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Affordances of music composing software for learning mathematics at primary schools

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Music composing is associated with various positive learning outcomes, but in several countries, such as Finland, it is not part of the primary school music curriculum. There are several issues as to why music composing is not taught at schools, such as beliefs that composing requires extensive knowledge of music theory, lack of teachers' confidence, lack of evidence on the method's effectiveness and difficulty of assessment. Composing software has the potential of solving some of these issues, as they are connected to mathematics via music theory and technology, and with practical opportunities arising from adopting phenomenon-based learning at schools, the affordances of music composing technologies for learning mathematics are investigated in this study. For this purpose, 57 music composing software were categorised and reviewed. Our analysis identified eight types of music visualisations and five types of note input methods. The music visualisations were compared to the mathematics content in the Finnish primary school curriculum and the note input methods were evaluated based on their relationship to the music visualisations. The coordinate grid-based *piano roll* was the most common visualisation and the *tracker visualisation* had the most affordances for learning primary school math. Music composing software were found to have affordances for teaching mathematical concepts, notations and basic calculus skills, among others. Composing methods involving direct interaction with visualisations support the experiential learning of music theory, and consequently, the learning of mathematics. Based on the findings of this study, we concluded that music composing is a promising activity through which mathematics and music theory can be learned at primary schools.

Keywords: music technology; composing; mathematics; primary education; software review

Introduction

Music in general has been found to, for example, reduce stress and anxiety (Nilsson 2008), support literacy development (Paquette and Rieg 2008), enhance motivation to exercise (Edworthy and Waring 2006) and affect feelings (Habibi and Damasio 2014), which have holistic positive effects on a persons' life (Thompson 2015). Music compositions are the kind of permanent creations that give a person a sense of

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self-accomplishment (Runco, Ebersole, and Mraz 1991). Just as playing an instrument creatively or painting a picture can be forms of self-expression, so can a musical composition. Creating music and listening to music spark positive emotions, which consequently lead to increased motivation and more effective learning (Sylwester 1995). Music has also been a medium for conveying ideas and influencing people and cultures. It is an integral and undeniable component of being a human, and it is thus no wonder that music is being taught at Finnish (Finnish Ministry of Education 2014) and British primary schools (UK Government 2013) and elsewhere throughout the entire primary school curriculum. Primary school music education covers various aspects of music from playing instruments and collaborative music making to understanding music-related culture. However, the aspect of music which is seldom covered is music composing (Byo 1999; Strand 2016).

Phenomenon-based learning was introduced to the Finnish national educational curriculum in 2014 (Lonka *et al.* 2018; Symeonidis and Schwarz 2016). Phenomenon-based learning focuses on teaching traditional subjects and curriculum content via phenomenon, for example, mathematics and music via music composing, instead of teaching subjects separately (Lonka *et al.* 2018; Mattila and Silander 2015). Several different subjects can thus be learned during a single lesson (Mattila and Silander 2015). Phenomenon-based education calls for novel teaching methods. A promising area is music composing, which naturally blends together mathematics, music and logical thinking, and, when digitised, information technology (IT). The possibilities of integrating music with mathematics have already been explored in previous studies (An and Capraro 2011; An and Tillman 2015; Bamberger 2003; Lim, Lee, and Ke 2018; Tossavainen and Juvonen 2015). In addition, skills in problem-solving and IT as well as scientific thinking have also been taught through music composing (Berkley 2014; Manaris and Kohn 2016; Rogers 2016; Ruokonen and Ruismäki 2016). Figure 1 illustrates how music composing can be seen as a phenomenon through which IT skills, mathematics and music can be learned.

The current study focuses on the intersection of music and mathematics education, and the affordances music composing technologies have for combining the two subjects in primary school education. A related study was conducted in 2005, where

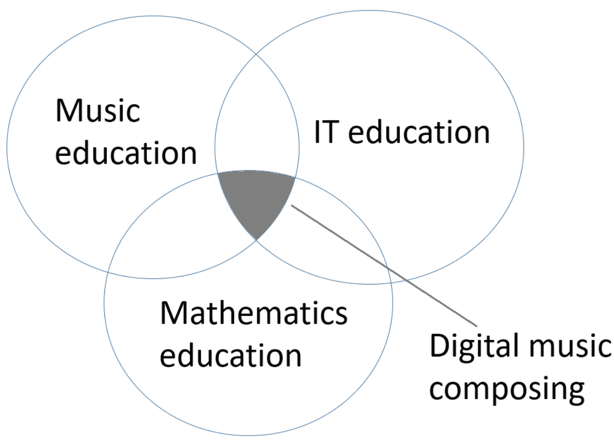

Figure 1. Mathematics, IT and music education can all be combined through the phenomenon of digital music composing.

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the multimodal affordances of technology for teaching music composing were investigated (Gall and Breeze 2005). The study utilised empirical work with children as a research method, and came up with promising results, highlighting the affordances composing technologies offer for education (Gall and Breeze 2005). However, instead of general affordances of software for music education, the current study focuses on the affordances of the composing software for mathematics education, as the musical benefits of composing are such an integral part of the composing process that they can be assumed to be present in all solutions. Mathematics, on the other contrary, manifests differently depending on the type of composing activity and technology used (Mazzola, Mannone, and Pang 2016).

