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Experience Design and Interactive Software in Music Education Research

By

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Abstract

This paper examines the integration of computing technologies into music education research in a way informed by constructivism. In particular, this paper focuses on an approach established by Jeanne Bamberger, which the author also employs, that integrates software design, pedagogical exploration, and the building of music education theory. In this tradition, researchers design software and associated activities to facilitate the interactive manipulation of musical structures and ideas. In short, this approach focuses on designing experiences and tools that support musical thinking and doing. In comparing the work of Jean Bamberger with that of the author, this paper highlights and discusses issues of significance and identifies lessons for future research.

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Music educators and researchers have used specially designed technology resources and developments in music education practices as long as technology has been available. In the context of Western formalized educational practices, the integration of technology in music education achieved particular attention in the 20th century; examples include the tuned percussion instruments used in Orff Schulwerk practices and the bells and other sensorial materials used in Montessori practices. The connections between the use of available technology and the use of computer software resources are made explicit in Jeanne Bamberger's research. For example, her explorations of "hot-cross buns" tune-building tasks with Montessori bells (Bamberger, 1991) parallel similar explorations using the *Logo* software (Bamberger, 1979).

The explosion in recent decades of software systems for music education is obvious. With the advent of ever more powerful mobile computing devices, such as Apple's iPad, for which over 5000 music applications had been developed at the time of writing, this trend in technological growth seems ever more likely to accelerate. However, cases where software usage is accompanied by the type of careful integration of music education research that Bamberger practiced are much more rare. It is this co-design of tool and activity in the service of enhancing music learning experiences that extends the intellectual spirit of Orff and Montessori that Bamberger took up and that motivates my own research in the network jamming project outlined below.

Constructivism

Like Bamberger, I have conducted my work in the spirit of constructivism, a theory of knowledge that emphasizes the generation of understanding and meaning through experience and thinking about those experiences. Bamberger's constructivist leanings are evident in her models of learning where "internal mental structures develop in the course of an individual's accumulating music experience, both formal instruction and also cumulative informal learning" (Bamberger & Brody, 1984, p. 34).

Constructivism is strongly based on the developmental psychological theories developed by Jean Piaget during the mid-1900s. According to this theory, people internalize and construct new knowledge through experiences in the world, and through these experiences they develop and transform their understanding and ideas. Given that Piaget's work focused on how knowledge developed, he often conducted his experiments with children and his experiments have long been of interest to educators. Constructivist teaching approaches emphasize practical activity over passive consumption of information in the belief that people are not simply vessels into which knowledge is injected, but that knowledge needs to be internalized as mental representations, which are transformed by each person's trial and error interactions with the external world. Jeanne Bamberger was fortunate to be involved with the Massachusetts Institute of Technology Artificial Intelligence (MIT AI) laboratory from the 1960s to 1980s, which served as the center of applying constructivist ideas to computing in America. My own teacher training took place in the 1980s in Australia where constructivist ideas were considered to be at the leading edge of educational thinking and they have since had a significant influence on my own educational research.

The development of software-based music education practices has broad intellectual and practical roots, even within the general constructivist frame. In order to elucidate these contexts, I will trace constructivist influences on both Bamberger and myself, showing how they are complementary but differentiated instances that converge into similar practices. I will also consider a range of influences on the introduction of computing in school education and its impact on experience design as a musical educational practice.

Bamberger's Context

Bamberger established a strong connection between her ideas and the ideas of Piaget while she worked at the Massachusetts Institute of Technology (MIT) where Seymour Papert, a student of Piaget, was the Director of the MIT AI laboratory. This was during the influential years from the late 1960s and through the 1970s. Papert was a mathematician who applied constructivist ideas to math education and was particularly well known for encouraging children to engage with computational ideas through computer programming in the *Logo* language that he and colleagues had developed. Bamberger and others took these ideas and applied them directly to music making. Papert laid out his approach in the landmark publication *Mindstorms: Children, Computers and Powerful Ideas*, in which the connection with Piaget is make explicit:

> This book is an exercise in an applied genetic epistemology expanded beyond Piaget's cognitive emphasis to include a concern with the affective. It develops a new perspective for education research focused on creating the conditions under which intellectual models will take root. (Papert ,1980, p. vii-viii)

The directions Papert developed had a strong influence on Bamberger and others at the time and continue to resonate with researchers today, displayed clearly through the continued work of the Lifelong Kindergarten Group at the MIT Media Lab (Rosenbaum & Silver, 2010). These directions included an emphasis on embodied understanding, on experiential pedagogy, and on the use of the computer as a simulation tool that provides leverage for media interactions.

An influential colleague of Papert's at the MIT AI Lab was Marvin Minsky, who developed the theory that the mind worked as a "society" of interacting "agents," each focused on a different goal or working from a different perspective (Minsky, 1985). Minsky's theory resonated with one of Bamberger's persistent ideas: people's musical understanding is constructed from multiple hearings, particularly if these exposures are primed to reveal different perspectives on music. Conversely, this also applies to performance where the interpretive “challenge to the performer is to develop a ‘hearing’ of the work… while still remaining true to the score … [and] subtle means particular to their instrument” (Bamberger, 2000, p. 57).

Minsky’s debt to Piaget and Papert was explicit in *Society of Mind*, and he was skeptical of educational attempts to hasten the progress of developmental stages. Minksy warns that

> educational programs allegedly designed ‘according to Piaget’ often appear to succeed from one moment to the next, but the structures that result are so fragile and specialized that children can apply them only to contexts almost exactly like those in which they learned. (Minsky, 1985, p. 106)

His theory of mind reflected related constructivist leanings when he outlined how new agents and connections among them accumulated and developed through learning resulting from reflection about the consequences of actions and reactions. Through this process, he suggested “we accumulate more low-level agents and additional intermediate layers to manage them, this grows into [a] multilevel hierarchy” (Minsky, 1985, p. 107).

Other important areas of influence at MIT in the 1970s and 1980s included Robert Schön’s theories about the reflective practitioner (Schön, 1987). Schön was a colleague of Bamberger and they publishing together about reflective practices in music education (Bamberger & Schön, 1983). Also based at MIT was Ray Jackendoff, who developed the Generative Theory of Tonal Music (GTTM) with Fred Lerdahl that gained influence from the generative linguistics of yet another prominent MIT academic, Noam Chomsky (Lerdahl & Jackendoff, 1983). Bamberger was specific about the influence of the GTTM theory on her ideas, especially its emphasis on rules of musical grouping and transformation.

