Cognitive loads and the empowering effect of music composition software

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Abstract An investigation of music composition software in classrooms was used to study some ways in which open software can support problem solving and thinking. Students of different abilities and ages were observed doing music composition with the software in a variety of teaching contexts. The observations, and the resulting compositions, often showed a level of sophistication in musical structure which could not have been achieved unaided. A number of explanations are considered for this: it is argued that an explanation based on cognitive loads is most convincing in this case. The removal of cognitive loads does nothing positive to help students, but simply gives more space to think by transferring low level cognitive burdens to the software.

Keywords: Cognitive load; Composition; Information technology; Music

Introduction

It is helpful to distinguish two ways in which computer software supports us: software can be *powerful* and software can be *empowering*. Powerful features of software do difficult thinking for us, but the empowering features of software help us think for ourselves. For example, a powerful feature of spreadsheet software is that it can carry out difficult arithmetical calculations rapidly. An empowering feature of the same software is that it lays out information in a clear, visual way that may enable users to think about patterns and relationships in the data.

This paper is concerned with understanding the processes by which open software can empower human thinking. An investigation of music composition software is used as the main example. The empowering aspects of open software have been widely acknowledged in educational computing. For example, they were a major theme in *Mindstorms* (Papert, 1980). But their importance is by no means universally accepted: the Integrated Learning System movement (reviewed by McFarlane, 1995), represents a move away from empowering aspects of software towards more tutorial approaches.

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In making balanced judgments about empowering features of software, it would help to have a clearer understanding of the way it functions. It is useful to consider two possible mechanisms. One of these will be called *scaffolding* and the other *removing cognitive loads*. With scaffolding, the software helps by guiding the student through the more difficult aspects of the task. As the metaphor suggests, it is a temporary support that is later removed (Brown & Palinscar, 1989). In contrast, the removal of cognitive loads does nothing positive to help students, but simply gives them more space to think by transferring low level cognitive burdens to the software.

Lajoie (1993) presents scaffolding and cognitive load as closely linked concepts, but here they will be separated in order to understand their different contributions. The key difference is perhaps that one approach works by adding extra information while the other works by taking something away.

Cognitive load is a central idea in understanding the processes of thought. At any moment in time there is only so much mental processing that can be done. Although people often carry out several different information processing tasks simultaneously (e.g. driving a car, talking, looking for signposts) there is evidence that certain types of processing can interfere with each other and compete for limited processing capacity in the brain. One example of this is Baddeley and Hitch's (1974) 'working memory' experiments that show that a variety of reasoning tasks reduce the capacity of short term memory. They argue that the reasoning and the memory tasks make use of the same limited capacity store and so interfere with each other.

The concept of cognitive load has been difficult to study experimentally and it is most often used as a theoretical explanation. For example, Sweller (1988) makes use of the concept in modeling the effects of problem solving activities on learning. Cheng (1996) claims the reduction of working memory load is one advantage of using diagrammatic representations like law-encoding diagrams. The methodology employed here is to seek evidence for the concept by observing realistic learning situations:

Cognitive load and composition

When somebody is given the task of composing a short, simple piece of music, they need to make judgments that involve remembering parts of the music. For the experienced musician, the demands on memory are unlikely to pose any challenge. Professional musicians can hold large amounts of music in their heads and also have little difficulty in writing it down. But young children, and others who are musically inexperienced, are likely to find the memory demands a significant burden on composition. Sitting at a music keyboard, they can experiment and easily find a pleasing sequence of half a dozen notes, but it is difficult to progress further because of the difficulty of remembering what has gone before.

This paper reports on some observations on a music program called *COMPOSE* which allows inexperienced musicians to compose tunes from musical phrases rather than individual notes. The phrases are represented

on screen by pictures and stave notation is not used. This approach is likely to considerably reduce the memory load on the user.

Method

The software

COMPOSE is a music composition program which can be used by complete beginners but is still challenging for experienced musicians. The software has both powerful and empowering features but it is the latter which are of interest here. This description is a poor substitute for experiencing the software at first hand, and the reader is encouraged to do this if possible. The version of the software described here is that seen in the majority of observations (Pierson, 1986). More recent developments have added additional features to the software e.g. polyphony (Pierson, 1991).