In the realm of human–computer interaction (HCI), the term affordance has been reported to have some ambiguity, with two definitions circulating in research, one by the original discoverer of the term James Gibson, and the other by psychologist Donald Norman, who popularised the term in the realm of HCI (McGrenere and Ho 2000; Norman 1988). The so-called Norman's affordances are defined to be perceived properties of an object that may or may not exist, which can be dependent on the experience, knowledge or culture of the actor (McGrenere and Ho 2000). In comparison, in Gibson's affordances, the properties of an object exist independently of the observers' ability to identify them (Greeno 1994). In the current study, Norman's definition was adopted, as the potential and the supporting properties music composing technologies have on mathematics and music education are observed and analysed. Moreover, previous studies on the affordances of music composing technologies have also used Norman's definition (Gall and Breeze 2005).

For clarification, the current study makes a difference between composing music, as opposed to creating sounds, playing music and listening to music. Obviously, these four are all intertwined in music creation, and for most people effective composing is impossible without, for example, being able to hear what the piece in progress sounds like. Approaches to composing vary from soundscape composing (Fourney and Fels 2009; Martin 2018) and context-dependent composing (Koutsomichalis 2018) to theory-based composing (Bunting 1987), with each having their own artistic effects. In the current setting, the traditional music theory-based composing is explored. Visualising compositions with the help of music theory provides the most suitable platform for mathematical abstraction, and hence the best tools for learning logic and mathematics in comparison to alternative composing techniques. The term "Music composing software" is in some contexts used to describe algorithmic composing tools, but in this study, the term is used explicitly for describing software that aids the user in composing music, but does not generate music on its own.

Background

Music composing has historically not been taught to others than exceptionally gifted children, at least partly due to the presumption that it is an activity that requires extensive knowledge of music theory, mastery of *Western music notation* (sometimes also referred to as *sheet music* or simply *musical notation* [Smith and Williams 1997]) and sufficient skill on at least one instrument (Beckstead 2001; Pope *et al.* 1995). Modern music technology removes the two later arguments, as mastery of *Western music notation* and mastery of an instrument can now be replaced by mastery of composing software. The argument for the need for knowledge of music theory still stands; however, a composing software can be seen as an object through which learning of music theory can happen. It can, however, be argued that instead of seeing music theory as a requirement to start composing, music theory can be learned by composing. For example, Piaget's theory of cognitive development argues for learning through personal experiences, and heavily emphasises the importance of inventing things as a way of learning compared to being thought the things directly (Piaget 1970). Other theories including Empirical Modelling (Beynon 2012) and Experiential learning, focusing on learning from experiences (Kolb 2014), echo Piaget's theory, and in the spirit of radical empiricism (James 1976) argue for learning through personal experiences. It is therefore reasonable to presume that with sufficient tools to learn with, that is, construals at disposal (Beynon 2012), music theory can be learned through composing music, instead of seeing quite vast music theory knowledge as a prerequisite for starting to compose music.

Music composing is not currently part of the Finnish educational curriculum (Finnish Ministry of Education 2014). In some other countries, such as the United Kingdom, composing is being taught as part of music education, and it is embedded in music education in the national educational primary school curriculum (UK Government 2013). However, how music is being taught in practice at primary schools heavily depends on the music teacher. Composing has been perceived to be the most difficult aspect of music to be effectively taught in a primary school setting (Byo 1999), and techniques and tools that are available for teaching it vary greatly. The raw numbers of to what degree music composing is being taught at primary school level have been measured by some studies. For example, in the state of Indiana where composing is not a compulsory part of the primary school music education (Indiana State 2016), 89% of educators said they sometimes still use some sort of music composing tasks in their teaching. However, only 6% of Indiana teachers reported to use composing activities regularly as part of their teaching (Strand 2016).

Challenges of music composing as a classroom activity

Composing as a classroom activity has been explored in several studies (i.e. MacGill 1988; Pitts 2000; Sætre 2011; Savage 2005; Selwyn 1993; Strand 2016; Winters 2012), but it has not yet established itself as a part of the Finnish primary school music education curriculum (Finnish Ministry of Education 2014). Studies focusing on technology as a solution for helping the teaching of music composing argue for its usefulness (Beckstead 2011; Finney and Burnard 2010), but overall research on practical technological solutions for classroom composing education is lacking. One of the earliest studies of composing technologies for classroom use is Peters' article from 1992 where he lists 27 unique music software from four development generations (Peters 1992). The study shows how the software improve with each generation and are better suited for educational purposes. Sætre (2011), on the contrary, highlighted the role of the teacher as the most important factor in teaching music composing instead of technology.

General reasons found in the literature of why music composing is often not thought at primary and secondary school level include teachers' lack of confidence in their abilities to teach music (Atkinson 2017; Winters 2012), the lack of evidence that composing as an activity produces useful tangible learning outcomes

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compared to other teaching methods (Savage 2005), the difficulty to assess compositions and the learning outcomes (Savage 2005), and the lack of practical technologies, or educators' knowledge of such technologies, that would allow students to focus on their composing during class in a limited amount of time (Winters 2012). A more practical unproven hypothetical reason for not including composing music as part of the primary school music education is a historical reason, more specifically the lack of technology. Without the help from technology all practical composing activities would either be too difficult or produce too much sound and noise to be carried out in a standard classroom setting. The reasons why composing music is not being taught in primary and secondary schools can thus be summarised as follows:

- Composing music is only seen as something that gifted musicians who know music theory are capable of.
- Music teachers lack the confidence to teach music composing.
- Lack of evidence that composing music is an effective teaching method for music theory and mathematics in comparison to alternative methods.
- The difficulty to assess music compositions.
- A composer needs to be able to hear what the composition sounds like, and without proper software and headphones this would result in cacophony in a classroom setting.

