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Preservice Teachers Use of Digital and Non-Digital Music Composition Systems as Resources for Teaching Elementary Mathematics

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Cover Page Footnote

Dear Editor, We just make all the changes as your indicated in the comments. Please be aware that we we unblinded the reference, there's a one page increases in the manuscript. Also, the affiliation of the 4th author is updated in the manuscript as she is now working at a different university. Thank you for the hard efforts you've made in editing the article. Song An and Co-authors

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ABSTRACT

This study was planned and performed with the main goal of examining preservice teachers' (n=61) pedagogical reflections regarding the comparison of two educational music composition programs (i.e. Color-Tune and M-Flow) available for teaching mathematics. Empirical evidence that was collected and analyzed indicated that the two music composition programs each have distinctive strengths that may serve as appropriate teaching resources. The findings from the present study have shown that music composition and performance activities, if properly developed and supported by sound educational principles, learning theories, and educational technologies, can be used as classroom activities to support formal mathematics education while also providing out-of-school learning resources for making connections with informal mathematics education.

Keywords: Mathematics Education, Music Composition, Teacher Education, Interdisciplinary Teaching, Educational Technology

The artform called music involves generating desirable sounds that are audible to humans, generally within the vibrational frequencies between 20 Hz and 20,000 Hz. Regardless of whether they are sound engineers, composers, or performers, there are almost limitless variables that musicians can manipulate in order to create their own original music. Some of the more common aspects of sound that are played with by musicians when generating original song compositions include the composition's duration, dynamics, overall pitch, speed and tempo, harmonic levels, rhythm, effects and tone, orchestration, and mixture of instruments (Bresin & Friberg, 2011). Via the creative options provided during music composition, students learning mathematics at the elementary and middle-grade levels can have opportunities to explore, discover, and apply their acquired math knowledge (Pesic, 2022; Viladot et al., 2017). To illustrate this pedagogical approach, educational researchers along with curriculum developers have previously designed, implemented, and evaluated several approaches to using music composition as an instructional resource during mathematics education (e.g., Azaryahu et al., 2020; Azaryahu et al., 2023; Divis & Johnson, 2021).

One of the key barriers that STEM educators must address when developing and implementing music composition activities is simplifying the musical notation system. Conventionally, music composition has been recognized as an advanced creative undertaking—to master the skill of composition, artists generally receive multiple years of vocal or instrumental music training and often take a series of college-level courses including music theory, instrumentation, harmony, and music analysis (Campbell, Myers, & Sarath, 2016). Whether working on solo pieces such as a sonata, or chamber music like a string quartet, or orchestra music such as a symphony, composers are typically expected to apply sophisticated analytical competence during the arrangement of musical elements (Goulding, 1995).

Yet there have been child prodigies throughout history such as W.A. Mozart, F. Chopin, and F. Mendelssohn, or more recently E. Kissin and J. Greenberg, who composed complex music before the age of ten. The majority of children are incapable of achieving similar results, due to the extensive preparation or innate abilities required for such a task. As an example, educators have pointed out that when using staves and noteheads to write and read sheet-music, a black circle and a white circle with the same size have different durations with one of them being twice the time length of the other, and this along with many other aspects of traditional musical notation are not intuitive (An, Tillman, & Lesser, 2018; Gaare,1997; Kaschub & Smith, 2009). Thus, teaching music composition to early-childhood students is systematically excluded from nearly all elementary schools' official curriculum because of the perceived infeasibility (McPherson, 2016; Quinto et al., 2016).