COMPOSE presents the user with some picture phrases at the top of the screen. Each picture phrase represents a short phrase of music, typically a few notes. The icons are chosen to be attractive and discriminable but they do not depict notes themselves. In any set of picture phrases, the pairing of icons to musical phrases is usually arbitrary.

The picture phrases can be listened to individually by pressing a single key. A number of different sets of phrases are supplied which cover different styles and moods of music. Users can also create their own sets of phrases. The phrases are all monophonic and are restricted to a two octave chromatic scale.

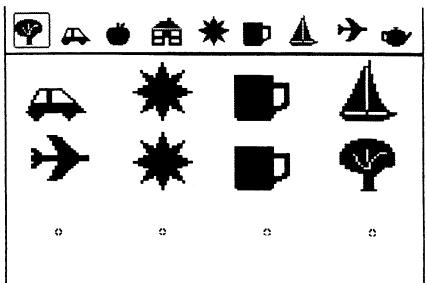


Fig. 1. A typical COMPOSE screen

Note: All the picture phrases in the current set appear at the top. The user has placed eight of these in sequence below to begin a composition.

To build a composition, the grid in the lower half of the screen is used to contain the ordering of any of the available picture phrases. Users may construct and edit their composition freely. A single key press starts the playback of the sequenced phrases. Each phrase is highlighted on the screen as it is played. The tempo (speed of playback) may be altered.

All users of COMPOSE begin by using the sets of picture phrases provided with the software, but there is an editor that allows the user to create new musical phrases and new pictures, which can be combined to create new sets.

The software has been widely used in schools in the UK and in other countries (Congdon, 1989; Pierson, 1990). Close links with children, teachers and the classroom generally have been central to the development of COMPOSE. An account of the design rationale behind the software appears elsewhere (Pierson, 1996).

Observations

A programme of observations has been carried out to study how COMPOSE was used in classrooms and similar realistic settings. The open nature of the software means that it has been used in a wide variety of styles and a very wide range of age and ability levels in primary education, secondary education and beyond. From a large number of lessons and activities using COMPOSE which have been observed, 21 detailed observations were described and analyzed. A full account of these is given by Pierson (1996). The selected observations were intentionally diverse so as to ensure that they included pupils of different ages (5 years to adult), pupils with different abilities, teachers with different musical backgrounds, activities that are varied in nature, and groups of different sizes. The reports were collected by interviewing a total of seven teachers and from personal observations.

Because of space limitations only two of these observations are reported here. The first of these is selected as fairly typical of the pattern of learning activities seen with COMPOSE, but observed here in quite a young child. The second observation illustrates a more exceptional use by a severely handicapped student who controls the software with foot switches.

Observation A

This first observation describes a ten minute interaction between an observer/teacher and a 5-year-old boy who used the software with some enthusiasm. The aim was to introduce composition by asking the child to explore the standard set of musical phrases in COMPOSE and to make a sequence that 'pleased' him. The following (Fig. 2) is a step by step description of the way in which the task was approached and completed by this pupil. The observer/teacher played a passive role except for the two questions that are in italic.

This account is an adult's interpretation of what the child was doing, observed partly from what the child said, but mostly from the operations he carried out on screen. In many respects this description is typical of the work observed with COMPOSE.

Try the tree first - sounds good Put the mug next - now play the two together Don't like the mug next, so I'll put it back.

Now, try the car next, that's OK Then the apple The car and apple 'rhyme' together Get rid of the tree at the start.

Add the house, so we have car, apple, house Play it so far That 'rhymes' What do you mean 'it rhymes'? Because it sounds like it rhymes.

Now listen to the star (it was the next one along) Yes, that's OK Skip over the mug and put in the next ones Boat, plane, teapot Play that so far - OK Can you tell me anything about the boat and the plane? Yes, the boat and the plane make the same sound but lower down.