The role of technology in music composing

The rise and development of digital audio processing has had several positive effects on music composing. MIDI technology enables songwriters to immediately hear what even the most complex compositions sound like, which has had a great impact on music education and composing (Beery 1995). Software can create sheet music straight from playing a MIDI keyboard using automatic melody dictation (Cambouropoulos 2000), which makes the process of composing fluent. In addition, with technology, revisions and rewrites to the composition are fast to do, and, for example, the entire order of sections in a song can be quickly turned around (Rabiner and Gold 1975). Converting analogical instruments to digital representations for editing is a craft, that is still being developed, but some software is already quite good at it (Melodyne 2019).

Algorithmic composing refers to music composing procedures that utilise software for automating the song writing process (Cope 2015). Algorithmic composing has become possible through software that, for example, automatically generates bass lines or harmonies to an existing melody (Beckstead 2001). These kinds of composing software can differ vastly from each other, and consequently, the programme authors can be seen as the composers. Machine learning techniques also allow for previously unobtainable ways to compose music. For example, a study by Malmi *et al.* (2016) demonstrates how rap lyrics can be generated automatically through a machine learning powered programme. Cope (2015) argues that using algorithms or at least some level of automation in composing is natural, and that algorithms simply serve the purpose of informing someone how to proceed (with music).

Visualisation of music can guide the user to think about music in a certain way, and it has the potential of making music more memorable, even assisting in understanding it (Foote 1999; Fourney and Fels 2009; Hiraga, Watanabe, and Fujishiro 2002). For a composer and for a learner, the way to visualise music is equally important. Technology allows for previously unobtainable or completely impractical visualisations, for example, visualisations that require constant movement or animation (Hope 2017; Miller *et al.* 2018). Furthermore, technology allows the switching between various visual representations of a single musical score, making it easier to establish a connection between the music and its potentially endless visual representations. For a composer this can be helpful, as different visualisations draw out and highlight different parts of the musical score.

The influence of technology on music education at primary and secondary school level has been discussed in several studies (Bauer, Reese, and McAllister 2003; Beckstead 2001; Finney and Burnard 2010), which provide examples of how various hardware and software can be used in a classroom setting and outside. Technology has now evolved to a point (Holmes and Holmes 2002; Taylor 2014) where it allows composing to be integrated into music education in previously unattainable ways (Gall and Breeze 2015; Pitts and Kwami 2002). New technologies and ideas for music composing emerge constantly, a few recent examples being multiplayer music making (Wejam 2018), a distributed programmable computer music system (Shapiro *et al.* 2017) and a mathematical composing tools with gamified elements (Laato *et al.* 2017; Lim, Lee, and Ke 2017). Even early studies where students composed music using MIDI technology show promising results (Airy and Parr 2001). Recently also serious games for learning music have been proposed (Hendradjaya 2018).

Research design

To address the discussed research problem of what affordances current music composing software offer for mathematics education, the following research question was formulated:

> What kinds of music visualizations and note input methods exist in contemporary music composing software, and what affordances do these have for teaching mathematics and music theory in late primary and early secondary school?

The age groups of 10–15 years were chosen for this study because mathematics in music composing should be introduced as early on as possible, but students should be old enough to have the required skills and capabilities to get started with composing. To find the optimal target audience, the curricula of Finland (Finnish Ministry of Education 2014) and the United Kingdom (UK Government 2013) were analysed and based on the mathematics and music contents in the existing curricula, the target age of 10 years was determined to be an absolute minimum requirement. The semantic fields of music notation and the visual representation of music also overlap; however, the visual representation of music can be more than just notation (Hope 2017). Several notations exist, for example, the GUIDO Notation format (Hoos *et al.* 1998), the graphics colour music notation (Holcombe 2016) and the Haskore music notation (Hudak 1996), but this study aims to look beyond the notations to the concrete visualisations present in available composing software.

The research design of this study has two stages, which are explained in detail in the following sections:

1. Systematic search of music composing software
2. Analysis
   - Identification of the genre of the composing software based on existing classification.
   - Analysis of the composing software in each genre to identify all unique visualisations and note input methods.
   - Going through the mathematics education curriculum of Finland for the chosen age groups, and finding mathematics concepts that could be supported by identified music visualisations.
   - Determine which kinds of affordances each note input method provides for education by looking at the magnitude of the connection to the abstraction of the music.

