidson, 2016; Jimenez et al., 2016;

McCormick & Lucas, 2011; NCES, 2015, 2016; Parker et al., 2010; Rothman, 2012). Snipes and Finkelstein (2015) argued the lack of math proficiency begins in middle school, with U.S. state means ranging from 19–50% of eighth graders at or above proficiency level with a national average of 34% (NAEP, 2017). Incorporating technology has been touted as a solution (Dobransky, 2015; Fletcher, 2014; Morgan, 2015; Smirnova & Bordonaro, 2014), particularly in light of greater use of technology in society and in careers (Chowdhury & Shanmugan, 2015). Research has been mixed, some showing the integration of technology in teaching math leading to improved student learning (Ertmer et al., 2012; Fletcher, 2014; Shirley et al., 2011; Smirnova & Bordonaro, 2014), others contradicting the claim, showing no reliable improvement when technology is used (Causey, 2014; Dudley, 2011; King, 2011; Rigdon, 2010; Seo & Bryant, 2009). Zelenak (2015) emphasized that simply using technology is not enough.

What is needed is a way to connect technology with learning value (Zelenak, 2015). Others have shown the importance of this in trying to train teachers to use interactive technology in teaching mathematics, notably by using the TPACK framework (Hofer et al., 2016), which focused on understanding a teacher's flexible knowledge of digital tool and media integration in the instructional process while considering technological, pedagogical, and content interactions (Mishra & Koehler, 2006; Vaerenewyck et al., 2017). For example, Wijaya et al. (2020) tried to do this using Hawgent Dynamic Mathematics Software while Salas-Rueda (2020) used WALF, a Web Application. The challenge of that approach however, is that too often, technology integration has focused on specific tools (Harris, 2016). Hill and Uribe-Florez (2020) also indicated the TPACK framework had failed as a concrete evaluation tool for effectively measuring how teachers combine the three areas when integrating technology in the math classroom due to the complexity of countless variables. This study looks more closely at how teachers used existing technology, a more feasible approach to first demonstrating to school districts the difference an investment in training teachers could make. The SAMR model (Puentedura, 2006, 2014) is well aligned with Bloom's (1956) hierarchy of learning, with considerable qualitative support (Beisel, 2017; Dobransky, 2015; Moye, 2017; Pfaffe, 2017; Savignano, 2017; Stepanian, 2017; Thornton, 2017; Townsend, 2017). This study adds a quantitative component, using multiple linear regression to investigate the independent and collective contribution of Substitution, Augmentation, Modification, and Redefinition in improving student math performance on standardized assessment criteria.

Theoretical Framework

The theoretical framework derives from Bloom's (1956) hierarchy of learning that established an increasing cognitive level from remembering, to comprehending, to applying, to analyzing, to synthesizing, and finally to evaluating. The basic principle of Bloom's (1956) construct was that as you increase the cognitive level, learning becomes a deeper and longer lasting enterprise. Puentedura (2006, 2014) applied Bloom's (1956) taxonomy to how technology could be used to improve student learning, resulting in the conceptualization of the SAMR framework, associating increased learning value as teachers advanced their use of technology in the classroom from Substitution, to Augmentation, to Modification, and finally to Redefinition. Carrington (2016) provided a key connection in developing the Padagogy Wheel, linking the elements of Puentedura's (2006, 2014) SAMR learning value, Bloom's (1956) hierarchy of learning (Dobransky, 2015; Kaufman, 2016; Mo, 2011; Morgan, 2015), and the use of 188 technology tools (Harris, 2016). The underlying framework emphasized the way technology is integrated into the classroom, connecting actions to each SAMR level (Carrington, 2016; Puentedura, 2014; Walsh, 2015). Adaptation of the Padagogy Wheel (Carrington, 2016) enabled teachers in this study to identify *how* they were integrating technology in their classrooms, enabling quantified assessed contribution of each of the four independent presumed learning value SAMR variables (Puentedura, 2006, 2014) to student gain in math proficiency from the start to the end of the academic year, as measured by their MAP Growth (Northwest Evaluation Association [NWEA], 2016, 2018).

