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Complexities of Learning with Computer-Based Tools: A Case of Inquiry about Sound and Music in Elementary School

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Computer-based technology is increasingly becoming available for students at all grade levels in schools, and its promise and power as a learning tool is being extolled by many. From a constructive perspective, if individuals actively construct meaning from their experiences, then simply having particular tools to work with via a computer doesn't ensure that desired learning will result. Thus, it is important to examine how students construct meaning while using such tools. This study examined what fourth grade students learned from the use of two computer-based tools intended to help them understand sound and music: software that emulated an oscilloscope and allowed students to view sound waves from audio input; and software that turned the computer into an electronic keyboard, which provided students with standard pitches for comparison purposes. Principles of *selective attention* and *prior knowledge and experiences*—foundational ideas of a constructivist epistemology—were useful in understanding learning outcomes from inquiry with these tools. Our findings provide critical information for future instruction with the goal of supporting learning about sound and music from such tools. They also indicate the need for more studies examining learning from computer-based tools in specific contexts, to advance our understanding of how teachers can mediate student activity with computer-based tools to support the development of conceptual understanding.

KEY WORDS: Selective attention; prior knowledge; conceptual understanding; oscilloscope.

INTRODUCTION

The development of microcomputer-based technology has created significant opportunities for expanding learning opportunities for students (deCorte *et al.*, 1993; Hawkins and Pea, 1987; Linn *et al.*, 1993; also see review by Berger *et al.*, 1994). Nevertheless, although these tools are often touted as powerful facilitators of learning, the tool metaphor itself suggests that whether and to what extent learning will occur is a function of how the tools are used and how information from that use is interpreted. Thus, we need to be mindful of the potential gaps between the promise of learning that is intended from the use of computer-based technology, and the actual outcomes.

In the work reported in this paper, microcomputer-based tools were used both to provide important learning experiences for students, and in the subsequent assessment of their learning. This work was part of a research and development effort in which colleagues and I supported teachers in planning and enacting instruction about sound and music in a fourth grade classroom (Magnusson and Palincsar, in press). The instruction included the use of two very simple pieces of software which required no additional hardware other than microphones that came with the Macintosh computers that were available in the school in which we were working. One computer program simulated an oscilloscope and allowed stu-

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dents to investigate differences in the waveforms produced by different sounds that were picked up by an attached microphone. The other computer program simulated an electronic keyboard, sounding notes when "keys" in the graphic display were selected using a mouse. Students used this program to listen to specific pitches for the purpose of tuning instruments they made as part of the instruction. Both of these pieces of software were utilized during interview assessments that occurred following the classroom instruction, but not during interviews conducted periodically while the instruction was taking place. Results from the assessments indicated that the use of the software did not necessarily result in desired learning outcomes. In this paper I discuss possible reasons for the discrepancies between what was expected and what occurred, and discuss recommendations to enhance the learning potential from the instructional use of these and related computer-based tools.

LEARNING WITH COMPUTERS

Many have argued that the use of computer-based technology has the potential to substantially change and improve the teaching-learning process (Lepper, 1985; Lepper and Gurtner, 1989; Papert, 1980); however, research to date has not convincingly demonstrated that the use of computer-based technologies has produced the development of conceptual understanding consistent with its promise. This result should not be surprising in that, by itself, computer-based technology cannot improve learning (Perkins, 1985); indeed, there are possible learning effects of the technology itself as well as learning effects that result from the environment that the technology helps to create (Salomon, 1990, 1992). Thus, there are multiple sources that can influence learning resulting from any educational use of computer-based technologies.

This study focuses on understanding learning in instructional situations in which computer-based technologies are designed to be *tools*, not situations in which a computer is the means of instruction (CAI). Computer-based tools can place learners in an "intellectual partnership" for the purpose of accomplishing tasks such as composing music or writing reports, analyzing environmental data, or building and testing models of complex systems (Pea, 1985; Levin and Waugh, 1988). Tools of this type are partners in learning because they free the learner to engage in higher-order thinking and processing of information (Salomon, 1988).

Systematic investigation of learning in situations in which students learn from using the computer as a tool lags behind the development of computer-based tools. Studies of programming and CAI have dominated the field of research on computers in education, and attention to computer-based tools has largely been at the level of their design and the design of learning environment in which they are to be used (Brown, 1985; Berger *et al.*, 1994). Thus, there is a need for more research that examines learning outcomes from the use of specific tools.