> Like Lerdahl and Jackendoff, we argue that grouping structures are not found in the stimulus alone, but rather are made; but we wish to examine, as well, the specific processes wherein the

> musical stimulus, notation systems used to describe it, and an individuals particular repertory of internalized mental strategies interact. (Bamberger & Brody, 1984, pp. 48-49)

While these influences may appear primary and immediate in Bamberger's context at MIT, additional American intellectual influences were at work from further afield and further back in time. Notable amongst these was Nelson Goodman's (1976) musical semiotics research that focused on relationships between representational and structural affordances and the opportunities they present for development of musical understanding and meaning. In symbolism and visual representation, Bamberger found a window into the developing musical mind and was dynamically engaged with "the power of descriptions to both *reveal* and *conceal*" (Bamberger, 1991, p. 269). Bamberger's continued interest in musical representations reflected this influence. Also apparent were influences of Mihalyi Csikszentmihalyi's (1992) theory of "Flow," or optimal experience, that originated from visual art education, and of Andy diSessa (2000) who, like Papert, pursued computing in education and its cognitive effects with his *Boxer* environment.

These influences in Bamberger's life, which continue to influence contemporary researchers, were situated in the historical context of American pragmatism, particularly the pervasive influence of John Dewey's ideas on education and psychology. In essence, this approach privileges experience and intuition, a notion well established even in Bamberger's writings:

> the primary emphasis in our classes should be on experience itself rather than on facts about music, terminology, or techniques… The learning process must be an active one, one in which you are always personally involved, questioning, and critical. (Bamberger & Brofsky, 1975, p. xix).

As a music educator, Bamberger was deeply interested in the psychological aspects of musical knowledge, as displayed in her book, co-authored by Howard Brofsky, *The Art of Listening: Developing Musical Perception* (Bamberger & Brofsky, 1975). In it, her trademark interlocked processes of analytic listening and compositional experimentation were already apparent. Her approach to learning about music involved paying attention to the elements of music such as texture, rhythm, melody, harmony, and structure as well as applying the insights gained in compositional experiments that explored these elements and their treatment. Consistent with the constructivist approach, Bamberger emphasized starting with the affect or intuition about music and then investigating how that musical perception came about. In her later work, Bamberger added computer-based activities to this general approach (Bamberger, 2000). While experiential music education advocates have championed this approach of co-designing experiences and contexts, Bamberger's work always seemed to have an empirical or scientific edge to both its conceptual and pedagogical design, perhaps reinforced by the academic context provided by her work at MIT.

Brown's Context

Even as a piano major in a music education undergraduate degree in the early 1980s, I was fascinated with synthesizers, recording studios, and computers. I spent hours playing with programming for the Apple II computer, and for my final year concert, I performed original works for piano and live computer using software I developed on the Yamaha CX5M computer. An interest in making music with technology was evident early on.

My computer-based compositional work in education included the co-development of the *jMusic* library that supports music composition in the language Java (Sorensen & Brown, 2000). The book *Making Music with Java* (Brown, 2005) includes tutorials about algorithmic music techniques with examples using *jMusic* and is associated with the *jMusic* library. More recently, I have developed the *SoundCipher* (Brown, 2009) music library for the *Processing* environment that is widely used in courses teaching computational arts. In recent years, I have been actively involved in music psychology research, including algorithmic control of the affective qualities of music and modeling music intelligence with computational models of perceived melodic organization (Brown, Gifford, Narmour, & Davidson, 2009). Like Bamberger, my interests included an intersection of music, technology, and psychology. Of course, some important intellectual figures resonated with and shaped these interests.

Keith Swanwick's writings on music education had a strong influence on my constructivist educational tendencies. Like other constructivists, Swanwick was intensely interested in the experiential aspects of music, how these developed, and the role that action and exploration played in that development. Swanwick (1994) articulated what he saw as unique about artistic thinking:

> The essential difference between thinking in the arts and in other symbolic forms is that consciousness of the process of creating meaning is deliberately extended, explored and celebrated; this intensifies experience, draws things together, giving us not the confusion of mere experience, but what Dewey call 'an experience.' (pp. 36-37)

While acknowledging that such experience is largely intuitive and sensorial, Swanwick was also concerned, as an educator, with reflection as a method for development. He suggested that "Conceptual thought and dynamic theorising...can illuminate experiences without destroying them" (Swanwick, 1994, p. 85). Like, Bamberger, he also saw the value in examining children's expressions as a "useful way to get into their musical worlds" (Swanwick, 1994, p. 85) and understanding their musical development.

Another lesson I learned from Swanwick was his focus on holism and authenticity in educational experience. This was reflected in his work in a number of ways, including his willingness to be stylistically inclusive, which was reflected in his early writings on popular music in education as early as the 1970s. This focus on holism and authenticity was also apparent in his subsequent emphasis on multicultural musics and connections with the musical cultures more generally relevant to students' lives. Reflecting this, he wrote "Genuine musical experience has within it something of metaphorical richness. Without this quality of experience music education is impoverished" (Swanwick, 1999, p. 99). A further reflection of his holistic view of musical experience is Swanwick's development of the CLASP rubric, an acronym which stands for composition, literature, audition, skills, and performance, as a guide to assist breadth and balance in curriculum development (Swanwick, 1979).

As is the case for many educationalists of the last century, the ideas of John Dewey were significant in shaping my views on learning and the role of education. Dewey's broad concerns for how ideas are contextual and that the value of ideas resides in their utility when enacted in the real world fit well with my experiences of arts culture that valued making and meaning. The fact that he directly addressed the arts and education in his writings made the significance of his ideas all the more straightforward (Dewey, 1934). Of particular interest for me was Dewey's reluctance to see the arts as separate from sciences or technologies and to rise above such distinctions to see the importance of an engagement with productive inquiry. That lack of distinction would allow computer programming and piano playing to serve as techniques for aesthetic exploration.

For me, reading Dewey provided inspiration about the transformative power of education and the role of experience design in shaping educational reform. In his book *Experience and Education*, Dewey stated directly that he was very "confident of the possibilities of education when it is treated as intelligently directed development of the possibilities inherent in ordinary experience" (Dewey, 1938, p. 89). This belief in the value of education and inquiry into learning provided a firm basis for many educational experiments, including those in areas such as computation and music.

Dewey is a well-known pragmatist who advocated for experientialism and instrumentalism; that is, for testing ideas or knowledge against lived experience and testing the practical utility of ideas in applied contexts as a method of assessing their "assertability" or value. Dewey claimed, "Knowledge is instrumental to the enrichment of immediate experience through the control over action that it exercises" (Dewey, 1938, p. 294). This justification of a very practical method of research lends itself well to the kind of classroom-based methods employed by many music educators, including Bamberger and me.