Now the final square - I'll use the tree because that rhymes well Play the final piece.

Fig. 2. Sample of the interaction during Observation A

Although there are some differences with older and more experienced students, the key elements observed here are almost universal:

- trial and error,
- listening,
- making value judgments,
- editing.

Before this observation, the child had shown a healthy interest in music, in playing instruments and singing songs. He had used the computer regularly at home and school for over 6 months.

The approach to this composition showed a number of tactics. Firstly, there is an interest in using all of the available building blocks. A typical first use of COMPOSE by children of this age is to select the pictures in the order which they appear on the screen and often not listening to them until all the available slots in the sequence are filled. This child had already tried that approach on a previous occasion and so was now at the next stage of being willing to be a little more selective. The selection criteria may be the pictures or the sound or a combination of the two. In this case the selection focused on the sound with the pictures acting as references to the phrases.

The child used the facility to play the whole sequence more than the facility to listen to an individual phrase before selecting it. This, again, is typical of younger children who are quite happy with the extra effort that is

involved with selecting and playing the whole sequence even with the likelihood that the phrase might have to be removed. The idea that listening first would save some effort seems to come later.

The pupil's criterion for making decisions seemed to revolve around this intriguing idea of the phrases 'rhyming'. He was unable to give a detailed description of what he meant by the word. The meaning can be imagined by looking at the context in which it was used (see Fig. 3). Firstly the car and the apple were described as rhyming. The interval jump between the end of the car and the start of the apple is small (a tone) as opposed to the octave jump between the end of the tree and the start of the mug. The 'flow' from apple to house is also a single tone and was judged as rhyming.

The next move, to the star, is an octave jump however. The sequence as a whole therefore appears to be made up of three 'rhyming' sections as shown in Fig. 3.

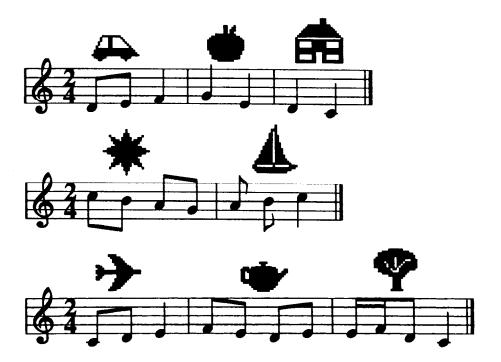


Fig. 3. The pupil's composition from Observation A

Note that the stave notation is provided only for the reader's benefit and was not shown on screen.

Another refinement used by this 5-year-old composer is that each of these three sections ends on the key note, adopting a widespread convention in Western music. Children at this age seem able to recognise patterns that fit a familiar style and to sequence them in a way that matches that style.

Observation N

Here the student was a 12-year-old boy who was severely handicapped. His communication with the observer was limited to using his eyes to indicate a yes/no response to questions asked. His ability to concentrate on a task was no longer than 20 minutes after which he had to stop and rest on a bean bag usually in a muscular spasm. The student had been involved in music therapy sessions before where his contribution would be playing a cymbal. One aim of this composition activity was to encourage the student to improve control of some of his bodily movements using a task that would give a suitable reward.

The student had begun to use the computer for a few minutes at a time. He had most control with his feet so the teacher had attached a switch to his feet to operate the computer. By making leg movements, a box at the top of the screen could be moved along and a particular picture/phrase selected.

Slowly and methodically the student listened to each picture and made selections for the sequence. At the end of twenty minutes he had completed a task more complicated than most he had achieved to date, and he proudly played me his tune. The excitement for all involved was substantial. In this activity the software provided a means of musical expression where one did not exist before but where musical ideas and understanding did. An interesting point here is that the student deliberately chose to listen to the phrases before selecting them. The listening would involve moving between the phrases and listening to each in turn and returning to a particular one to confirm that it was the one that was wanted before selecting it. This showed that the student had much more musical awareness than was apparent from other activities.

This student had persistently refused to co-operate with attempts to use foot switches to control other software whereas here he was willing to work for some substantial time to succeed in this task. No attempt was made by the observer to help the student, even though there were times when it was difficult to watch the student struggle to achieve something that could normally be done quickly.