Method

Design

A non-experimental correlational research study with hierarchical multiple linear regression was chosen to analyze if technology integration that increases learning value along the SAMR scale significantly contributes to gains in math proficiency among middle school students. There were four independent variables, the levels of Substitution, Augmentation, Modification, and Redefinition used by each of eight math teachers in each of 12 sixth grade, 12 seventh grade, and 12 eighth grade math sections. There was one dependent variable, the MAP Growth in math, as determine by the difference in the beginning and end of the school year MAP assessments.

Instrumentation

MAP Assessment

MAP assessment is determined via the NWEA (2004) instrument with strong demonstrated content validity of $r = .85$ to $r = .88$ and test-retest reliability of $r = .83$ to $r = .94$. The participating Indiana middle school provided beginning of school year and end of school year MAP math scores for 921 middle school students, indicating their math class and teacher. Of these 921 records, 55 were deleted as not having both beginning and end of school year MAP math scores, and 168 were deleted as per NWEA (2017) guidelines due to low student engagement during testing. A net of 644 middle school math student NWEA records resulted, enabling calculation of MAP Growth for each student.

SAMR Integration

Recognizing that teachers would likely not be familiar with the SAMR terms, they were provided examples to identify which type of technology integration they were using in their classrooms. In completing the SAMR integration instrument, teachers were provided information about each prior to the respective survey section.

- **Substitution** is when technology acts as a direct tool substitute with no functional change. The goal of using technology as a substitution tool is to facilitate remembering and understanding. Common substitution activities include searching or googling, mind mapping, highlighting, commenting, recognizing, social bookmarking, blogging, journaling, word processing, social networking, bookmarking of favoriting, bullet pointing, subscribing, recalling, naming, and listing. Action verbs associated with substitution are match, summarize, paraphrase, compare, expand, find, describe, infer, interpret, retrieve, explain, identify, locate, report, exemplify, and classify.

- **Augmentation** is when technology acts as a direct tool substitute, but with functional improvements. The goal of using technology as an augmentation tool is to facilitate application of the material. Common augmentation activities include editing, taking photographs, role playing, movie making, demonstrating, interviewing, presenting, mapping, simulating, sculpturing, making a diary, collecting, making puzzles, scrap booking, drawing, and diagramming. Action verbs associated with augmentation are play, edit, implement, simulate, share, carry out, upload, draw, use, operate, record, hack, construct, execute, load, interview, run, and teach.
- **Modification** is when technology allows for significant task redesign. The goal of using technology as a modification tool is to facilitate analyzing and evaluation. Common modification activities include charting, graphing, diagramming, creating mashup media, summarizing, spreadsheeting, creating advertisements, surveying, reporting, building questionnaires, recommending, self-evaluation, simulating, surveying, expressing opinions, making judgments, and critiquing. Action verbs associated with modification are outline, deduce, mash, sequence, determine, compare, simulate, demonstrate, classify, examine, deconstruct, differentiate, contrast, distinguish, categorize, infer, survey, interview, critique, conference, prioritize, post, justify, conclude, network, moderate, discuss, rank, judge, collaborate, debate, appraise, support, defend, and give your opinion.
- **Redefinition** is when technology allows creation of a new task that was previously inconceivable. The goal of using technology as a redefinition tool is to facilitate creation. Common redefinition activities are hypothesizing, video editing, writing rap songs, creating new games, videocasting, animating, cartooning, podcasting, writing an ePub or iBook, mixing, creating a TV/radio program, storytelling, and making a multimedia presentation. Action verbs associated with redefinition are invent, hypothesize, find an unusual way, produce, design, rearrange, change, suggest, create, originate, suppose, transform, imagine, and compose.

Following the pattern provided in previously validated instruments (Burkhart, 2011; Park, 2014; Yemothy, 2015), a 7-point Likert scale instrument was developed to assess how often teachers used each SAMR element (Daily, Most Days, Weekly, Most Weeks, Monthly, Less than Monthly, and Never). While descriptions and examples of each element was provided, there was intentionally no indication of the value of each of these elements. The goal was to get an honest self-assessment from each teacher about what they were currently doing, not provide an indication of which was better, to avoid bias in self-reporting (Rosenman et al., 2011). The post-study Cronbach's alpha of $\alpha = .87$ exceeded the $\alpha > .8$ level of good reliability (George & Mallery, 2016), suggesting very good reliability for the developed instrument.