Finally, another source that informs my use of technology in music education is the philosophical writing of Martin Heidegger. His deep phenomenological interrogation of the human condition privileged experience over contemplation, valued aesthetic insights, and advocated a poetic disposition as a superior way of being and knowing. These aspects of his work added richness, and perhaps complication, to constructivist notions of experiential knowledge development. This complexity arose because Heidegger—and to some extent Dewey—was concerned with knowledge construction and development in a historical and cultural time frame, not simply with the construction of knowledge of an individual agent. These concerns also foreshadowed more recent work on embodied, situated, enactive, and extended knowing, advocated by the likes of Clancey (1997), Clarke (1997, 2008) and Noë (2004). One might consider the work of these researchers to be the next steps in pragmatism and constructivism.

Heidegger (1977) also wrote about relationships with technologies with a broad understanding of technologies as both challenging and revealing. He viewed technologies as artifacts of human construction that range from tools such as hammers, to symbol systems such as language, to artistic products such as painting and poetry. Heidegger suggested different degrees of attitudinal proximity that people can adopt toward technologies. He suggested that the different degrees of these relationships implicate the use of technologies. In particular, he mentioned two dispositions: present-at-hand, where the user is conscious of the tool and the ways of exploiting it, and ready-to-hand, where the tool becomes part of the user in the way Donald Norman (1998) would call invisible, just as performers hope their musical instruments become when playing. Heidegger's comments on both the functionality and dangers of these approaches to technology have informed my design and use of computer systems in music education.

Not all of the influences on my work were as academic as those discussed above. I was involved with introducing computing into school music programs in Australia in the 1980s and that direct engagement had a significant influence on my work. At the time, I was involved with the leading edge of music technology innovation. This technology included synthesizer labs where educators taught sound design, improvisation, and keyboard skills. This technology also included MIDI-based computer systems such as the *Notator* software of the *Atari*, the early version of *Max* on the first Apple Macintosh computers, and various MIDI controllers modeled on acoustic instruments, including versions that used wind, percussion, brass, string, guitar, and keyboard interfaces. These experiences clarified the motivational aspects of electronic technologies, even though they were largely used to replicate, rather than innovate, musical practices.

In the late 1980s, I became involved in the *Sunrise* project conducted by the Australian Council for Educational Research. This project explored "how computers might best be utilized in the classroom, and how their influence can be identified in various social and cognitive contexts" (Rowe, 1993, p. v). This project included introducing laptop computers to all students in year 6 and 7 and working with teachers to integrate these into the curriculum. Researchers associated with this project introduced some related work from the USA to me as well as a number of the same kinds of sources influencing Bamberger at the time. While Papert's work on *Logo* was prominent, Andy diSessa was directly involved with the *Sunrise* project and his work on the *Boxer* environment was important. These ideas are most comprehensively expressed in his book *Changing Minds* (diSessa, 2000) and less directly expressed in Alan Kay's work on *Smalltalk* (*Squeak*) and the *Vivarium* simulation project (Yaeger, n.d.). While I have been a part of many projects since, these were formative years, and many of the issues and methods developed at this time are still the basis of my research using interactive software in music education.

These discussions of the contextual influences on both Bamberger and me make it clear that constructivist or experiential learning approaches emerged quite broadly in Western music education research in the 1970s and 1980s. In music education, practice-based pedagogy was well developed through movements such as Kodály, Orff-Schulwerk, and concert band programs. Research at MIT advanced the application of computing simulation to education. The Boston area, where Bamberger worked, became a focus for developing theory and practice to support this approach. However, as my own story indicates, a constructivist orientation in the use of computing technologies that support music education arose in areas around the world. British influences such as Paytner and Swanwick were prominent in Australian music education in the latter part of the 20th century, but an awareness of Dewey, Papert, and others in the USA was not uncommon.

These two personal histories display that the research context for interactive music software has shifted over recent decades, especially regarding the use of computing technology in music production and communication networks. Computing resources have become much more powerful, affordable, and mobile. The internet has enabled collaboration during performance and for sharing and discussing recorded outputs. There has been an emergence of electronic music styles with a corresponding acknowledgement of the computer as an instrument, not only a music production tool.

Music distribution is now dominated by internet downloads, both paid and pirated, and the internet is also a significant location for accessing information and sharing material. It is unlikely that any music education researcher can ignore its' influence. In addition, the cultural context has also evolved, especially around the role of music in youth culture and the music consumption habits of people through the availability of digital distribution channels.

This all amounts to a changed research context such that “adolescents constantly listen to music produced through the use of technology and they form impressions of how it may be created, so there is no such thing as a musically naive adolescent” (Seddon & O’Neill, 2003, p. 134).

Music education research in the early part of the 21st century operates in a different context to that in which Bamberger did much of her work in the latter parts of the 20th century. Although school music instruction might look surprisingly similar in many classrooms, the technical and cultural context has shifted significantly. The musical styles now covered in music programs have diversified in many cases, and the students’ familiarity with electronic and computer-based musical styles is vastly different. As a result, use of the computer in the music classroom is common, especially to assist compositional, arranging, and sound recording tasks.

Despite varied pathways, it seems the connection between Bamberger’s research and my own includes a commitment to experiential pedagogy and a belief in the capacity of computing systems to offer new educational encounters. Constructivist and pragmatic ontologies certainly enhance these insights, but examining our backgrounds makes clear that there are many directions from which one can approach the use of interactive software in music education. Hopefully the telling of these stories has highlighted many of the significant findings that follow, beginning with a discussion of the use of software that Bamberger and I have developed independently.

Computational Microworlds

The history of computers in education has shown that while the opportunities to connect these two worlds are promising, the possible ways of connection are many and varied. For those with a constructivist orientation, the idea that computers can provide simulations and virtual worlds is powerful because of the capacity to design spaces for interaction customized to particular musical or non-musical tasks. These spaces often have limited options in order to focus attention on selected issues, or spaces may provide access to enhanced experiences otherwise difficult to obtain. Examples of these customized virtual spaces include music composition software that supports the beginner by limiting choices to particular pitch, rhythm, or timbral options and selected transformations of these elements. Later sections of this paper will examine further examples of software systems designed for music education. Software simulations of this sort continue a tradition of designing accessible music learning tools such as tone blocks and the Autoharp.