A major principle of the constructivist learning theory guiding the instruction featured in this research is that individuals actively construct meaning and knowledge from their experiences. An important corollary of that principle is that the construction process involves *selective attention* to stimuli and the generation of links between that input and an individual's *prior knowledge/experiences.* These principles are aptly represented by the Generative Learning Model (Osborne and Wittrock, 1983; 1985), which is one model illustrating cognition from a constructivist perspective. The dependence of meaning construction on these variables signals their importance in understanding and enhancing learning outcomes from any particular set of experiences, and they guided the interpretation of student performance using two computer-based tools for constructing understanding about sound and music. The tools examined in this study were: *Digital Oscilloscope*, which simulates an oscilloscope, and *KidsNotes* which simulates a piano keyboard.[1]

The questions guiding this research were:

(a) How do students interpret information from their tool use?
(b) To what extent does selective attention seem to influence that interpretation?
(c) What do students understand as a result of their experiences learning from computer-based tools?
(d) To what extent does prior knowledge/experience seem to influence learning?

[1]*Digital Oscilloscope* was written by Hansruedi Baer at the University of Zurich and is free. Hans can be reached by email at baer@gis.geogr.unizh.ch. *KidsNotes* is part of a software package called KidsTime Delux. It is available from Great Lakes Software, (408)438-1990.

METHODOLOGY

The Development Context

This research occurred as part of a research and development effort in which colleagues and I worked with elementary school teachers to design and implement instruction consistent with an approach to science instruction called *Guided Inquiry* (Magnusson and Palincsar, 1995). In this endeavor we collaborated with a group of 15 teachers (representing grades 1–5) in two schools in the development of curriculum materials and instructional activities for a Course of Study on Communication. One school served primarily working-poor families and the other served a broader socioeconomic mix of families. Both schools consisted of ethnically diverse but linguistically homogeneous populations. Each school was involved in externally-supported, school-wide endeavors fostering professional development.[2]

The collaboration to plan and enact Guided Inquiry instruction included a summer institute during which teachers: (a) experienced Guided Inquiry Instruction, (b) were introduced to the principles of Guided Inquiry, (c) began to identify guiding instructional goals, and (d) began specific planning of their respective Communication units. The topic of communication was selected because it was rich with regard to its complexity and the opportunities it provided for sustained inquiry that would yield scientific understandings of enduring value, flexible with regard to developmental issues, and relevant to the lives of children so that it was both accessible and interesting to children. During the fall of the 1993–1994 school year, bi-weekly meetings of the school and university staffs enabled additional planning of the course of study on Communication. Finally, intensive study of the enactment of Guided Inquiry instruction was conducted with a subset of two classrooms (grades one and four) during the spring of that school year. University and school members of the project team collaborated on very specific planning prior to the enactment, and each teacher was paired with a university staff member to support the enactment. This paper describes our experiences with the fourth-grade participants in one classroom.

[2]One school was an Exploring Essential School, and the other was a Professional Development School.

The Classroom Context. The fourth grade class was taught by Ms. Johnson, an experienced teacher of 22 years who had been recognized by her district as an outstanding teacher, and was active in the school's efforts to incorporate technology into instruction in the elementary school. Ms. Johnson was particularly motivated to have technology in her classroom, and had sought additional computer resources in addition to those provided by the district.

Ms. Johnson indicated that she was quite comfortable having students involved in inquiry-based instruction because she often engaged her students in projects where they produced physical models and developed written materials to represent what they were studying. She was also comfortable having her students use technology because it was a regular part of their activity during the day. For example, Ms. Johnson regularly had students enter information such as their results from spelling tests into a spreadsheet file that she created using Microsoft Works. She encouraged students to take responsibility for helping others learn to use the technology in the classroom by directing those who were sufficiently knowledgeable and skilled to help others during small group work. Thus, Ms. Johnson's students were typically comfortable with using technology. These features of Ms. Johnson's class room are consistent with important elements of the learning environment required in Guided Inquiry instruction, including the ability to draw upon technological tools for learning.