Search of music composing software

The Prisma literature review method by Moher *et al.* (2009) was adopted and translated to the realm of software to conduct a systematic search for composing applications. A composing software was defined as a computer application with which users can create original music and listen to it. For the initial collection of composing software, existing lists of composing software, research databases and prominent available search engines were used. Existing non-scholarly lists of composing software were also used, for example, Wikipedia's list of composing software (2018). The covered research databases were the Springer database, IEEE Xplore, SciTePress and the research database search engine Google Scholar. The search engines used were DuckDuckGo and Google. For making queries in the databases and search engines, the search terms "music composing software" and "composing software" were used, and the first 30 results were checked. The list of software was also supplemented with information found on news articles and forums. The platform was narrowed to desktop only, as the composing software of which available studies were found were primarily made for desktop operating systems, for example, work by Pejrolo (2012), Farbood *et al.* (2004) and McCoid *et al.* (2013). A certain quality consideration had to be made when choosing which software to include in the final data set. The software had to either be available on latest desktop operating systems, or academic research had to be published of it. Remixing software, non-musical audio editing tools and other software which did not allow the user to freely composer music were excluded. Thus, the following items were excluded:

1. Items that did not fit the chosen definition of a composing software.
2. Items that were never published or made available to the public.
3. Items that were only available for mobile platforms (Android/iOS/Windows phone).

Identifying the genre of the composing software

Firstly, the software was sorted into genres based on the existing literature. The following categories were used: Digital Audio Workstation (DAW) (Leider 2004), Tracker (Obarski 1987), Midi sequencer, Notation Software, Educational software, Game, Beat machine and Sound editing software. This way of categorising composing software is ubiquitously present in music software discussions and studies (Leider 2004; Peters 1992; Walzer 2016). The genre was determined by the features of the software, and found and determined by looking at external sources, aka manuals, websites and marketing material related to the software. Most of the time the genre was defined by the developers themselves, but in some cases the features of the software had to be looked to determine the genre.

Categories for music visualisations and note input methods

From each genre, all unique music visualisations and note input methods were recorded. The categories were formed by observing the logic behind the solutions. For each unique logic, a new category was created. Music visualisations and note input methods are sometimes put into a bundle and called an editing interface or just an interface of a music editing tool (Marrington 2010). In the current study, the two were separated, as it is evident that several programmes offer the possibility to visualise the same song in multiple ways, and also offer a variety of ways to input notes (Hosken 2014).

Affordances of the visualisations for education

The mathematics content in national educational curricula of the United Kingdom (UK Government 2013) and Finland (Finnish Ministry of Education 2014) was observed for the chosen target age groups of 10–15 years. The found areas of mathematics were compared to the music visualisations in the composing software. There were two ways the visualisations could support the mathematics content: direct and indirect. In case the visualisation contained direct references to specific mathematics content, for example, geometric shapes, it was recorded to have the affordance for teaching geometry. However, the visualisation could also indirectly support the learning of some mathematics content, by, for example, containing a logical structure, which taught processes needed in mathematics. An example of this would be visualisations that rely on an x- and y-axis to represent aspects of the music. These visualisations might not directly show the coordinate grid, but essentially working which such visualisations would still have the affordance of teaching how a coordinate grid functions (Gall and Breeze 2005).

Affordances of note input methods for education

In addition to visualisations, note input methods were looked at. Based on the theories of cognitive development (Piaget 1970), experiential learning (Kolb 2014) and empirical modelling (Beynon 2012), it was assumed that the more direct correlation between the input and the feedback, the better the learner is able to grasp the connection between their actions and the output. It was also presumed that in case a visualisation was found to have the affordance of teaching mathematics, interacting directly

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with the visualisation would boost the learning effect (Kolb 2014). In comparison, note input methods that were not related to the visualisation, and that had a delayed feedback loop, were seen as suboptimal from the standpoint of effective immediate learning outcomes.

Results

The initial list of programmes gathered through search engine results, research databases and supplemented with additional information comprised 115 programmes. After filtering out items that were not composing software as defined in this article, 57 programmes remained (see Appendix A). Before looking into the visualisations and note input methods present, the programmes were sorted into eight genres based on their features. The results of this categorisation are seen in Figure 2. Each software was sorted into the primary category it belongs to based on its features, meaning that each software is presented only once, even though some software might have features that could place them into several categories.

Software from each genre was then analysed to identify categories of unique visualisations and note input methods. Many of the programmes contained multiple visualisations of music as well as several note input methods. For example, in programmes classified as DAWs, a certain visualisation and composing logic might be prominent or encouraged, but other options are almost always included (Leider 2004; Marrington 2010). The user was able to switch between various visualisations for the same composition, and also input notes in a multitude of ways. Besides being the most popular genre of composing software, DAWs on average contained the most versatile selection of note input methods and music visualisations. The second most popular category, MIDI sequencers, could also be found embedded in DAWs. Trackers were the third most popular in terms of quantity; however, lately they have had only minimal use in the industry (Marquez 2014).