Research Questions

1. To what extent is there an association between student academic year math MAP Growth and level of technology integration?
2. How can the association of Substitution, Augmentation, Modification, and Redefinition technology integration be modeled to explain student math MAP Growth?

Assumptions Testing

Linear regression required the development of dummy variables as per Keith (2015). First, a level of use vs. non-use was determined, leading to Most Weeks being the minimum use level requisite for determining if a teacher used that technology, similar to Duke's (2015) approach of using linear regression to analyze the impact of the highest level of technology integration used. This was followed by hierarchical assignment of the class instructor according to the highest level of technology integration they used on an at least Most Weeks basis in reverse order. Redefinition User was coded first, with those who used Redefinition User at least Most Weeks being coded = 1, indicating a Redefinition User and those who did not use Redefinition at least Most Weeks being coded as = 0, indicating Not a Redefinition User. As per Keith (2015), this was repeated for Modification, and finally for Augmentation, following the $n - 1$ dummy variable protocol, with Substitution not included.

Assumptions of normality of residuals, homoscedasticity of residuals, absence of multicollinearity, and the lack of outliers were tested. Q-Q scatterplots formed a relatively straight line, approximately the solid line theoretical quantiles, validating the normality assumption (Bates et al., 2014). Model residuals plotted against the predicted model showed points appearing randomly distributed with a mean of zero and no apparent curvature, thus meeting the homoscedasticity assumption (Osborne & Waters, 2002). Variance Inflation Factors (VIFs) were calculated to detect multicollinearity between predictors, with the VIFs ≤ 1.22 indicating no multicollinearity concern (Menard, 2009). Existence of outliers was determined by calculating the studentized residuals and plotting their absolute values against observation numbers, with no data points outside the 3.0 limit and even a 2.0 limit being satisfied, validating the assumption of no outliers (Nurunnabi et al., 2016).

Results

Eight math teachers combined to teach 12 sixth grade, 12 seventh grade, and 12 eighth grade math sections resulting in technology integration teacher reports for 36 separate math sections. Within these 36 sections, 644 students, the *N*, were used in comparing MAP Growth. Table 1 presents the descriptive results.

Table 1. Technology Integration Frequency Use

Frequency	Substitution		Augmentation		Modification		Redefinition	
	n	%	*n*	%	*n*	%	*n*	%
Daily	215	33.39	106	16.46				
Most Days	57	8.85			114	17.70		
Weekly	57	8.85	114	17.70			114	17.70
Most Weeks	58	9.01	167	25.93	97	15.06	58	9.01
Monthly	102	15.84			67	10.40	106	16.46
< Monthly	155	24.07	60	9.32	162	25.16	109	16.93
Never			197	30.59	204	31.68	257	39.91

Note: User defined as Most Weeks or more frequent, Non-User as less.

As shown in Table 1, all teachers reported integrating technology at the Substitution level during math instruction, with 42.24% using it Daily or Most Days and an additional 17.86% using it Weekly or Most Weeks. Augmentation technology integration was reported in 69.41% of classes, with 16.46% incorporating it Daily or Most Days, and an additional 43.63% incorporating it Weekly or Most Weeks. Modification technology integration was reported in 68.32% of classes, with 17.70% incorporating it Daily or Most Days, and an additional 15.06% incorporating it Weekly or Most Weeks. Redefinition technology integration was reported in 60.09% of classes, and while none reported incorporating Daily or Most Days, 26.71% did incorporate it into their math instruction Weekly or Most Weeks. In determining mean use, Likert scale frequencies were coded as 7 = Daily, 6 = Most Days, 5 = Weekly, 4 = Most Weeks, 3 = Monthly, 2 = Less than Monthly, and 1 = Never for each level of technology integration. Results are shown in Table 2. Skewness of < |2| indicated all variables were symmetrical about their mean and kurtosis of < 3 indicated all variable distributions were normal (Westfall & Henning, 2013), satisfying parametric data analysis assumptions.