The Instructional Context. A major goal of Guided Inquiry instruction is to support students in investigating the physical world, and constructing and evaluating explanations of the findings from their investigations. In this class, the students participated in a long-term study of how humans communicate through the arts, in particular, through musical expression. Their inquiry included exploration of sound and its characteristics, and culminated in the design and construction of their own instruments for the purpose of playing music of their own design. A major conceptual goal was to have students develop knowledge of the relationship between pitch and wavelength.

To facilitate learning in this context, the teacher and a co-instructor from our project team guided the students in constructing a class instrument, which created opportunities for students to work together to determine how to make the instrument so that it could play a major scale over the range of an octave. This activity took place during regularly scheduled science instruction, which occurred twice a week in blocks of time that lasted two to two and one-half hours (generally with a recess in the middle). Some additional instruction occurred outside of the designated time for science.

The inquiry about sound and music took place during Ms. Johnson's second year with the same class (following them from the third to the fourth grade). These students (along with Ms. Johnson) had participated in a university-supported, inquiry-based project the year before; thus, both teacher and students had some familiarity with the instructional orientation, and the roles and responsibilities that were required. Ms. Johnson expressed concerns about her ability to support students in exploring music because she lacked a strong sense of pitch; however, she thought it was an appropriate choice for the students, and with the aid of a project staff member and the computer-based tools, she felt comfortable in conducting the instruction. Ms. Johnson viewed the project staff member as providing leadership and support for what she referred to as the technical aspect of the instruction. By "technical" she meant the targeted scientific concepts and the musical phenomena.

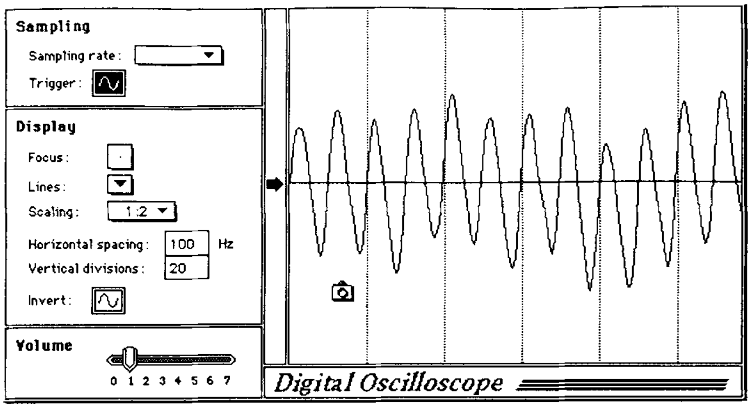
The Guided Inquiry topic of Communication was introduced to the students at the beginning of the 1993–1994 school year, but the formal, intensive involvement in Guided Inquiry instruction did not commence until February. The inquiry about sound and music spanned three months, ending in early May. The research reported in this paper concerned instruction that occurred during March and April.

Computer as Oscilloscope. In the early stages of the instruction when students first explored sound and its characteristics, students were expected to specifically investigate the relationship between the physical characteristics of an object making sound, and the nature of the sound that was produced. We were interested in seeing to what extent students could develop an understanding of waves and the relationship between pitch and wavelength, which could be explored using software (called *Digital Oscilloscope*) that emulated and oscilloscope. The software was used early in the instruction in a demonstration by the teacher to introduce students to the idea of sound waves. During the middle stages of the project, the instructors helped students use the program to explore sounds that they produced with various materials (e.g., blowing across bottles filled with water). At the end of the project, students used the program to produce images showing the waveforms from different pitches produced from the instruments that they constructed and tuned.

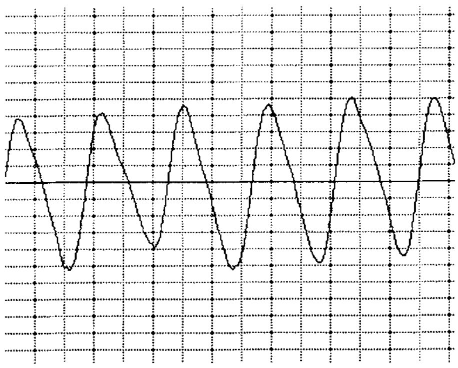
The goal of the use of this software was to have students explore the relationship between pitch and wavelength. Figure 1a shows the typical screen image that students see when using this software. To preserve a particular waveform for further study, the student simply clicks in the grid area (being in the grid area is signaled by the cursor changing into a small icon of a camera) and the waveform is captured at that instant. The image that is captured appears in a new window, shown in Figure 1b, which can be saved within the program and/or pasted into other programs.