Developments in digital technologies, beginning with the invention of the computer but now expanding far beyond via advancements such as color-printing (the traditional music sheets were printed with black ink only) and open-source software, now offer young composers opportunities to create original music using tools that were unavailable to anyone decades ago. For example, students can now experiment sonically with musical composition software that provides visual representations of the sounds being manipulated (Pierroux & Rudi, 2020). This type of software is in coalition with various alternative musical composition systems that have been proposed during the past century, often with a goal to simplify the traditional notational system and thus allow amateur musicians to record, express, and communicate their musical ideas (Chen & O'Neill, 2020). Some of the more popular alternative musical representation systems have included *cipher notation*, which uses Arabic numerals to indicate the pitch and length, as well as *colored notation*, which employs hues beyond just black and white. *Colored notation* has previously shown potential as an age-appropriate composition method for children (An, Capraro, & Tillman, 2013; An, Kulm, & Ma, 2008; An, Ma, & Capraro, 2011; An & Tillman, 2014; An, Tillman, & Lesser, 2018; An, Tillman, & Paez, 2015; An et al., 2014a; An et al., 2014b; An et al., 2015a; An et al., 2015b; An et al., 2016; An et al., 2023) and has been introduced and implemented with young students who successfully created music by arranging the provided colored cards on their tables. In this system, each unique color represented a different note, for example green meant an F note, and the finished composition was then performed on bells with matching notes and corresponding colors.

While alternative notation systems have been helpful, computer-based software has been the main impetus driving the modern revolution in amateur music composition. As an illustration, information technology advancements have enabled the automation of melody transcription,

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converting analog sounds obtained from singing or instrument playing into digitally notated representations (Chen & O'Neill, 2020). Further, some of the more advanced computer programs can also be used to generate additional layers of harmony to coincide with given melodies, or even transform a child's tune into a performance by a string quartet (Hernandez-Olivan & Beltran, 2022). As an educational technology that could be implemented throughout the K-12 music education curriculum and elsewhere as appropriate, music composition software—particularly with options for visual representation—could be used more widely for supporting classroom activities (Laato et al, 2019; Lim et al 2018).

Previous studies have investigated the impacts from students creating original music in their learning of mathematics, and findings have consistently confirmed the usefulness of music creation as a context for generating math instruction that is engaging, memorable, and that helps in developing students' productive disposition and conceptual understanding of mathematics (An et al., 2013; An et al., 2014a; An et al., 2014b; An et al., 2023; Azaryahu et al., 2020; Chahine & Montiel, 2015; Crowther et al., 2016; Kalinec-Craig, 2015). Comparatively, there has been almost no significant research addressing the pedagogical nuances involved in distinguishing between teaching mathematics using music composition software programs versus methods that do not require digital tools, such as the use of colored bells and matching cards as described earlier. Therefore, the goal of the current study was to speak to this gap in the literature by offering preservice teachers an opportunity to compare two established music composition creation systems, each of which was developed by a team of STEM educators—one with the advantages and features provided by a physical, hands-on, and table-based composition system, and the other one with the advantages and features of a digital, computer-based, and software-driven composition system. This research study specifically aimed to narrow the identified research gap by collecting empirical evidence helpful for recognizing any distinctive pedagogical values or limitations of these two composition methods in regard to mathematics instruction. The main research question that guided this research study were: What were the participating preservice teachers' perceptions regarding any differences between using hands-on, non-digital composition methods compared to the digital, computer-based composition methods?

Methods

Participants and Setting

The study was conducted at a large public research university located in the southwest of the United States. Over three-quarters of the university's student population identify as Hispanic and most are also first-generation college students. For this current study, a total of 61 participants were recruited from the teacher education program (this included 54 female students and 7 male students). These participants were recruited from two cohorts of senior undergraduate students who were, at the time of this study, working as student-teachers performing their one-year residency in local elementary schools. Each week, the participants would work in their respective schools for four days, and then have one day during which they took teaching methods courses on campus at the university; the data for this current research study was collected during their mathematics teaching methods course.

Procedure and Tasks

Two music composition systems were developed by the researchers (i.e. An team's Color-Tune and Minces team's M-Flow) for use in this study. Next, a series of eight music composition tasks were embedded into the mathematics teaching method classes during the regular, 15-weeks Fall and then Spring semesters. These music activities, each of which lasted around thirty minutes, were introduced as alternative, supplementary teaching methods for addressing mathematics content areas including whole numbers, fractions, geometry, measurement, data analysis, probability, and algebra. When assigning the non-digital composition tasks, color-coded cards as well as corresponding handbells were provided, and participants received guidance as they arranged the cards into original music compositions that achieved specified mathematical criteria such as vertical symmetry (see detailed description of activities in (An & Capraro, 2011, An et al., 2015, An et al., 2023). Once the non-digital composition task was achieved, their music was played by using color-coded handbells (see Figure 1).