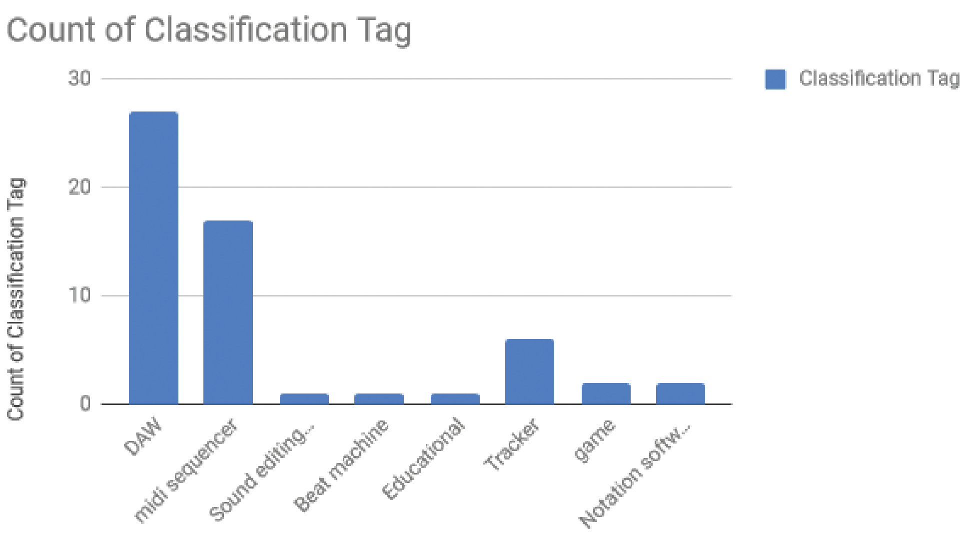

Figure 2. Analysed software sorted into categories based on their features.

Visualisations of music

Some of the software had different visualisations for single melodies and whole orchestras, but for visualisation of the three components of a note: pitch, duration and instrument, the following two categories with four subcategories were discovered:

1. Coordinate grid-based visualisation:
   - Piano roll
   - Tablature
   - Western music notation
   - Waveform view

2. Other visualisations
   - MusicXML (code)
   - Tracker visualisation
   - Pattern/grid view
   - Instrument emulations

Coordinate grid-based visualisations

The most popular way of displaying music among the analysed programmes was found to be a coordinate-grid based visualisation, a two-dimensional (2D) coordinate system where the x-axis represents time and the y-axis represents note pitch. Examples of this kind of a solution are *piano roll* and *western music notation*. As only the pitch and duration are determined by the coordinate grid, the blocks that are placed on the grid have metadata on them that determines one or more of the following: the velocity of the note, the instrument the note is played on and any pitch bends done or additional effects on the note. For example, the instrument is often not assigned to a single block, but rather the whole track, an example of which one can find in *western music notation*. In Figure 3, the composing software *Mario Paint Composer* is displayed, where the type of note determines the sound of the note. The song in question is Bonetrousle aka Papyrus theme from the game Undertale by Toby Fox (Fox 2015), arranged by Youtuber "pokesonicddrninja/DeepFreeze757."

Some coordinate grid-based solutions where the duration of the note was not determined by the coordinate grid at all were identified. This approach is mainly used in *Western music notation*, which is featured in several composing software, for example, *Sibelius* and *Guitar Pro 7*. Figure 4 shows the MIT laboratories composing software *Hyperscore* (Farbood, Pasztor, and Jennings 2004), which combines the approach of *Mario Paint Composer* and *Western music notation*, displaying at once both a unique looking note like in *Mario Paint Composer* and *Western music notation*, and then allowing the length of that unique looking note to be manipulated. A coordinate grid is also used to visualise patterns, verses and other bigger blocks of composed music in most analysed programmes. Even though multiple solutions exist for displaying melodies and chords, the bigger blocks of music are almost exclusively presented in a coordinate grid, where the x-axis shows time and the y-axis shows all individual tracks.

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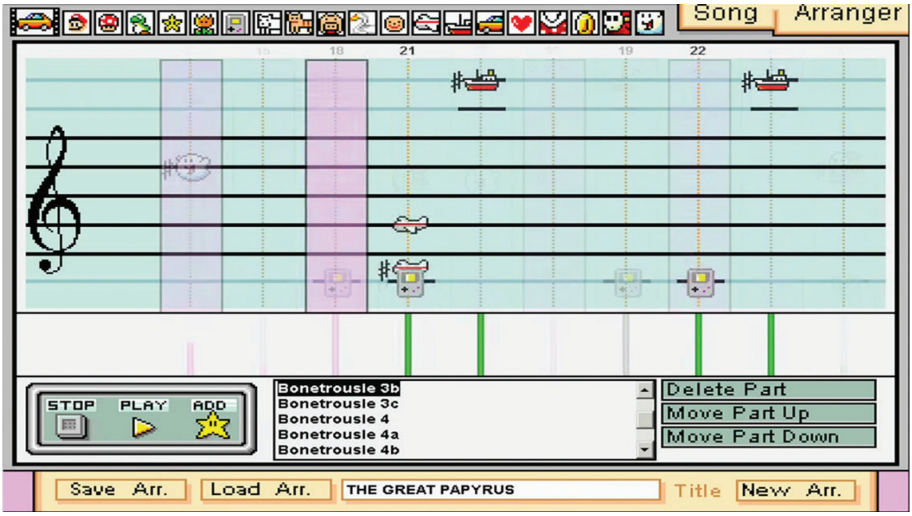

Figure 3. The visualisation of music in Mario Paint Composer is based on Western sheet music.