Other observations

These examples show just two of the wide variety of contexts in which the software can be used. Pierson (1996) gives an account of all 21 observations.

Discussion

The observations suggest that *COMPOSE* has the effect of supporting or empowering users. Over a wide range of ages and musical abilities, students produced musical compositions which were well beyond what they could achieve unsupported. This fact was frequently remarked on in interviews with teachers, and can be judged at first hand from the musical transcripts (see Pierson, 1996). The question addressed here is: how is *COMPOSE* achieving this? It is helpful to begin by considering some of the cognitive processes underlying the musical activities. *COMPOSE* provides

phrases as the basic musical building blocks rather than individual notes. The observations show that students can handle these pre-prepared phrases irrespective of their musical training and background. In other words COMPOSE meets them at a point where they understand the musical meaning of the phrases and can do much more advanced things with them than they could with a blank stave.

This clumping of notes into phrases is important for a number of reasons in musical composition. It is unlikely that professional composers will always start from the bare notes. In most cases a composer will be using building blocks that they already have to hand. The processing of musical phrases seems essential for musical composition, but those without performance skills are likely to encounter a number of difficulties which relate to memory, naming, and the manipulation of phrases.

Memory Span

Sloboda (1985) stresses the importance of short term memory in music:

"The way one hears music is crucially dependent upon what one can remember of past events in the music. A modulation to a new key is heard only if one remembers the previous key. A theme is heard as transformed only if one can remember the original version of which it is a transformation. And so on. A note or chord has no musical significance other than in relation to preceding or following events."

Sloboda (1985, pp. 174-175)

One way cognitive psychologists understand short term memory is to test memory span. Ask somebody to repeat back to you exactly what you say. Begin by giving them five random letters (e.g. D J T F S). They should have little difficulty in repeating them. Then give them six random letters, and then seven, and so on. Most adults will have made a mistake before you reach ten letters, with an average span of about seven or eight. If the task is now repeated with random words rather than random letters, it is surprising that performance is very similar with an average span of about seven words. It may seem paradoxical that the span is about seven for both letters and words, because words are composed of letters.

Miller (1956) demonstrated that a memory span of about seven meaningful items occurs in a wide range of contexts. For example, someone beginning their training as a Morse code operator, will be able to recall only about seven dots and dashes. As they begin to learn, they will be able to recall about seven Morse letters, and a more experienced operator will be able to recall about seven words. As training progresses the operator has learned to clump together dots and dashes into letters, and later to clump these letters into words. Immediate memory seems to have a capacity of about seven meaningful and familiar items. What is 'meaningful and familiar' depends on the experience of the individual. Sloboda (1985, p. 81) supports the idea of similar processes in memory for music. It is likely that early experiences of music are limited to the storage of individual notes (or perhaps intervals) and soon there is a development of the skill to store some simple musical phrases by clumping together the notes. The range and

complexity of these musical phrases increases with experience, in time allowing whole tunes to be recalled as one unit. Sloboda (1985, p. 3) argues that prodigious acts of musical memory (such as Mozart's recall of Allegri's Miserere) are just a logical continuation of this clumping process into larger and larger musical units.

In COMPOSE, a likely consequence of grouping notes into phrases, is that it places less demand on short term memory than conventional composition. Short term memory is not only important for recall: Baddeley and Hitch (1974) have demonstrated that it is often used as a 'working memory' for a range of information processing tasks, and that sometimes there is a trade off between our ability to reason and to hold information in immediate memory. In other words, reducing the burden on short term memory, is likely to improve our ability to carry out other kinds of thinking, possibly including musical composition.