Table 2. Summary Technology Integration Results

Variable	*M*	*SD*	N	SE_M	Skewness	Kurtosis
Technology Level						
Substitution	4.63	2.04	644	0.08	-0.04	-1.65
Augmentation	3.57	2.15	644	0.08	0.17	-1.23
Modification	2.80	1.80	644	0.07	0.71	-0.84
Redefinition	2.48	1.51	644	0.06	0.54	-1.17
MAP Growth Score	7.13	4.11	644	0.16	0.09	-1.02

The *F*-test was significant, F (3,640) = 5.40, p = .001, R^2 = 0.02 indicating that approximately 2.0% of the variation in MAP Growth could be explained by Augmentation, Modification, and/or Redefinition use. The next step was to determine actual MAP Growth point gain that resulted from technology integration. Table 3 shows the results for the multiple regression analysis explaining MAP Growth technology integration values.

Table 3. Summary of Multiple Linear Regression Analysis

Variables	*B*	*SE*	*β*	*t*	*p*
Constant – Substitution Only	6.39	0.25		25.16	.000
Augmentation User	1.06	0.40	0.11	2.66	.008
Modification User	2.12	0.70	0.12	3.04	.002
Redefinition User	1.19	0.40	0.13	2.97	.003

Note: F(3,640) = 5.40, p = .001, R^2 = .02.

Substitution represents the constant variable since it was the independent variable eliminated in the n – 1 dummy variable protocol (Keith, 2015) as the lowest learning level of technology integration and the one used in all classrooms, thus providing a base level of MAP Growth of 6.39. Adding Augmentation to the default Substitution use was significant for MAP Growth, p = .008, with moving from the Not Augmentation User to Augmentation User category, i.e., adding Augmentation at least Most Weeks to the constant Substitution use, increasing mean value of MAP Growth by *B* = 1.06 points. Modification also was significant for MAP Growth, *p* = .002, with moving from the Not Modification User to Modification User category, i.e., adding Modification at least Most Weeks, increasing mean value of MAP Growth an additional *B* = 2.12 points. Redefinition was also significant for MAP Growth, *p* = .003, with moving from the Not Redefinition User to Redefinition User category, i.e., adding Redefinition at least Most Weeks, increasing mean value of MAP Growth by an additional *B* = 1.19 points.

Discussion

RQ1: Association between MAP Growth and Technology Integration

As shown in Table 2, the overall mean MAP Growth for the 644 students was 7.13 points. The extent of technology integration in the classroom decreased as the learning level of technology integration increased from Substitution (mean = 4.63), to Augmentation (mean = 3.57), to Modification (mean 2.80), and to Redefinition (mean = 2.40). While the use of technology integration was small, contributing approximately 2.0% to MAP Growth score variation, the effect was significant (p = .001), suggesting rejection of the null hypothesis and support for the alternative hypothesis.

These results are encouraging in terms of meeting established normative MAP Growth goals. From the current 2020 goals (NWEA, 2020), there is an expected MAP Math Growth from fall to spring testing of 8.13 points for sixth graders, 6.52 points for seventh graders, and 5.38 points for eight graders, for an average of 6.68 points. In this study, the students exceeded this growth achieving a mean 7.13 point increase. While comparing means across different years is not ideal (NWEA, 2020), this still gives insight into how much the students at the study site gained with higher and more frequent level of SAMR technology integration contributing to even greater gains. This could be especially valuable for schools where their students are not meeting NWEA goals, noted nationwide as being two-thirds of eighth graders (NAEP, 2015, 2017).

RQ2: Model Development

Table 3 presents the hierarchical multiple linear regression model of MAP Growth contribution when adding Augmentation, Modification, and Redefinition beyond a starting point of Substitution. Adding Augmentation was significant (p = .008), increasing MAP Growth by 1.06 points. Modification was also significant (p = .002), increasing MAP Growth by an additional 2.12 points. Redefinition provided added significance (p = .003), further increasing MAP Growth by 1.19 points. The highly significant hierarchical contribution ($p < .01$) of Augmentation, Modification, and Redefinition, resulted in a net 4.37-point increase in MAP Growth, rejecting the null hypothesis with support for the alternative hypothesis. While not predicting what the MAP Growth value would be, this study suggests an advantage of each learning level of technology integration, such that a teacher using Augmentation, Modification, and Redefinition at least Most Weeks could see a net increase in their student's MAP Growth scores of 4.37 points over a teacher who used only Substitution in teaching the same material.