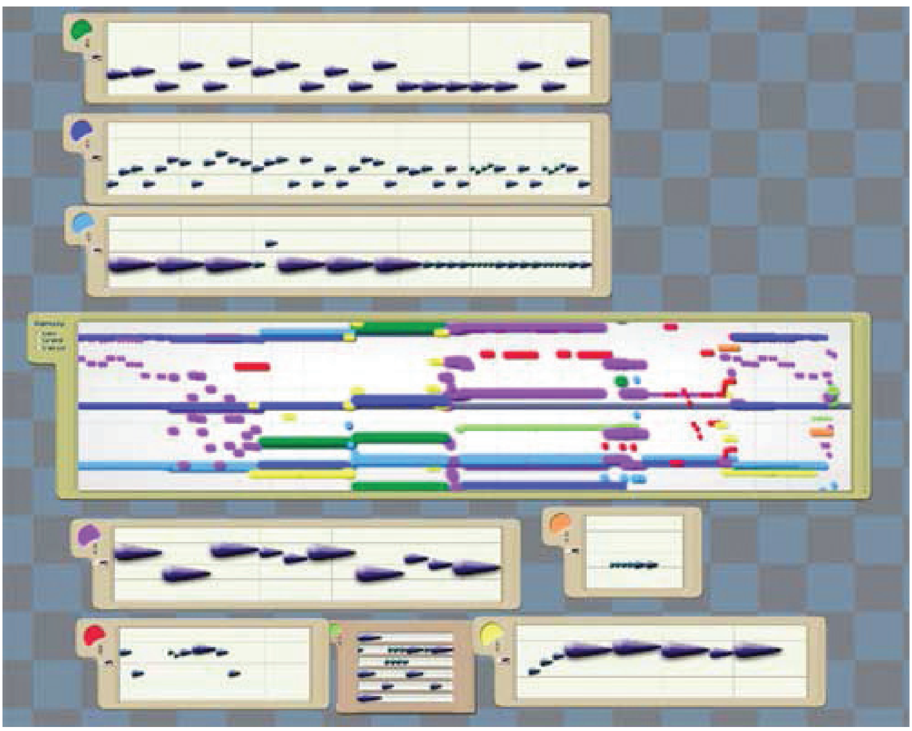

Figure 4. The visualisation of music in the Hyperscore programme, developed by MIT laboatories (Farbood *et al.* 2004).

Other visualisations

A close relative to the coordinate grid visualisation of music is the so-called tracker visualisation. The name tracker comes from the composing software, created by Karsten Obarski in 1987, and called *The Ultimate Soundtracker*. The tracker visualisation features a discrete 2D matrix to visualise notes. The notes are written with plain text to the grid, for example, the F note in the 5th octave could be written as F-5. This kind of a 2D grid visualisation is not only present in trackers, but also seen in more recent software like the *Song Maker* (2018) by chrome experiments music laboratory. Furthermore, the *Western music notation* can be seen to be divided into grids, with bar lines as the dividing factor.

Virtual instruments in the analysed software could have their own visualisations when inputting notes, but after the notes are input, the visualisation shifts back to a coordinate grid. For example, *Audiotool* and *FLStudio* provide virtual beat creation synth user interfaces that have their own visual representations of the beat in a pattern/grid view, but once the beat is complete, it is presented as a single block in a higher level abstraction of the whole song. The tablature visualisation is identified to be an instrument-based visualisation, as it is based on the neck of a six-string guitar. The instrument-based visualisations are arguably more useful for those musicians who are familiar with a specific instrument, and want to utilise their knowledge of that instrument in composing.

Music can be looked at and edited in code, and of that MusicXML is a good example. Pitch, duration, velocity, instrument and so on are all defined in code using string, numbers, arrays and variables. However, this kind of visualisation is not prominent in almost any software. Rather, the software only uses this kind of data structure underneath and provides a more user-friendly interface for the composer to work on.

Note input methods in the software and their affordances for education

Note input methods can be split into two categories: (1) internal methods where the user directly interacts with the visual representation of the music to manipulate it, and (2) external methods where the user uses another way to input a note, which then appears on screen. Most DAWs and complicated software, for example, *Guitar Pro*, *Cakewalk Sonar, FL Studio, Cubase* and *GarageBand*, host a variety of note input methods (Leider 2004; Marrington 2010). The categories for note input methods found in the software were as follows:

- Interacting with or manipulating visualisations (internal)
- Playing a real instrument or singing (external)
- Playing a virtual instrument (external)
- Typing in notes or code (internal)
- Using AI to generate music (external)

The first category, interacting with or manipulating visualisations, can occur in multiple ways. A note can be typed in, dragged and dropped, or it can be placed by touch controls, for example, drawn like in the *Western music notatio*n. These types of note input methods are present in the majority of the software. The other direct or internal note input method category was typing in notes, which is present in, for example, when composing with the MusicXML programming language or trackers

(Obarski 1987). Internal methods were found to be always dependent on a visualisation, and could not exist on their own. External methods, on the contrary, could be things like singing, playing a real or virtual instrument or generating music with the help of artificial intelligence. These categories represent note input methods that are not linked to a specific visualisation.

In terms of affordances for mathematics education, it was concluded that based on the theories of cognitive development (Piaget 1970) and empirical modelling (Beynon 2012), directly linking action into empirical experiences and feedback strengthens the learning process. Therefore, note input methods classified as internal offer better affordances for mathematics education and learning music theory, as they provide instant visual feedback to the composer, and are thus better tools for experiential learning (Kolb 2014). External methods, such as playing a virtual instrument to input notes, require an already existing knowledge structure of music theory for the composer to be in total control of the composition. The external note input methods can, however, support understanding music as a whole, as the composer will learn to draw links between various abstractions of the same musical score.