The digital composition system (see detailed description of activities in Minces & Akshay, 2023; Song et al., 2023) was introduced to the preservice teachers after they had completed a series of non-digital activities. During the digital activities, the participants received instructor guidance as they created their original music using the provided Internet-based software. The digital music composition process included: (1) recording a piece of audio (for example, hum a tune into the microphone), (2) choosing the drum sound (from different drum sounds provided by the software), (3) selecting the looping patterns for musical sections (such as, for example, A-B-B-A), (4) picking the number of repetitions for the composition, (5) deciding whether to use alternating patterns, and (6) adding optional randomization to make some of the sounds unpredictable. Once the music composition process is accomplished, the music is performed by the computer when the participant clicks the "Play" button within the software (see Figure 2).

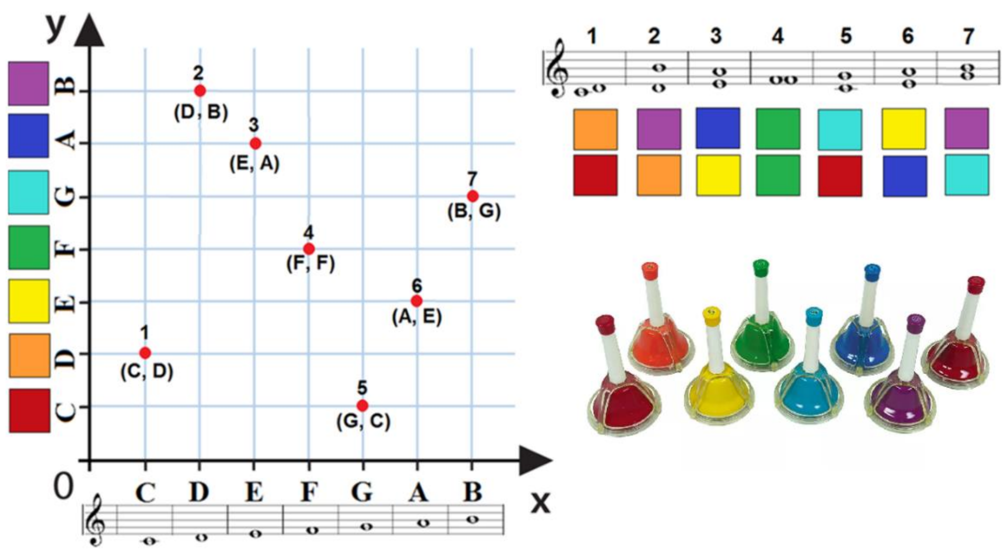

Figure 1. Intervals (notes that are paired) composed using the non-digital system (Color-Tune).

Data Collection and Data Analysis

At the end of the semester, after having completed all the music composition tasks, the participating preservice teachers were each asked to write a reflection essay. The guiding topic for this essay was a prompt asking them to discuss their thoughts on the instructional opportunities for teaching and learning mathematics that were offered by the two music composition systems. A total of 61 essays with an average of 417 words each were collected from the study participants. The collected data was analyzed based on the Grounded Theory Approach (Corbin & Strauss, 2014) and involved detecting and cataloging the features of the

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music composition systems that the participants had described in their essays as relevant to supporting mathematics education.