Names and icons

COMPOSE allows the naming of phrases with recognisable words and icons like 'house' and 'car'. This link from the familiar to the abstract opens up opportunities to analyze and discuss music that are much harder when only the abstract is available. To talk about 'a house' and 'a car' in the knowledge that all involved will know what you mean and what the corresponding phrases sound like, is much easier than talking about the notation that corresponds to those phrases. It is also easier than talking about 'bar 1' or 'phrase 4' which might refer to the same items but still contain abstractions that easily lead to confusion. The use of pictorial representations can also provide a simple score or means of directing a performance. Children very quickly remember the simpler phrases to the point at which singing a 'Tree' to order is quite natural and may well be more familiar than the notational equivalent.

These findings with *COMPOSE* are in agreement with an experiment by Delis, Fleer, and Kerr (1978) who found that short pieces of music are remembered best when they were labelled with concrete representational titles as opposed to abstract conceptual ones. They argue that concrete titles help the listener construct a kind of story to which the music is associated and so is better recalled.

Manipulation

Traditional musical composition normally involves playing an instrument while recording the musical information, either by writing it down, or recording it on tape. In *COMPOSE*, the importance of being able to manipulate the order and combination of the phrases was seen in many of the observations as an advantage over live composition. In composition it is necessary to hold on to musical phrases long enough to repeat them and modify them, but this places too great a cognitive load on many students.

The ability to keep track of the composing process and to make changes easily has clear parallels with other creative activities with computers such as graphics art and word processing. The advantages in each of these cases of being able to manipulate the data with additions, deletions and repetitions all seem to stem from the reduced cognitive load. Phillips (1986) has used the term 'progressive graphics' to describe this use of computer graphics which changes closely in step with the user's thinking.

Low and High Level Cognitive Processes

By working with COMPOSE, a number of cognitive loads are taken away from the student, including some demands involved in memorising, manipulating and naming. But these are all quite 'low level' cognitive processes. How much can they really explain the improved 'high level' cognitive process of composition?

For someone trying to master a high level skill, obstacles often lie in a low level skill that have not yet been mastered. Given the efficacy of COMPOSE over such a wide range of musical ability, this process is likely to happen in different ways with different people. There is a little evidence that students sometimes adjust the way they use COMPOSE to give them the low level cognitive support they need. This comes from observation of how students choose the next phrase to put into a growing composition. They have a choice of:

- 1. either listening to a single phrase at the top of the screen, or
- 2. dragging the icon into the composition and listening to the whole, with the possibility that it may have to be dragged back if it is

Option (1) is certainly simpler in manipulating the software because it requires only one action with the mouse or a few simple key presses. But it does place a much bigger demand on memory because the student must try to recall enough of the composition to decide whether the new musical phrase is appropriate. With option (2) the student hears everything and so this memory demand is removed. There is a tendency for students to move from (2) to (1) as their musical experience increases. The youngest student (Observation A) used option (2), despite the manipulation difficulties, perhaps because he needed to hear the new musical phrase in context. However, the special needs student (Observation N) who had to control the program with special switches, used option (1), despite his little musical experience, probably because the control of the program was more arduous with option (2).

Scaffolding or cognitive load?

It has been argued that the removal of cognitive loads could be indirectly responsible for the quality of students' compositions. An alternative explanation is in terms of scaffolding. Although the program offers no explicit help or guidance to students, could other forms of scaffolding be operating?

The value of picture phrases in COMPOSE could be seen as scaffolding. It is extra information provided to guide students in the early stages of a difficult problem solving activity. At a later stage the support can be removed by asking students to produce their own picture phrases, or to work without them altogether. Although this meets the definition of 'scaffolding', the explanation is not entirely satisfactory. The same scaffolding information could be provided when composing without a computer. A teacher might provide a set of phrases to use in a composition, perhaps by playing them to the students and by writing them down, either as icons or on a stave. But it is hard to imagine that the results would be comparable to *COMPOSE*.

The provision of picture phrases does not offer students any strategic guidance with the activity. It also does not account for the sophistication of some of the compositions produced (e.g. in terms of structure, endings etc.).

An explanation based on cognitive loads is simpler and more convincing. The removal of cognitive loads does nothing positive to help students, but simply gives them more space to think by transferring low level cognitive burdens to the software. This modest change produces spectacular results in terms of music compositions that are attractive and sophisticated in their musical structure.

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