Seymour Papert articulated the value of computational simulations in education with his concept of a "microworld," a constrained computational universe that children could control and explore through programming (Papert, 1980). The *Logo* language was designed for children to use when exploring microworlds, and Papert's leading example of a turtle graphics library became very popular for teaching concepts of geometry by instructing a robotic or virtual "turtle" to draw shapes. In his book *Mindstorms*, Papert (1980) outlined the constructivist and experiential underpinnings of the use of microworlds in education. Building on the metaphor of how infants learn to speak, he proposed that immersion in a "world" was an effective approach to understanding the rules of that domain. In the case of computational microworlds, it was better to have children program machines than be programmed by them.

Bamberger and others at the MIT AI and Media labs were significantly involved in these and associated efforts. Educational research colleagues close to MIT, especially David Perkins and Howard Gardner at Harvard University, supported these ideas. Perkins worked on the concept of distributed intelligence, primarily around social learning, and extended this to child-computer partnerships. Perkins (2009) also clearly articulated the effectiveness of microworlds through his notion of "junior" versions of activities as effective learning contexts. Somewhat less directly, Gardner's (1983) theory of multiple intelligences added reinforcement to the significance of cognitive psychology in educational research. For Bamberger and other music educators, Gardner's work provided a legitimizing framework for music as a distinct ability and guidance for ways of developing musical intelligence.

Around the same time as Papert's work with microworlds, Bamberger and a number of graduate students were working on the development and trailing of the *Music Logo* program, an extended version of standard *Logo*. Educational activities associated with this work included musical interactions with both the computer and various classroom instruments as well as the drawing aspects of *Logo*, which aligned with Bamberger's interest in students' visual representations of music. The Terrapin company released a commercial version of *Music Logo* in 1986. Another version, *Logo Music Writer*, dates from around 1990. Research into musical microworlds became more widespread in the 1980s, including research using *Music Logo* itself by Gregory Gargarian (1993) and the development of alternative *Logo Music* implementations including *LOCO* (Desain & Honing, 1988) and *Object LOGO* (Greenberg, 1988).

Bamberger's work in building musical microworlds led to software applications that were musical worlds in themselves and required interaction, but not programming. Even more impressive was the fact that these software environments were creative tools in an era when educational computing was dominated by drill-and-practice software, which aimed to support rote learning of musical facts. Many of the applications Bamberger developed are now collected together on the internet (Tuneblocks, 2004).

The *Time Machine* application was one of Bamberger's early applications. Students interacted with *Time Machine* via a drum controller connected to a computer. The program captured a performer's rhythmic performance and the onset times displayed visually as marks on a time line. Users could play against a pre-sequenced rhythm or against other performed rhythms.

Another application, *Tune Blocks*, was based on the well-established principle that music involves motivic compositional organization. The graphical interface shows square blocks representing segments of a simple musical phrase. The user's task was to restructure the music by arranging blocks. Bamberger designed the application to encourage active manipulation and context dependent listening.

The *Impromptu* software (Bamberger & Hernandez, 1999) amalgamated and extended the *Tune Blocks* and *Time Machine* concepts. Contemporary versions of *Impromptu* are written in the language Java, rather than the *Logo* language used for earlier software. In line with broader computer education, Bamberger's work shifted from programming focused activities, such as *Music Logo*, to applications that provided scaffolded environments, such as *Tune Blocks*, which did not require programming. This trend has continued, despite the fact that music programming tools are significantly more developed now than in the past. My own research in software for music education reflects this trend, which is somewhat ironic since my personal music practice is live coding performance.

***Jam2jam* Software**

Over the past decade, I have been involved in developing software for exploring how software instruments can facilitate young people's engagement with music. This work prominently includes the development of the *jam2jam* systems that was conducted with several colleagues. The music educational framing involved Dr. Steve Dillon and the software design involved Andrew Sorensen and Thorin Kerr. The research around *jam2jam* explores how software systems can increase participation in authentic music making experiences. A team of researchers works with *jam2jam* in their local contexts around the world and their insights, as well as those of the students in their trials, have been very important to understanding the issues present in the research behind *jam2jam*.

While there are several versions of *jam2jam*, their differences are not significant for the purposes of this paper, so I will discuss them as a single entity. The *jam2jam* software is a microworld for musical improvisation through the control of a generative music algorithm. We designed the *jam2jam* software to support collaborative music performance by inexperienced users, which resulted in the use of two technical features. In the program, the performer controls an algorithmic music engine that generates the output, rather than being responsible for note-by-note details. Real-time network communication between computers allows them to connect as a coordinated ensemble, which we call “Network Jamming.” There are parametric controls for well-established musical dimensions such as tempo, pitch range, dynamics, timbre change, textural density, and note duration. Users can network computers locally or remotely, which provides a wide variety of ensemble configurations. Other instrumentalists or vocalists can also be part of the ensemble.

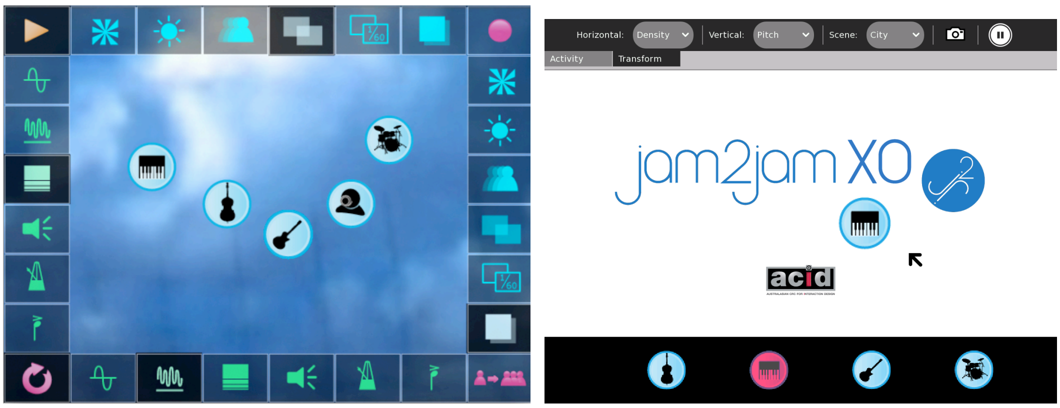

Figure 1. jam2jam-av and *jam2jam*-xo interfaces.

The software interfaces of the *jam2jam*-av and *jam2jam*-xo versions shown in figure 1 allow users to control parameters of the generative music engine during performance. The *jam2jam*-av version also allows for display and parametric change of image and video elements. There are visual icons representing each instrument on the screen, and their location on the X-Y plane adjusts any two at one time. Buttons around the edge of the screen allow users to select parameters on each axis. When *jam2jam*-av systems are networked together, the software broadcasts movements by any performer to all others performers who may be co-located on the same local network or remotely located via an internet connection. Networked in this way, anything one performer does effects everyone else, which underscores the need for cooperation. With *jam2jam*-xo, the collaboration model also synchronizes networked computers, but requires users to select one “instrument” to control. The sound of the selected instrument is heard on the user’s laptop, with the practical implication that users need to be co-located.