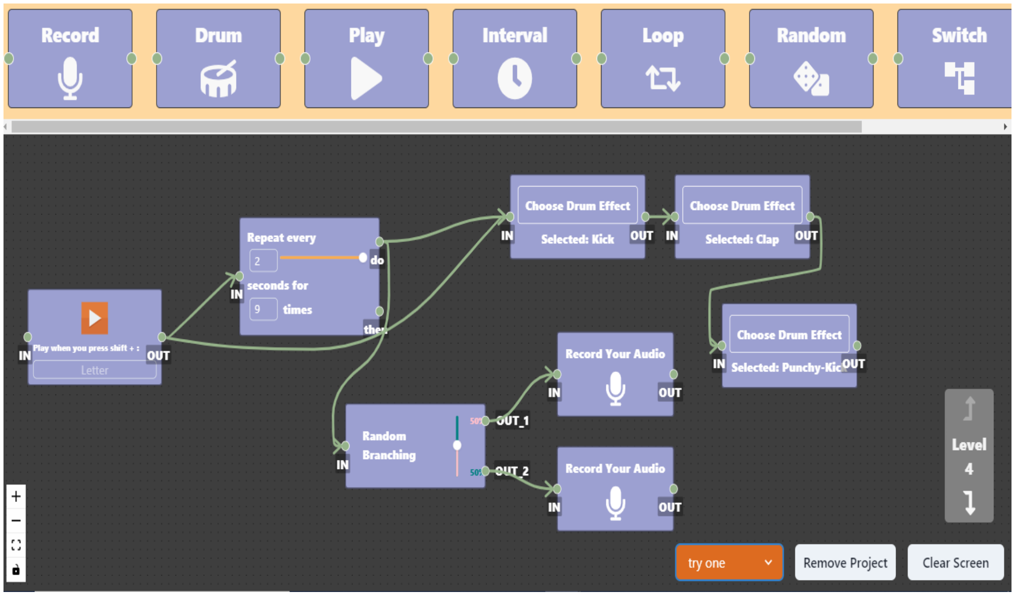

Figure 2. Example of music created by using the digital music composition system (M-Flow).

The main goal for the first phase of coding was to develop a sense of the instructional opportunities provided by both the digital and non-digital music composition approaches employed, as well as a framework for identifying any major differences resulting from these two approaches. This task was performed through continuous identification and comparison of the collected data until a set of primary groupings were sufficiently distinct while also saturated with content. The main goal for the second phase of data analysis was to refine the coding categories and thereby generate subcategories further reducing repeated entries with comparable ideas, while also extricating information about frequency of emergence. To improve the coding accuracy, two coders independently analyzed the data and the results were compared to determine presence of consistency. The inter-rater agreement rate was about 89%, and the 11% of inconsistencies were resolved through negotiations among the entire research team until a consensus was attained.

Results

Analysis of the results from this study revealed noticeable differences between the two music composition systems in regard to their respective abilities to facilitate mathematics education. From the analysis of the written reflections emerged a total of 471 coded entries, which were sorted into 20 specific themes, and then these themes were organized into four main categories: (1) mathematics inquiry opportunities, (2) musical expression/style, (3) learning process/style, and (4) flexibility/operability (see Table 1). More generally, the data showed that many of the participants expressed a belief that when teaching mathematics, the non-digital approach was more appropriate for younger (early childhood) children, while the digital approach was more appropriate for older (upper elementary/middle school) children. The participants also recognized differences in the digital and non-digital systems in regards to flexibility of musical expression, and facilitating group versus individual learning. To illustrate these pedagogical differences, selected excerpts from participants' reflection essays were chosen based on ability to provide clarity and insight regarding their representative perspectives. Since the pedagogical advantages for using the non-digital music composition approach have already been comprehensively discussed in previously published studies (An et al., 2008, 2010, 2013, 2014a, 2014b, 2015a, 2015b, 2016, 2023), this analysis will strategically emphasize the distinctive features provided by the digital approach while also providing a comparison versus the non-digital option.

Table 1
Comparison Between Non-Digital and Digital Approaches

	Non-Digital Approach	**Digital Approach**	**(*n*=61)**
Mathematics inquiry opportunities	Composing to accomplish mathematical tasks	Composing for iterate mathematical patterns	4 (6.6%)
	Young children friendly (low-entry)	Higher grade engaging (high-entry)	41 (67.2%)
	Fits better in the beginning of the learning period	Fits better at the end of the learning period	28 (45.9%)
	Fits students at first stage of reasoning	Fits during transition from concrete to abstract	15 (24.6%)
	Connect to multiple mathematics contents	Connect mathematics and physics	7 (11.4%)
	Composing and decomposing	Coding and programming	3 (4.9%)
Musical expression/style	Arrange tunes (chromatic scales with 1.5 octaves)	Manipulate sound (with any audible frequency)	38 (62.3%)
	Linear based and sequence oriented (chords additive)	Loop-based and recurrence-oriented sound layers	12 (19.7%)
	Melodic and harmonic oriented	Rhythm and tempo oriented	17 (27.9%)
	Powered sound that is dynamic and tempo flexible	Computer generated with precise volume & tempo	51 (83.6%)
	Favorite kids' songs available	Original music required	6 (9.8%)
	Consistent sound effects	Various sound effects	10 (16.4%)
Learning process/style	Group collaboration and students centered learning	Self-driven and self-paced learning	33 (54.1%)
	Hands-on interactive approach	Online based and independent learning	57 (93.4%)
	Visual-kinesthetic-auditory combined	Logical-mathematical	31 (50.8%)
	Deductive reasoning	Inductive reasoning	3 (4.9%)
Flexibility/ operability	Handbells, xylophone and composition cards required	Computer, internet and speaker/headphone required	44 (72.1%)
	Multiple players required for complex compositions	Easy replayability, easy pause for any compositions	25 (41.0%)
	Fit both class and school wide play	Fit both formal (class) and informal (home) learning	29 (47.5%)
	Professional development and instructor required	Self-learning with tutorials	17 (27.9%)