The left-hand side of Fig. 1a shows that several elements of the display can be varied in *Digital Oscilloscope.* For example, both images in the figure show the waves against a white background, but the background can be reversed to black. Another variable is the presence of gridlines, including the option to not display any (e.g., notice that Figs. 1a and 1b differ in the presence of horizontal grid lines). Gridlines enable students to specifically compare the size of waves from different pitches, either with respect to their amplitude (height of the waves) or their wavelength (distance from a point on one wave to the same point on the next). Moreover, if quantitative relationships are of interest, notice that the horizontal spacing defines the x-axis in terms of hertz units, which means that students can calculate actual wavelengths.

Computer as Electronic Keyboard. The second software program that was used during the instruction provided students with a tool to help them create functional musical instruments. Their task was to make an instrument on which they could play a major scale, and to determine how to do that required that they learn what a major scale is and be able to compare how it sounds with the pitches produced on their musical instruments. The software that was used to help accomplish this task is called *KidsNotes*, and it emulates an electronic keyboard. A typical screen image seen when using this software is shown in Fig. 2. There are two main uses of the program: (a) to select songs to be played and see them represented in musical notation, or (b) to play a new song and see it represented. The figure shows the resulting output from a new song being played. The keyboard is shown without the note names indicated on the keys, but that feature can be selected, and letters appear below the white keys.



(a)



(b)

Fig. 1. Images from the public domain software entitled Digital Oscilloscope.

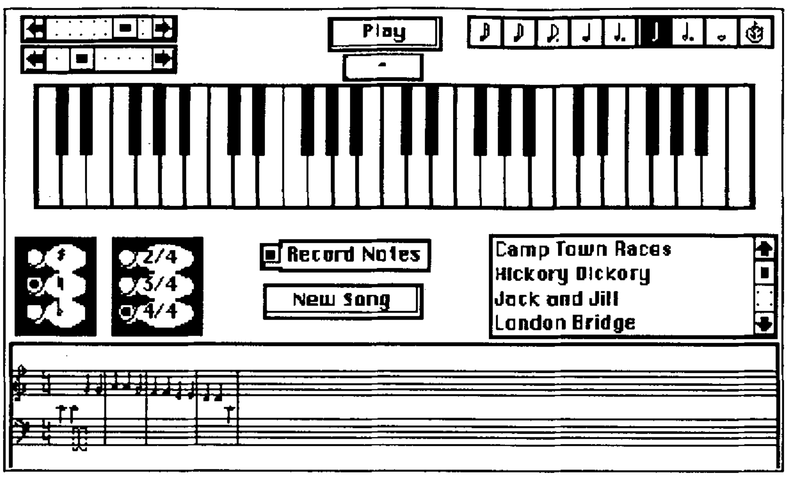


Fig. 2. Screen image from Kid Notes.

Instruction concerning musical scales and defining a major scale drew upon the image of the keyboard in the *KidsNotes* program to illustrate that musical pitches differ by half-steps and whole steps. For example, the change in pitch from playing consecutive black and white keys is a half step whereas the change in pitch for two consecutive white keys separated by a black key is a whole step. By learning the relationship between pitches in a major scale, and matching the pitches on their instrument to those played using the software, students could tune their instruments and determine how to play a major scale on it.

These software programs were available on two computers in the teacher's room, which were frequently accessed during science instruction. The oscilloscope program was also installed on computers in the school's computer lab (containing 30 computers), so there were multiple opportunities for all the students to work with the programs.

Research Design

Given the unique context of the instructional project in which these computer-based tools were used, one research strategy employed was a within subject, multi-element design. For this aspect of the research, a subset of the students in Ms. Johnson's class was selected for intensive study ($n = 8$; ≈25% of the class). The students participating in the research were selected by the teacher to represent the range of students in her class. The visible racial identity of the group was 50% black and 50% white, and 50% of the target students were male. Three of the target students were characterized as high achieving, two were characterized as average achieving, and three were characterized as low achieving, including one child who spent part of her day in a resource program for special needs students. A range of data collected in this classroom provided information about student's understanding of sound and music at periodic points in the instruction. The data sources will be described later.