Jam2jam supports the recording of performances, and users can reflect on these recordings, share them with others, or even post them to a school web site or to public internet sites such as YouTube. In addition, the program captures performers’ control gestures in a log file on the computer. This data of performer actions for all performers in the “band” can be displayed using the *jam2jam* visualize software that graphs gestures over time and synchronizes them with the video recording of the performance for even more in-depth review and analysis.

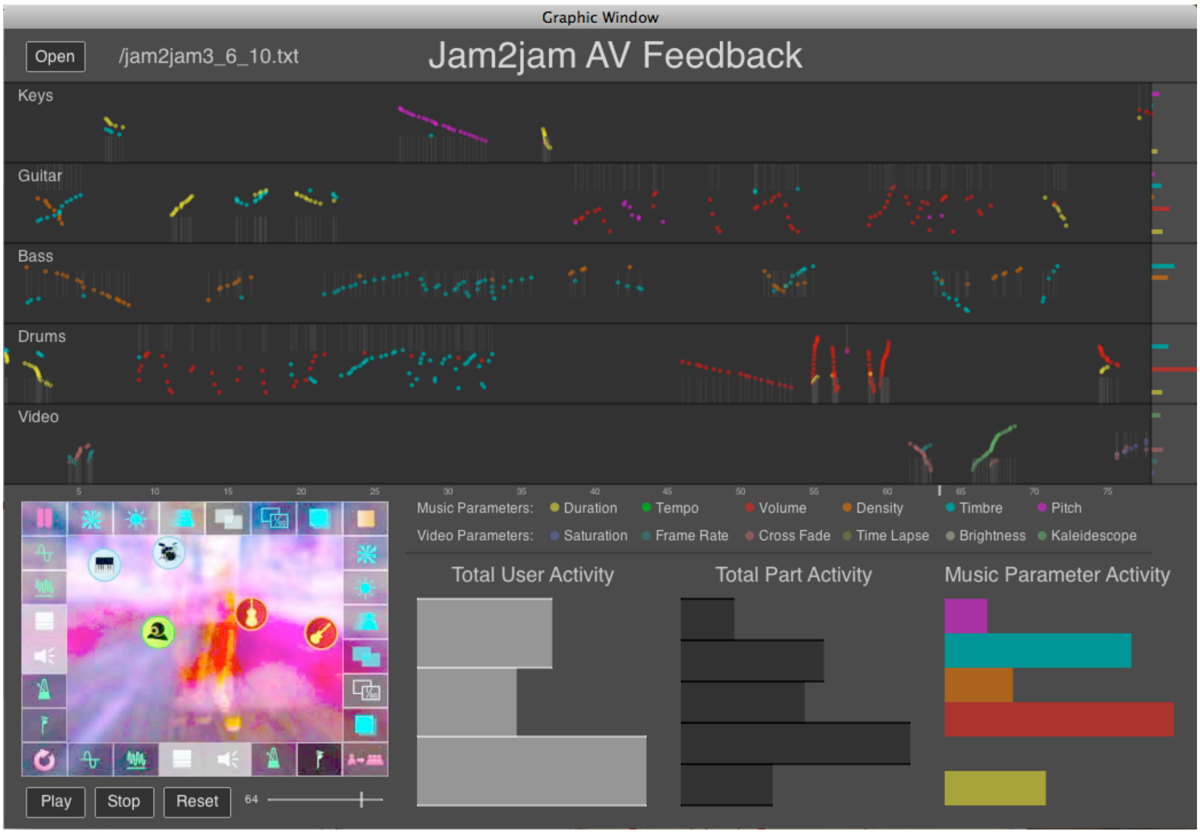

Figure 2. Jam2jam visualize interface.

Jam2jam provides several musical "scenes" or styles of music to jam with, mostly based on electronic music genres that were appropriate given the cultural and technical context of use. However, new materials can be composed for a *jam2jam* scene, facilitating a wide choice of repertoire and enabling students to compose their own material to jam with.

While users can vary the musical parameters by dragging an on-screen icon with a pointing device, there is also provision to connect external hardware controllers via MIDI or OSC protocols. This enables greater gestural flexibility and dexterity as well as allowing one computer to support multiple performers, each with their own controller such as a MIDI control surface or a tablet computer with appropriate interface software.

As mentioned previously, some versions of *jam2jam* support video and image manipulation as an addition to musical control. The audiovisual nature of the software is an important aspect of the cultural currency of *jam2jam* by reflecting the DJ/VJ overtones that the software carries and allows students to explore the integration of sound and image common to digital media. The developers found that the use of visual images expanded the types of educational uses of *jam2jam* significantly, especially beyond music education to other areas of the curriculum. However, a full discussion of these outside connections is beyond the scope of this article and serves as the topic for several other articles by *jam2jam* researchers (Dillon, 2006; Adkins, Dillon, Brown, Hirche, & Gibbons, 2007).

Bamberger's applications and *jam2jam* all serve as examples of the possibilities of interactive software in music education. Further studies in music learning through software design contexts include research by Holland (1989), Upitis (1990), Hickey (1997), Seddon and O'Neill (2003), Folkestad, Hargreaves, and Lindström (1998), and Rosenbaum and Silver (2010). Other sources include extensive work at MIT by Todd Machover and his students, notably Mary Farbood, who produced the *HyperScore* software (Farbood, Pasztor, & Jennings, 2004). The development of the software aspects of the musical microworld is only part of the educational story as Papert understood. Effective experience design also entails concurrent development of tasks and activity management. Therefore, the next section focuses on examples of the applications of interactive music software with children.

Case Studies

The use of case studies as a method for interrogating student understanding has long been popular. Bamberger was a strong believer that research insights arose in the course of everyday work with students. Therefore, she had a deep commitment to case studies and the ability of a rich description of detailed engagements with students to reveal insights into the development of musical understanding. This is perhaps most evident in her book *The Mind Behind the Musical Ear*, in which interactions with music learners are recounted and analyzed in some detail (Bamberger, 1991). Bamberger's colleagues, including Papert, shared this approach of grounding research in lived experience. Papert called upon ethnographic accounts of his own and other's experiences in *Mindstorms* (Papert, 1980) and *The*

Children's Machines (Papert, 1993) to show how his theories derive from lived experiences and to provide texture to his descriptions of learning processes and technologically scaffolded contexts.