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One of the participants, Harper [all names used are pseudonyms], shared her insights about the distinctive advantages provided by the digital music composition system based on her experiences using both options: Harper expressed that composing and playing music without physical instruments helped ensure the feasibility of implementing this approach with students in a classroom, noting that while not all classroom teachers have access to musical instruments, computers are available in most schools. Specifically, she stated:

> ……some unique strengths of [digital music composition] methods for mathematics education is that there are no physical instruments required. Some schools prefer to save that money on technology such as computers and laptops for students. [Digital] technology consisted program show music yet you wouldn't [need to] be able to use an instrument or see an instrument or know how it sounds. You could only move it around and make a harmony based on how you move certain instruments. I believe the [digital] method for mathematics education involves the pitch and the amount of times that it can repeat itself or play itself. I believe the [digital] program introduces a way of getting to know instruments without physically having them but knowing how they sound. Although [non-digital] methods of composing with color cards and playing music with handbells is efficient, it can be challenging to not have enough instruments for everyone in the class. Also, there is a limit on the time of how many minutes we can spend in each subject teachers cannot afford to do the assignments or activity twice just because there's a lack of instruments.

In addition to making comments about the role of technology in education, Kayden pondered about the distinctive strengths presented by the digital and non-digital approaches. For example, Kayden specified that the non-digital approach may engage a wider range of learners and could be used to support classroom activities during which students work in groups; in contrast, the digital approach might serve as homework activities or informal learning because of the open-ended composition opportunities. Kayden presented her insights through her comparison of the two methods:

> The two methods mentioned share similarities in pattern recognition, spatial awareness, creative problem-solving, and multi-sensory learning. However, they differ regarding the tools and medium used, complexity and precision, technical skills required, interdisciplinary connections, and accessibility and cost. [Non-digital] activity in my opinion is more interacting because they are to solve a problem and put hard thinking to find the solution and create the song according to their findings. The students are to work with the problem in a more kinesthetic way in which they are to manipulate the "colors" that are provided by the instructions. This activity also requires the students to implement their reasoning and gather proof of them finding the solution of whatever problem was assigned, if the problem is not solved properly then the song will not work as it should. I really enjoy the activities to play music with [non-digital] program because playing the music when we solve the problem it was like a reward for us.

One of the participants, Raven, expressed her viewpoint on the educational value obtained from digital music composition programs. Raven indicated that the digital music composition program offered mathematics learners an unbounded learning environment in which to create their unique patterns of sound combinations, thereby allowing students to demonstrate their mathematics abilities with a creative end product. In her view, the music composition software best allowed students to manage rhythm by organizing beats based on algebraic reasoning and pattern creations. As Raven revealed:

> With [non-digital] methods, we are only able to listen to the music composition until after finalizing the composition using the color cards. In comparison to [digital] methods, as one uses the computer software we get to listen to the composition as we go to see if we do like it or not and make any instant corrections. [Digital] made it absolutely clear how music is just a pattern of different sounds and that we can create those patterns by using different mathematical terms such as repetition. Some unique strengths that [digital] offers is the ability to give us a blank canvas to produce our own music. It offers a lot of different tools that we can use in order to put different sounds together which I feel makes it a lot more interesting and fun to do. I feel that [digital] program can have a great impact on teaching patterns in a math classroom. Since there are many different sounds we can use as well as different tools that allows us to repeat our beats as many or as little times as we want. I also think it's neat that it has the option to add a recording because it allows for even a larger variety of beats/tunes that can be applied to patterns.