Affordances of music visualisations for mathematics education

The mathematics concepts and goals found in the Finnish and British primary and secondary school curricula were almost identical. This is in line with reports from Meyer, Kamens and Benavot (2017), who analysed a wide range of national educational curricula and found them to be, in most cases, similar with each other. The Finnish national curriculum (Finnish Ministry of Education 2014) lists 14 learning goals in mathematics for the age groups 9–12 and further 20 learning goals for the age groups 13–15. The UK national curriculum (UK Government 2013) is not as precise, and leaves more room for teachers to adapt their teaching to their own and to their pupils' preferences. Therefore, the Finnish educational curriculum was used in the comparison analysis between mathematics concepts in the educational curriculum and the visualisations found in the composing software.

Out of the 14 learning goals of the Finnish national curriculum for age groups 9–12, the first six related to working skills, values and attitudes. Similarly out of the 20 learning goals of the Finnish national curriculum for age groups 13–15, the first nine are not actual mathematics concepts. Out of the resulting 19 learning goals (8 for age groups 9–12 and 11 for age groups 13–15), five duplicates were removed. The final list of 14 (4 for age groups 9–12 and 10 for age groups 13–15) mathematics learning goals and visualisations that provide affordances for learning them can be seen in Figure 5. Surprisingly, the nowadays little-used tracker visualisation had the most affordances in terms of quantity: basic calculus skills, rational numbers, real numbers and mathematical concepts and notations. Moreover, pure code, that is, MusicXML also covered several categories. However, these results do not take into account the effectiveness of each solution in education, as, for example, gazing at XML notation is probably not as motivating for students as seeing say, a colourful piano roll representation.

Discussion and future work

The popularity of coordinate grid-based visualisations might be the result of the following factors: (1) they are the most intuitive and/or (2) the most practical tools for

Figure 5. Which mathematics concepts does each music visualisation support?

composers to work with. A coordinate system-based visualisation is in fact present in more than 90% of the analysed software. Its popularity could be partly due to how natural language is written and read, in fact, *Western music notation* is read from top to bottom and from left to right, just as western written natural languages (Smith and Williams 1997). Professional musicians are capable of accurately playing sheet music they have never heard before (Truitt *et al.* 1997), but with the amount of training required it is not clear as to whether the same feat could be achieved with the same or even less training with another music visualisation method. The coordinate grid visualisation guides towards thinking music in a certain logical framework, thus enabling the learner to form an intuitive understanding of music theory based on empirical experiences. For primary and secondary school students getting familiar with the number line, composing music with the coordinate grid visualisation seems a promising activity to support the learning.

Based on the theory of constructivism and the current understanding of the human brain, learners construct new knowledge on top of their prior knowledge. The process can happen via empirical experiences, but changing existing knowledge structures requires conceptualisation and reflection (Troelstra and Van Dalen 2014; Von Glasersfeld 2013). Hence, visualising music through ways that students are already familiar with can assist in getting started with composing. Furthermore, familiar mathematics concepts encountered while composing serve the same purpose (Troelstra and Van Dalen 2014). Once students obtain a grasp of the underlying music theory, it is easier to guide them to connect it into mathematics and other related fields. Many DAWs, for example, *Guitar Pro,* offer multiple visualisations of music including several instrument emulations as well as guitar tablature and traditional sheet music. Being able to see the same piece of music through different visualisations can be a powerful pedagogical tool for assisting students to draw connections between music and various visual abstractions of it. Different visualisations spark different thoughts in the brain, resulting in more creative thinking and to birth of new musical ideas. Motivating children for creative thinking is important for several reasons, one of them being that creation itself is a process that sparks motivation to study further to be able to create a better outcome for the purpose of self-actualisation (Runco *et al.* 1991).

Soundwave visualisation and other visualisations where the pitch and/or rhythm cannot be deciphered just by looking seem impractical from an educational standpoint. This is because they rely heavily on listening and often lack the required visual support. These presentations are therefore unable to support the learner's construction of a logical theoretical structure of music. *Soundwave visualisation* is special in the way that it shows the music in a lossless analogue format, meaning that it represents real sound as opposed to many other visualisations of music that are digital and symbolical in nature. This further supports the point that the most intuitive and effective visualisations of music are abstractions instead of accurate depictions.

Interaction and feedback are essential in forming an understanding of the relationships between a phenomenon and an action (Kolb 2014). Previously, it was established that the note input methods can be divided into two categories: one where the user directly interacts with the visualisation and one where they do not. Overall, it can be argued that input methods that are directly linked to the visual representation of the music have higher potential to be pedagogically effective for novice composers. This is due to the fact that they get immediate feedback when meddling with the visualisation about how it now sounds, and they see the effects of their actions without a delay, something that is not achieved with other input methods. Professional composers that are already familiar with music theory might prefer external input methods, but for novice composers of the target age group in the current study, the note input methods that are directly linked to the visualisation are pedagogically most promising.