Through descriptive evidence from case study observations, researchers can gain insights into how real experience match the experience design. In order to provide background for a dialogue between Bamberger and my research in this area, I will provide some brief case study descriptions of research done with *jam2jam*.

Case Study 1

The first case study involves research conducted by Pam Burnard, Alex Baxter, and Teresa Dillon (2010) at Cambridge University in the UK. The focus of their research was on the merits of collaborative learning amongst groups of peers engaged in joint activity. In this case, the joint activity was collaborative jamming with *jam2jam*. The researchers were interested in 1) the types of understandings that were stimulated by the jamming, 2) the capacity for students to rapidly acquire the skills to use *jam2jam*, and 3) the linguistic and aesthetic communication between participants during computer-mediated improvisation.

A day-long workshop was held with a small group of 13-year-old boys with varying degrees of formal music training. Students were in a classroom and each had a computer running *jam2jam*, connected over a local area network. The workshop included a number of stages designed to move students through a series of increasingly demanding scenarios. The stages were as follows:

1. Informal exploration of the software in pairs.
2. Pairs were tasked with doing duet jams.
3. Quartets were formed, jamming in different group combinations.
4. Live video input was introduced and groups practiced audiovisual jamming.
5. Groups rehearsed and performed a work with some "predetermined structure."

6. A group discussion was held about what was learned, enjoyed, or could be improved.

Researchers observed all stages and encouraged participants to talk aloud about what they were doing and thinking. At the end of the workshop, researchers conducted semi-formal interviews with the participants.

The researchers reported that "that the boys had a highly successful and enjoyable day, the software proved popular" (Burnard, Baxter, & Dillon, 2010, p. 3). Students found the software quite intuitive to use, but some suggested that more instruction, rather than open play at the start of the workshop, might have been more efficient. Observers reported clear evidence of symmetrical collaborative learning where participants helped each other, and knowledge about features and techniques were informally passed around the group. Comments made by participants about their own and other's performances revealed that during the day, there were shifts in "who were the experts" and that roles of explaining and learning were in constant flux. Some computers were connected to electronic whiteboards from which *jam2jam* could be controlled. It was clear that this physical interaction increased engagement and enjoyment significantly, as did the use of the subjects' own images in the live video streams. The absence of language in the interface, which was a deliberate design choice, seemed to encourage individual articulation of the musical effect of each parameter, and researchers report that the "new language was clearly gained through the ability to explore kinesthetically" (Burnard, Baxter, & Dillon, 2010, p. 4).

One aspect that researchers attributed to the success of students' music making with *jam2jam* in such a short engagement was its use of highly constrained, loop-based material and transformational algorithms. Researchers noted that this allowed "for the development of confidence and arguably promotes 'flow'" (Burnard, Baxter, & Dillon, 2010, p. 5). Researchers attributed the multi-dimensional interface of *jam2jam* and its individual yet collaborative control of musical elements in real-time with helping students realize "that there is a far greater depth and dimension to a musical experience" than they initially expected (Burnard, Baxter, & Dillon, 2010, p. 5).

Case Study 2

The second case study involves research conducted by Kathy Hirche, Barbara Adkins, and Craig Gibbons during "PowerKidz" *jam2jam* workshops held as part of a school holiday arts program at the Brisbane Powerhouse for Live Arts in Australia (Adkins et al., 2007). The physical context was a large, well-lit workshop space that included a set of laptop computers laid out on tables and linked via a local area network. There were headphones attached to each computer for personal rehearsal and computers were connected to a PA system for public performances and demonstrations. Each workshop was one hour long and involved a facilitated session that included 1) instruction in the use of *jam2jam*, 2) duet jamming, 3) small group rehearsals, and 4) performances to an audience of other workshop attendees and participants families who were free to be involved in the activity as they wished. Participants were between 6 and 12 years of age and randomly mixed in terms of gender and prior musical training.

The research was focused on evaluating different pedagogical approaches to creative interactions with generative computer systems and how qualities of interface design and ancillary support materials might affect participant engagement with music and with other participants. Researchers concluded that the experiences of using *jam2jam* were consistent with developing requirements associated with what Bourdieu called "the aesthetic disposition" (Bourdieu, 1984).

There were three workshop sessions each day over several days. A randomly selected participant in each session was video recorded using two cameras: one positioned over their shoulder that captured the computer screen and their actions as well as a second camera that captured their facial expressions with a wider field of view. An audio feed mixed sound from the selected participants' computer with a room microphone that captured discussions and spatial ambiance. Videos were taken both with and without researcher intervention in the participants' activities. During interviews, researchers found it useful at times to simply ask participants to demonstrate something, rather than rely on linguistic descriptions, knowing that the demonstration would be captured on video for later investigation. Researchers used these recordings to create a detailed transcription of participants' actions and comments. Researchers also made field notes and took still photographs of the session. These data were analyzed by coding against linguistic and behavioral patterns and with particular attention to the categories of experience in the meaningful engagement matrix (Dillon, 2009).

Analysis of the data showed that these young performers found *jam2jam* easy to use, but the effect of the parameter changes were not always clear to them. Researchers concluded that the reason for this was two-fold. First, some of the algorithmic variations were quite subtle, which was altered in subsequent versions. Second, session management that allowed participants to spend more time exploring each element separately might have aided participants in learning what kind of musical changes to listen for. Overall, researchers reported that *jam2jam*'s "generative processes can provide a basis for inexperienced users to access creative activities" and, more broadly, they suggested "generative arts tools… have the potential to enhance peoples' capacity for cultural participation" (Adkins et al., 2007, p. 1).

The researchers concluded that while structured and intense jamming workshops like those at PowerKidz are fun and engaging, they are too facilitator-reliant to be a sustainable pedagogical model in schools or in ongoing community arts settings. The researchers recommended that a web-based resource be created to augment and support the network jamming improvisations and such a site would enable users to access tutorials, share recorded performances, and communicate socially in addition to other benefits. As a result of this work, the Network Jamming project subsequently established a support site for *jam2jam*, which has since closed. More recently, *jam2jam* users have relied on public sites such as YouTube or privately hosted content management systems to facilitate communications and sharing around their jamming activities.

As these case studies demonstrate, researchers have conducted the network jamming research activities based around the *jam2jam* system in the same spirit as Bamberger's research. They are focused on assisting access to musical understanding and meaning by including interaction with software systems that provide access to rich musical experiences with minimal expectations of prior knowledge. The research approach also involves iterative cycles of theorizing, tool development, applied evaluation in authentic learning contexts, and a holistic approach to the evaluation and reporting of these experiences. A difference between these case studies and Bamberger's reporting, exacerbated by the condensed nature of reporting in this paper, is the greater attention she pays to the detailed activities and developmental progress of a single individual over time.