Another strategy that was employed was to select a comparison group of students to provide information about students' understandings about sound and music in a context in which a focus on sound and music was a part of the instruction, but computer-based tools were not employed. For this purpose, eight children were selected from a fifth grade class in the same school. These students participated in instruction examining human communication through music, but it was not planned in a Guided Inquiry fashion. Given these differences, this was not a comparison group in the strict sense of the term; however, there were enough similarities with respect to being representative of the student population and having some familiarity with the concepts of interest that it appeared reasonable to compare the understandings of these students to those in Ms. Johnson's class (the target group). The teacher in this comparison classroom similarly selected students from her class who represented a range of academic ability in the class. Four students were identified as average to below average achievers, and four were identified as average to above average achievers. Four of the students in this comparison group were male, and the visible racial identity was 63% black, 37% white.

Data Sources. In the target classroom, we observed and videotaped the instruction, and at the end of the instructional unit, we videotaped presentations by individual students in which they described the instruments they made and how they worked. We also asked the teacher during the instructional unit to record reflections in a journal, and following the instructional unit we interviewed her to document her perspective regarding the ideas she introduced to help students understand sound and music, and her perceptions of the target students and the understandings they developed. In addition to these data we conducted interviews with individual students, and the context of these interviews are described next.

Instructional Interviews. With the target students, we periodically conducted individual interview to discern what they were learning during the course of the instruction. These took place on a weekly or a biweekly basis, lasting about 10 minutes for each interview. The interviews were conducted by the university project team member who assisted Ms. Johnson with the instruction, and another university project team member who observed and took field notes during the instruction. Thus, the interviewers were familiar to the children. These interviews were exclusively verbal, and did not involve the use of any props or manipulatives or require any written statements from the students. All interviews were audiotaped and transcribed for analysis purposes.

Core questions for each instructional interview were of the following types:

- What have you learned so far about ______? [e.g., communication, sound, waves, pitch; typically one or two concepts per interview]
- How do you think ______ [e.g., waves, pitches] can be different (i.e., vary)?
- What could you do or how could you tell if the ______ was/were different?

The concepts targeted in each question matched what had been emphasized during instruction the previous week. Additional probing questions were asked as needed to establish the child's understanding.

Clinical Interviews. These interviews were conducted with the target and comparison students. They occurred within two weeks after the final activities in the Guided Inquiry instruction about sound and music. The interview was designed as a Dynamic Science Assessment (Magnusson *et al.*, in press), which meant that it focused on having students explain physical phenomena that were observed as part of the interview, provided students with opportunities to initiate activities to help them make sense of the phenomena they observed, and included support by the interviewer to help students develop their ideas. The general scheme of each interview was: (a) observe a phenomenon, (b) predict what would occur upon changing one variable, (c) explain the reason for the prediction, (d) observe the new situation and describe that was observed, and (e) provide an explanation for the observable pattern resulting from changing the variable. Thus, within each task there were opportunities for the students to get feedback about their predictions and construct new explanations to account for any disparity in prediction and observation. This is consistent with recent recommendations of using different methodological approaches for studying student learning from a constructivist perspective (e.g., Smith *et al.*, 1993), and to provide movies rather than snapshots of the development of understanding (Siegler and Crowley, 1991). The interviews were conducted by the author of this paper and another member of the university project staff who had been assisting instruction in another classroom in the school. Both interviewers had considerable experience with interviews of this type. The interviews typically lasted one hour, and were videotaped. The audio portion of each tape was transcribed for analysis purposes.

The clinical interview consisted of five tasks, two of which dealt specifically with music and three of which dealt with sound and waves. At least one task for each topic involved a phenomenon that had been explored in class or was analogous to it (near transfer situation), and at least one task for each topic involved a related phenomenon (far transfer situation).

For the purposes of this paper, I focused on a subset of the data that were collected: the instructional interviews, three tasks from the clinical interview, and the teacher interview and journal. With respect to the targeted clinical interview tasks, two of them consisted of having students listen to sounds of different pitches and predict how their waveforms would compare, and then compare the waveforms they saw using the oscilloscope software. The third task utilized the electronic keyboard software, and students predicted and then determined the placement of a finger on the fingerboard of a violin, for playing a major scale on that instrument. The resulting data for the distances between the finger placements on the violin were then compared to the keys on the keyboard and the relationship between half steps and whole steps as designated by black and white keys was discussed.