Another participant, Carson, related some additional strengths of the digital program: Carson mentioned that digital composition-playing methods might address students' different modalities of learning, such as visual, kinesthetic, and auditory. Carson also emphasized his concerns, including whether the software could facilitate the development of students' conceptual understanding of mathematics. Carson shared his thoughts on the opportunities and obstacles presented by digital music composition systems from a mathematics instruction perspective:

> The [digital system] to teach math concepts has several strengths. These strengths include thinking outside of the box, for pattern making there is no limit or a specific way to create the song, this is a tool that can help students that are visual learners, kinesthetic as well as auditory learners. The resource allows students to not rely only in one sense over the other. Instead, it is a combination of learning styles. For instance, a student that has issues with sounds can focus on the way the pattern looks, a student that has issues with images can focus on the constant movement of the squares or sound options. Although it is a great tool for students in many concepts related to math, there are several issues that may arise from the use of this tool. Some of these issues include lack of understanding of the math concepts since there are unlimited options for the students who would not have a clear guide or criteria to follow. Another issue is that not every student understands musical concepts. An example of this is me. I cannot hear sounds or discriminate between good and bad sounds or voices. In fact, when I was completing the composition activity, I was not able to tell whether the music piece was pleasing to hear or not. Another issue with the tool is that the sounds are individual which makes it harder to create a harmonic piece of sound.

Similar to Carson's insights, Amy also revealed some of the distinctive pedagogical value obtained from using the digital music composition system. Amy displayed her understanding of the digital system's usefulness with a number of concrete examples showing how the music composition process could help students learn mathematics. In her view, computer-based music

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composition might facilitate students' learning of a wide range of mathematical topics ranging from pattern manipulation during algebra to whole number and fraction computations. Amy proposed that:

> ……with [the digital] method students can predict their results when creating music because they can listen to the sounds of the instruments and thus create a symphony. So, we can say that this method helps students to sharpen their senses to form melodies with the use of patterns that they will create when they are developing their musical flowchart. [The digital] method helps students learn to make flowcharts that they can use in both math and computer class. With this method you will help students create flows where they can follow paths in different directions depending on the musical flow of the melody. In [the digital] program, students have the opportunity to explore patterns as they are creating different beats. They can see if they have a repetitive pattern by listening if they have sounds that they repeat. Students can learn about time be measuring and manipulating the time off their beats, time between intervals, and the length of their whole song. Students can learn about adding and subtracting by counting their beats and seeing how many more or how many less they need to create a new song especially if students are given a specific number of beats their song must have. Students can also learn fractions and percentages by exploring how many certain types of drums they have out of all the beats they used.

Another participant, Julia, also stated her views on the educational opportunities provided by the use of a digital music composition system: Julia explained how she recognized similarities between computer coding and music composition. She also recognized how computer-based composition can provide an alternative representation for showing mathematics concepts. While discussing the advantages of using the digital music composition system, Julia said:

> Music composition based on computer code has benefits for math students. Coding allows for more intricate manipulation and control over musical elements. By breaking down the composition process into logical steps and algorithms, students learn how to think algorithmically and solve problems. Composing music involves mathematical structures like sequences, loops, and conditionals, which help students understand patterns. Visualizing the relationships between code, musical output, and mathematical concepts enhances understanding. Computer-coding-based music composition allows for experimentation and iteration and provides a unique and engaging way to learn mathematics by emphasizing algorithmic thinking, mathematical structures, data representation, visualization, experimental learning, and interdisciplinary connections. [The digital] strategy can work excellent for homework activities, make-up assignments, or even reinforcement when students have doubts on how to complete the activity! Also, I noticed while doing [digital] activity was that there is no right or wrong answer; the user has the ability to create whichever style they prefer.