Discussion

Having outlined our backgrounds and introduced our interactive software designs, I will now consider some of the similarities and differences between my research using *jam2jam* and Bamberger's research using *Impromptu* and related software. They are deeply related in many ways as a result of sharing a constructivist agenda, however, there are also interesting differences. Understanding what these differences are and why they arise can help highlight important issues and trends in the use of interactive software for music education research.

Bamberger's research over many decades involved tune-building tasks. Over time, she developed and refined processes for tune-building and for analysis of the insights tune-building revealed about a student's musical understanding. My work on the network jamming projects has focused on collaborative improvisation and performance with generative music processes. Generative and networking technologies have provided access to musical interactions and helped gain insights into how people engage with music making and how music making becomes meaningful for them.

Both the tune-building and generative control tasks are remixing processes. They both require students to organize partially prepared material over time with the option of a set of transformation processes. The tune-building tasks are more compositional in character, while the generative control tasks are more performative. In keeping with this characterization, the tune-building tasks were often individual, while the generative control tasks were more often collaborative. Each task put different demands on students. Bamberger's research was concerned with the structural thinking required to build tunes from phrase blocks. Her analysis of tune building activities focused largely on rhythmic and tonal organization and how students achieve that organization through various transformations and manipulations. In my examinations of generative control tasks, structural organization was also a primary concern, revealed as the performative control of how the work unfolded over time. research using *jam2jam* dealt with tonal and rhythmic organization more abstractly as modifications to pitch range and rhythmic density. Other performative considerations, including timbral variation, note articulation, and tempo variation, were added to the combination of expressive options under investigation.

Solo or Collaborative Interactions

The tune-building tasks and software systems supporting them provide for individual interactions with musical elements and compositional building blocks, especially common pitch-time relations Bamberger refers to a "simples" (Bamberger, 1991, p. 11). Collaborations and interactions with peers are possible in class and these contextual and Bamberger addressed these social concerns directly in her later work (Bamberger, 2003, p.

10). However, the research mostly explores personal understanding of musical organization. The network jamming tasks and systems provide for individual interactions with music elements in a less detailed way, but also provide specific support for interpersonal interactions via ensemble performance. The differences between Bamberger's focus on individual task and my focus on collaborative tasks exist, to some extent, as reflections of traditional characterizations of composing and performing. The differences also reflect trends in technology and psychology. At the time Bamberger was active in designing her systems, computers were in the very early stages of development and real-time capabilities in sound generation were modest. The network jamming systems, such as *jam2jam*, were created at a time when real-time audio and video manipulation was becoming possible on commodity hardware. Research always interacts with shifting trends in disciplinary theory, and changes in the field of psychology can be influential in researchers approaches. As outlined previously, cognitive psychology and structural linguistics were dominant around the 1970s and 1980s. It seems reasonable to suggest that these trends are reflected in Bamberger's work as an attention to personal knowledge, representation, and musical structure. In the 2000s, when my work on *jam2jam* was forming, cognitive views in psychology were giving way to extended, embodied, and ecological views that took a systematic view of the person and their context. Thus, it is not surprising that interactions with the machine and with other musicians became a focus of my research. However, while the explicitly collaborative and performative nature of *jam2jam* differentiates it from the personal and compositional orientation of *Impromptu*, *Music Logo*, *Tune Blocks*, and other software developed by Bamberger, the methods of inquiry and the experience design show more similarities than differences.

Research Design

The stages of developing research that involves interactive software seem to be well established. First, identify and design an activity that may illuminate the locus of interest. Second, develop the software required to support it. Third, have students use it and evaluate data collected during those trials. Of course, this is a simplification of the iterations, false-starts, and many other details along the way. This process is one I have previously articulated as Software Development as Research (Brown, 2007a).

Choosing and designing an activity is critical to the process, as it must encapsulate the issues behind the research and the desired experiences for the study while enabling computers to have a constructive role. For Bamberger, the central activity seemed to be motivic representation and structure; for me it was improvising with generative systems. Designing the software involves identification of how computation, simulation, communication, representation, automation, and other features of computing can support or enable the activity. An interesting reflection from experience is that software designs are rarely correct the first time, so researchers should plan for iteration. The “tuneblocks” activity persisted through implications in different technologies from bells, to *Music Logo*, to *Impromptu* and the network jamming activity persisted across several version of *jam2jam* with changes in interface, features, audiovisual additions, and development platforms.

In keeping with the pragmatist tradition, the true test of any experience design is how it works in authentic contexts. Trails of interactive software in music education settings typically involve running activities in regular classrooms or workshops. These field trials are not tests of usability as found in interaction design practices, although researchers should undertake these during the software development stage. The field trials are often part of regular educational or community arts processes and researchers undertake them in the spirit of action research as an intervention that anticipates making a positive impact. Data collection methods are typically drawn from anthropology and ethnographic practices and are weighted toward observation and thick description. Like many education research processes, researchers maintain documentation of activities and outcomes. Bamberger's *Impromptu* software allowed users to keep a text log for reflective purposes, but researchers could also use this text log as research data. Interactive computer systems also offer the ability to log activity and researchers can collect and review this activity. The *jam2jam*-av system does this and the *jam2jam* visualize software provides data visualization of users actions during a jam session.

Visual Representations

Visual representations are not only important as research tools, they are also central to interaction with the software systems and can act as cognitive assistants in the development of musical awareness. For Bamberger, the importance of visual representations as a window into the child's musical understanding is evident in her careful analysis of children's drawings of music (Bamberger, 1991) and the use of visual depictions of tuneblocks and their organization in the interfaces of software such as *Impromptu* (Bamberger, 2000, 2003). Her usage of representations as "scores" is in line with one of the often-cited advantages of a computer music system: that they can externalize the music making process and make it available for reflection. Heidegger considered the ability of technologies to reveal understanding as an essential aspect of technology, suggesting, "Technology is therefore no mere means. Technology is a way of revealing" (Heidegger, 1977, p. 318).

While *jam2jam* visualize software also uses graphic representation as a way of revealing, it does so not as a score of the music, but as a depiction of the actions and interactions of users. Further, the *jam2jam* software itself makes no use of a visual score, but rather aligns itself more strongly with the aural traditions of music making, including those of popular music and jazz improvisation. While many of Bamberger's tools and analysis reinforce the pitch-time space familiar to musicians from stave notation (Bamberger, 1991, p. 242), the *jam2jam* interface allows for flexible allocation of musical parameters on either axis. This does not, however, include time; there is no visual trace during the activity. The recording function of *jam2jam* does allow for a record of the music and for reflection and analysis of it. As a result, there is an implied privileging of media output and interaction in *jam2jam*, compared to an implied privileging of structure and process in *Impromptu*.