While the 4.37 point gained over Substitution by using Augmentation, Modification, and Redefinition at least Most Weeks represents nearly an entire grade level of advancement (NWEA, 2020), the model development helps demonstrate that even advancing to Augmentation makes a significant (p = .008) increase the MAP Growth. This provides an opportunity for schools to support teachers with professional development that could help them make that transition where the technology does not merely replace (substitute) the traditional pencil and paper approach, but actually adds to (augments) it. The application that emerges from Augmentation also aligns with the focus of Common Core on helping student apply their math learning, the real-world application viewed as crucial in preparing students for college, career, and beyond (Burks, 2015; CCSSI, 2019).

Limitations

Adapting the Padagogy Wheel (Carrington, 2016) and providing extensive examples of what Substitution, Augmentation, Modification, and Redefinition elements were enabled teachers in this study to identify how frequently they were using each of the SAMR elements (Puentedura, 2006, 2014) in integrating technology in their classrooms. However, a limitation in this study was that the extensive examples led to teachers not completing the open-ended responses that were requested, asking them to describe how they were applying the technology integration in their classrooms. An initial concept was to focus on teachers describing what they did and then asking frequency of each, but concern was that the data would not be sufficient to truly compare use of each SAMR element. Thus, the study was limited by the compromise taken in providing participants with descriptions and then asking them to indicate a global frequency of integration without indicating which specific examples applied to their teaching.

Conclusion

In providing the ability to quantify the value of the SAMR model (Puentedura, 2006, 2014), the value of technology integration in the math classroom is not just theoretical, but can be modeled based on how technology is used ($F(3,640) = 5.40$, $p = .001$, $R^2 = .02$, see Table 3), rather than relying on data from specific technology tools. The results indicate a significant association between MAP Growth scores in mathematics and technology integration. While the linear regression model only explained 2.0% of the variation in MAP Growth, each SAMR element above Substitution contributed significantly ($p \leq .008$, see Table 3). On the basis of using the specific technology on an at least Most Weeks basis, addition of Augmentation added 1.06 points to the MAP Growth; Modification an additional 2.12 points, and Redefinition an additional 1.19 points, for a combined net MAP Growth benefit of as much as 4.37 points.

What is key is that each SAMR element provides benefit, enabling school leadership to know where and in which order to invest technology training efforts for math teachers to support a desire to increase MAP Math scores. While Substitution use is critical, all teachers should be encouraged to use it at least Most Weeks, instead of the 60.1% observed in this study. If only a single technology integration approach were added, Modification achieves nearly as much as Augmentation and Redefinition combined (2.12 vs 2.25, see Table 3).

The statistical rigor of this study extends value beyond the study, school, and its district, with generalizable findings for others interested in addressing the lack of math proficiency. Key in the study observations is concurrence with Zelenak (2015) that teachers be trained in how to use technology for increased learning value, not just making technology available. In this single school study, all teachers had access to the same technology tools, but the use of those tools varied widely (see Tables 1 and 2). If school leadership wishes to see improvement in the MAP Growth scores, providing ongoing professional development is vital (Newton et al., 2013). The highly significant findings ($p < .01$, see Table 3) in this study emphasize how critical it should be for all math teachers to learn how to integrate technology based on Bloom's (1956) hierarchy of learning, Puentedura's (2006, 2014) SAMR model, and Carrington's (2016) Padagogy Wheel.

Recommendations

A recommendation moving forward is that schools focus on evaluating the technology pedagogical skills of their teachers and then develop specific professional development efforts to improve those. The more recently hired, younger teachers, may have learned about technology integration in their teacher preparation training program, but older, more experienced teachers likely did not (Tweed, 2013). This was also an observation made in this study. This would require an increased professional development effort on the part of the school and is an insight gained moving forward at the study site district. This study approached how teachers were currently using technology to demonstrate that it could make a significant difference ($p < .01$) in student performance on standardized math assessments, even if at the most basic SAMR levels. Other models, such as the TPACK framework could be used in professional development efforts to help teachers build their technological pedagogical content knowledge (Herring et al., 2016).

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