Discussion

This study was planned and performed with the main goal of examining preservice teachers' pedagogical reflections regarding the comparison of two educational music composition programs (i.e. Color-Tune and M-Flow) available for teaching mathematics. Empirical evidence that was collected and analyzed indicated that the two music composition programs each have distinctive strengths that may serve as appropriate teaching resources for addressing: different educational environments (such as school education or informal education), different educational phases (such as beginning or end phase of the K-12 learning experience), different mathematics content (such as algebra or data analysis), and different learning formats (such as individual learning or group learning). The overall findings from this study also confirmed previous educational scholarship that claimed a musical approach, and especially the music composition process, could be developed as a learning resource appropriate for addressing all major content areas covered in K-12 mathematics (Lim et al, 2018; McDonel, 2015; Perger, Major, & Trinick, 2018; Trinick et al., 2016).

The findings in this study clarified and confirmed the key distinctions between non-digital and digital approaches to integrating music and mathematics in education, highlighting their strengths and applications. Non-digital approaches are particularly well-suited for early learners, emphasizing composing to complete mathematical tasks and making connections across multiple math concepts. These methods are hands-on, group-oriented, and focus on the beginning stages of reasoning, with tools such as handbells and xylophones fostering collaboration and interactive learning. The emphasis on melody and harmony, consistent sound effects, and suitability for classroom or school-wide activities aligns well with instructor-led settings. In contrast, digital approaches cater to more advanced learners, focusing on iterating mathematical patterns and connecting mathematics to physics. These approaches utilize coding and programming to manipulate sound with high precision, encouraging self-paced, independent learning. They emphasize rhythm and tempo while offering greater flexibility, such as easy replay and adaptation for formal and informal contexts. With tools like computers and headphones, digital methods require less professional instruction, as learners can follow tutorials to guide their progress effectively.

Teaching mathematics through the use of music has been increasingly adopted in daily teaching by classroom teachers, and an extensive repertoire of activities within this theme has been proposed by curriculum developers (An & Capraro, 2011, An et al. 2013, 2023; Azaryahu et al., 2020; Chahine & Montiel, 2015; Crowther et al., 2016; Kalinec-Craig, 2015). Among the currently available music-themed approaches to teaching mathematics, the use of a musical cover-story or music as background noise are still predominant—but more advanced and effective methods, such as those described in this paper, are becoming available to classroom teachers. Music composition, with its cognitive and practical complexity, has so far only seen limited development for and implementation in mathematics classrooms. So as to help address this constraint, the preservice teachers in the present study were encouraged to explore and compare two educationally appropriate music composition methods, with a focus on discerning mathematics teaching opportunities for serving their future students. The results from this study demonstrated that the two music composition systems each had distinctive pedagogical features, and that together they were compatible for achieving the goal of developing a comprehensive music-themed curriculum for supporting the entirety of K-12 mathematics education.

In particular, the reflections obtained from participants in this study provided evidence that digital, computer-based composition systems have pedagogical features that connect school-based mathematics inquiry with topics students find interesting such as music, and that digital music composition systems can help students perform independent mathematics learning by iterating rhythm patterns, manipulating audio elements, and other musical activities such as

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adding layers with loops. Similarly, non-digital composition programs have the potential for offering students opportunities to play and remix popular melodies, compose original songs, perform group-based and inquiry-driven learning, and undertake problem-solving tasks involving team collaborations. These pedagogical prospects emerged during analysis of the collected reflection essays obtained from our participating preservice teachers, which together illustrated many of the distinctive educational strengths that digital and non-digital music composition systems can provide during classroom mathematics instruction.

The comparisons in this study explored the unique pedagogical advantages from music composition activities as mathematics learning resources. The synthesis of digital and non-digital music composition promises a well-balanced music themed instructional model for implementing a mixture of formal and informal education based on elementary mathematics. For example, as informal education resources, digital computer-based composition systems allow learners at home, in an individual setting (e.g., on computer laptops or tablets) to conduct preliminary investigations into how audio elements can be arranged and structured based on their existing knowledge. Students can each contribute their initial composition works to class so they can be combined as a data set. Such data set can be statistically analyzed to illustrate a variety of statistical concepts, such as: mean, median, mode, and an early sense of distribution. Common features identified during data analysis may serve as a hint for students to compose melody and corresponding harmonic chords with physical composition cards in class and play new pieces of music in groups through handbells.