Commentary on visual representation in this context would not be complete without mention of the code-based description of music used in *Music Logo* and other music programming environments. Such textual descriptions emphasize the procedural nature of musical organization. In these software environments, music, typically construed as organized note events, is represented as a processes articulated using programming language structures such as if-then, for-loops, recursion, iteration, branching, abstraction, and concurrency as organizing principles. Details of this method of representing or describing music as a process are outlined elsewhere (Bamberger, 1979; Sorensen & Brown, 2007). While descriptions of music in programming languages can be quite direct as note-by-note descriptions, their power lies in the ability to abstract musical structures as formalized processes.

Figural and Formal

Representation of music with computer code confronts many issues that Bamberger highlights in analysis of children's drawn notation; there are different ways to represent and understand musical structures. Coding representations highlight this because of the precise or "formal" requirements of program specification. In less formal media, such as pencil and paper, representations can privilege "figural" aspects of musical understanding such as clustering or spatial relativity, even if these distort what is sounded. For Bamberger, the differences between figural and formal understandings are profound. In the conclusion of *The Mind Behind the Music Ear*, Bamberger makes her position quite clear.

> conflicts between figural and formal modes of representing phenomena may be the most general factor underlying the common breakdowns in understanding between teachers and students. But … when they are recognized, also hold the greatest potential for triggering new insight. (Bamberger, 1991, p. 278-279)

The point is significant for the design of interactive software for education because all systems must present some interface to the user that make ontological assumptions about music. Heidegger suggests that technologies "enframe" the world, which provides users with a certain perspective. In Bamberger's words, there can be a "conflict with respect to explicit feature focus" (Bamberger, 1991, p. 29).

The software examples in this paper show different ways of managing this situation in terms of their graphical user interfaces; each provides multiple notational options or none. The *Impromptu* software allows users to depict musical events and their properties in numerous ways including onset spacing, piano roll display, pitch names, numbers, keyboard position, or tune blocks. Mostly these depictions lend themselves to formal description. The *jam2jam* software provides no event-level notation options, but relies on interpretation of audio output for event-level understanding. It provides more figurative representations for parametric control over elements of each part through gestures more akin to conducting than composing.

Multiple Perspectives

Expanding upon the idea that figural and formal representations can highlight what users know intuitively, that there can be different ways of understanding the same music. The multidimensional nature of music as a phenomenon means that a complete knowledge is unlikely, and that the richness of understanding can arise from a richness of experience.

Bamberger emphasized the importance of multiple hearings on building musical understanding, a view that resonates with Minsky's theory of the Society of Mind:

> I conclude that the goal of musical development is to have access to multiple dimensions, and most important, to be able to choose selectively among them, to change focus at will. (Minsky in Bamberger, 1991, p. 4)

The use of selectable parameter spaces in *jam2jam* specifically allows for interaction with different musical dimensions and I chose these dimensions to align with commonly studied aspects of music.

In comparing the network jamming research with that on tuneblocks, a difference exists in the emphasis of what kinds of perspectives are under consideration in the research. The manifestation of this difference is that the tuneblocks research is particularly concerned with representation, while the network jamming research is particularly concerned with engagement (Brown, 2000). Both perspectives agree that these reflect multiple dimensions of music and music perception. A focus on representation, even when limited to external representations such as a score, lends itself to the computational theory of mind (Putnam, 1963). The mind contains and manipulates symbolic representations of the world. A focus on engagement, even when limited to behavior expressions of these, lends itself to enactive theory of perception where "what we perceive is determined by what we do" (Nöe, 2004, p. 1).

These subtle differences in emphasis result in somewhat divergent educational focuses. Bamberger's research results in her advocating different hearings or interpretations toward the development on intuitions (Bamberger, 2000). The network jamming research results in advocating different modes of engagement as interactions in meaningful contexts (Dillon, 2009). However, these distinctions are simply ones of emphasis. Just as Bamberger is also concerned with embodied understanding she refers to as "felt paths," I am concerned with cognitive decision-making, learning, and problem solving. To some extent, these differences simply reflect the impact of slightly different intellectual and technical contexts.

Future Directions

This research agenda has not only been productive over many decades, but will continue to be productive for decades to come. While future research can build on the work started by Bamberger and continued by others, it will likely need to evolve as it takes account of shifting understandings, technological capabilities, and socio-cultural contexts. Numerous opportunities will certainly emerge from the evolving intellectual and technical context for the experience design for future research with interactive music systems.

Findings in neurophysiology and its impact on psychological theories will likely have considerable impact on future work, as outlined for example in Daniel Levitin's widely read books on music and the brain (Levitin, 2006, 2008). The influence of findings in neurophysiology will simply continue a trend. Constructivist ideas were strongly based on Piaget's psychological insights, Bamberger's work developed during debates around linguistic grammars and their implications for music perception outlined by Lerdahl and Jackendoff, and my research continues to be influenced by probabilistic theories of mind and music perception as well as their generative computational models.

Another trend likely to influence computer-supported music learning is the ubiquitous nature of computing in the 21st century, which is apparent in the popularity of mobile devices and network saturated urban life. I have elsewhere outlined a vast array of contributions computing can make to supporting music making (Brown, 2007b), but it is clear that digital music will become pervasive and computing will continue to create opportunities for the development of musical understanding. Associated with this trend is the increased capacity for computational agency; for digital devices and device networks to meet the needs, habits, and contexts of users; and for researchers to be able to tailor musical experiences in a more refined way.

Conclusion

Bamberger's work in technology-supported music education was innovative. She engaged with the leading work in various fields including artificial intelligence, psychology, and pedagogy, and she energetically applied that work to research in music education. The work around the *jam2jam* system is inspired by this approach and reflects the technological, intellectual, and cultural context of the early 21st century.

Central to successful research of this kind is a focus on experience design; which involves keeping music making tasks as a core focus, understanding that software design should enhance these experiences, and understanding the significance of contexts—including that of the student, researcher, community and academic field—and the ability to leverage them and contribute to them. I look forward to interactive software systems continuing to energize music education research in the future. The technical and cultural conditions are full of opportunity. The field of music education research needs adventurous researchers willing to embrace developments in mobile and ubiquitous technologies, to engage with various disciplines, and to bring new knowledge and innovation to music education research and practice.

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