Limitations of the study

The methodology for finding existing composing software could be improved upon to include applications on mobile platforms. For example, a promising mobile game with unique note input methods and visualisations, Yatatoy's *Bandimal* (Yatatoy 2019) and a mathematical composing software Harmony Hippo (Laato *et al.* 2017) were excluded due to the platform limitations. In addition, the indicators based on which the eight visualisations and five note input methods were determined could be tweaked or changed. For example, editing interfaces could have been observed as a whole instead of a separate analysis of note input methods and visualisations. This change might have led to some insights, which did not emerge in the current study.

The chosen theoretical frameworks, from which the software evaluation methods were derived from, influenced the outcome. Empirical Modelling (Beynon 2012) and Experiential learning (Kolb 2014) are both very much focused on learning from empirical experiences, and emphasise conceptualisation and reflection less. Yet, several recent studies on effective learning of mathematics highlight the importance of deliberate practice (Ericsson, Krampe, and Tesch-Römer 1993), which includes thinking, analysing, reflection, conceptualising and problem-solving (Bonneville-Roussy and Bouffard 2015; Lehtinen *et al.* 2017). However, experiential learning does not automatically mean the lack of deliberate practice, and meaningful learning activities, such as learning mathematics by composing music, can foster an intrinsic motivation for deliberate practice (Bonneville-Roussy and Bouffard 2015; Kolb 2014).

Finally, due to the magnitude of the study and the chosen research method, the understanding of the affordances existing composing softwares have for mathematics education remains theoretical. In addition, the current study focused mainly on music composing technologies, and pedagogical models and theories for mathematics education were only briefly touched. A similar study could be conducted the other way around, by looking at pedagogical models for mathematics education, and studying what affordances they have for combining mathematics education with music. Nevertheless, the current study lays the groundwork for investigating the identified affordances in further detail in the future.

Conclusions

Several similarities were observed between many of the 57 software analysed in this article. The genre classification system used in the music industry and in previous studies proved to be quite accurate in determining which types of music visualisations and note input methods were present in the software. DAWs had on average the most features, supporting multiple visualisations and note input methods (Marrington 2010). Altogether, eight different visualisations and five types of note input methods were identified in the software. There were essentially two types of note input methods, which were classified as internal and external. Based on theories of cognitive development (Piaget 1970) and empirical modelling (Beynon 2012), the internal methods were more promising for mathematics education and the construction of the learners' mathematical music theory knowledge structures.

Piano roll, a coordinate grid-based visualisation, was the most prominent visualisation of all, with some versions of it being featured in almost all software except trackers. It was found to have the affordance for teaching at least two mathematics concepts in the primary and secondary schools: (1) understanding and interpreting tables and diagrams, and (2) functions and how they can be plotted into graphs. In terms of most affordances for mathematics education, the tracker visualisation had four (see Figure 5): (1) basic calculus skills, (2) rational numbers, (3) real numbers and (4) mathematical concepts and notations. The analysis did not go in depth to consider the magnitude and pedagogical effect of the affordance. In addition, it is worth noting that even if a visualisation does not support directly learning some of the associated mathematics concepts, those skills can still be learnt because of the mental processes that a composer must undergo while creating original music. Some visualisations also had the affordance to teach some concepts that were not present in the analysed national educational curricula, for example, working with number systems other than the 10-based number system.

The current study laid the foundation for future research on technologies aimed to teach mathematics through music composing. It gives a framework (visualisations and note input methods) for understanding the existing software and gives ideas for developing future software. The results of this study, which music visualisations and note put methods have affordances to teach mathematics, are general and need to be studied in further detail in future studies to fully understand their pedagogical potential.

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Appendix A:List of analyzed software and their classification.

Name	Classification
Ableton Live	DAW
ACID Pro	DAW
Adobe Audition	DAW
Anvil studio	midi sequencer
Ardour	DAW
Aria Maestosa	midi sequencer
Audacity	Sound editing software
Audiotool	DAW
B-step Sequencer	midi sequencer
Band-in-a-box	midi sequencer
Cubase	DAW
Deluxe Music Construction Set	midi sequencer
Digital Performer	DAW
Fairlight	DAW
Finale	midi sequencer
FLStudio	DAW
GarageBand	DAW
Guitar Pro 7	DAW
Hydrogen	Beat machine
Hyperscore 4.5	Educational
JFugue	midi sequencer
KeyKit	midi sequencer
Logic Pro X	DAW
MadTracker	Tracker
Mario Paint Composer	game
Maschine	DAW
MilkyTracker	Tracker
Mixbus	DAW
Mixcraft	DAW
Mozart	midi sequencer
MuLab	DAW
MuseScore	midi sequencer
Noteflight	Notation software
NoteWorthy Composer	midi sequencer
Nuendo	DAW
Numerology	midi sequencer
OpenMPT	Tracker
Podium	midi sequencer
ProTools	DAW
Psycle	Tracker
Qtractor	DAW
Reaper	DAW
Reason	DAW
Renoise	DAW
Rosegarden	midi sequencer
Samplitude	DAW
Sequoia	DAW

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Appendix A: (*Continued*)

Name	Classification
Sibelius	Notation software
Sonar X 1	DAW
Song Maker	Tracker
SoundTracker	Tracker
Studio One	DAW
Tracktion	DAW
TuxGuitar	midi sequencer
WEJAM	game
Xequence	midi sequencer
Z-maestro	midi sequencer