Music composition by listing color-based musical notes on classroom tables can address (1) geometrical transformation (e.g., develop next parts of music by sliding, rotating, and reflecting the initial sets), (2) algebraic modeling (e.g., create music based on proportional change—keep certain ratios among targets notes, and progress harmony based on growing patterns such as "2a+b"), (3) probabilistic reasoning (e.g., predict and generate melody and chords based on the results of multiple coin tosses), and (4) permutation and combination (e.g., iterate a melodic unit by re-sequencing any three notes, and determine distinctive chords based on a given pool of notes). These original music composition works can be uploaded into digital composition system, perhaps as an afterschool assignment, and software can visualize mathematical concepts used while remixing musical works into alternative versions (e.g., play three times faster with added sound effects from a typical rock band).

Educational Implementations

The tug-of-war regarding digital versus non-digital supports for education has been comprehensively debated by educators and parents since our current Digital Era began. With more schools across the United States increasingly offering digital tablets or laptops to every student, finding the optimal methods for use of computers and digital tools in the learning process has become one of the major challenges facing teachers. Modern teachers are often expected to provide lessons with a healthy balance of many dichotomies, including: hands-on and virtual, individual and group, academic rigor and intellectual engagement, as well as conceptualization and contextualization. The mixture of non-digital and digital music composition systems described in this paper is another example of how mathematics teachers might try to achieve such equilibrium, and could be valuable to teacher education programs that want to provide a tangible example of the advantages from both digital and non-digital pedagogical supports as well as the ways in which such systems can support each other.

The importance of employing a constructivist approach in the classroom, recognizing learners of all ages as individual people with heads full of information, has thankfully resulted in an overall decrease of teaching methods that highlight lecturing, copying textbook examples, and multiple-choice timed testing. These outdated methods have gradually begun disappearing from progressive classrooms, but the implementation of constructivist mathematics teaching is now overwrought with the an equally problematic concentration on trivial, entertainment-oriented adornments—instead of the deep mathematical connections to topics such as music composition that are the true domain of authentic constructivism during the mathematics teaching process. In our experience, music-themed mathematics teaching that has been implemented successfully in classes is most often based on deep connections that make mathematics relevant to learners as they recognize the usefulness of knowing mathematics, and not based on superficial connections to kid-friendly topics such as the clichéd singing of songs with new math-themed lyrics or listening to popular music while doing math problems (Minces & Akshay, 2023). The most essential aspects of music—composing and performing—are generally neglected in music-themed mathematics teaching practices. The findings from the present study have shown that music composition and performance activities, if properly developed and supported by sound educational principles, learning theories, and educational technologies, can be used as classroom activities to support formal mathematics education while also providing out-of-school learning resources for making connections with informal mathematics education.

The empirical evidence accumulated from this study underscored the value of music-themed mathematics teaching strategies, particularly those focused on composition and performance, for preparing preservice teachers at balancing digital technology with non-digital, hands-on experiences. As their instructional design abilities at developing lessons move beyond a compartmentalized vision of mathematics as a solitary, isolated discipline divorced from the real-world or any interesting applications, they begin to understand that mathematics instruction can be multidisciplinary, with students perhaps even composing original music during mathematics instruction as an opening to other artistry-themed math lessons. Contextualized and intellectually engaging music-themed approaches to teaching early childhood and elementary level mathematics merits further attention from teacher educators and teacher education researchers, so that this method can be further developed and incorporated into classroom mathematics teaching methods courses and curriculum.

Several limitations should be noted regarding the current study. First, the sample size of the participants was relatively small for making any inferential conclusions therefore this study analysis is focused primarily on the qualitative aspects of the findings. Additionally, the sample of participants was predominantly homogenous in terms of ethnicity and gender. Further, the training time for the participants to experience the two music composition systems was fairly short and therefore some of them were not able to gain proficiency at using the digital music composition software program. Partially because of these acknowledged limitations, the authors of the present study invite further research investigating the potential pedagogical opportunities that mixing digital and non-digital music composition systems could have upon preservice as well as inservice teachers' instructional practices. We also encourage further empirical studies investigating how mixtures of digital and non-digital music composition systems might impact students' learning in terms of both their attitudes and their mathematics achievement.

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