Data Analysis

Theoretically, the analysis we employed is consistent with heuristic inquiry, which is primarily concerned with "meanings, not measurements; with essence, not appearance; with quality, not quantity; with experience, not behavior" (Douglas and Moustakas, 1984). We used an approach that we call *emergent content analysis* to organize the data for identifying primary patterns (Magnusson *et al.*, in press). In this approach, a framework for categorizing the students' responses is constructed to identify the topics/concepts to use to code the data to guide the analysis in determining students' ideas. Following coding, students' responses are characterized on the basis of themes that emerge with respect to how students describe and explain phenomena relative to the targeted science concepts. In this way, students' understandings can be determined relative to targeted concepts in a way that preserves the unique expression of their ideas. The targeted concepts in this case were: sound, sound characteristics, physical characteristics related to sound production, waves and characteristics of waves, music, and scale.

That process was followed by a process that is similar to what is generally called analytic induction, although we agree with Katz (1983) that a process of systematically trying to construct meaning from data such as this is much like what philosophers of science call "retroduction" (Hanson, 1958)—a process involving "an alternate shaping of both observation and explanation" (p. 135). In essence, identifying patterns in the data is a process of selectively attending to critical aspects of the data that are determined to be critical because of their usefulness in understanding the larger meaning inherent in the data, and in this we brought to bear our concern for the issues of selective attention and the role of prior knowledge and experiences in sense-making during the knowledge construction process. The next section describes our findings from this analysis.

FINDINGS

Two themes emerged from our analysis: (a) students did not necessarily distinguish between amplitude and wavelength in noting relationships from comparing sound waves of different pitches captured by the *Digital Oscilloscope* program, and (b) students' pitch discrimination was poor, limiting the role of the *KidsNotes* software in facilitating the tuning of student instruments by comparing desired pitches with actual pitches. Each theme will be illustrated and discussed with respect to recommendations for improving the instructional use of these computer-based tools.

Distinguishing Amplitude and Wavelength. Amplitude and wavelength are independent dimensions of waves (Fig. 3a); that is, they can vary independently. Figure 3a illustrates these ideas. Our data from the clinical interviews indicated that students did not necessarily distinguish between amplitude and wavelength when describing differences in the waveforms of high and low pitches, which were produced using the *Digital Oscilloscope* program. This was a surprising result because data from the instructional interviews indicated that students did appear to distinguish between those dimensions. For example, in the instructional interviews, students described waves for high pitches as "skinny," having "more bumps," "squished together," and "having more crests and troughs." Two students even provided quantitative information that a high pitch might have 6 "bumps" or "6 tops and 6 bottoms" whereas a low pitch might have about 3 "bumps" or "3 tops and 3 bottoms." [JIIM3/28:P3; AIIM3/28:P4]. There was some evidence that students interchangeably referred to amplitude and wavelength

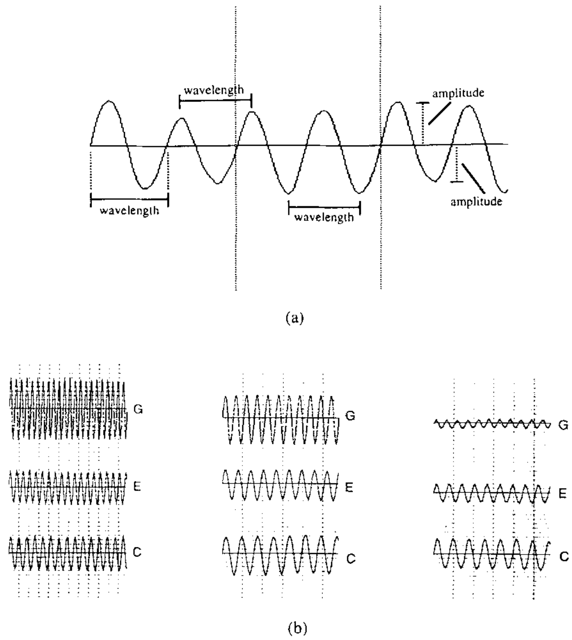


Fig. 3. Amplitude and wavelength of sound waves.

or frequency differences during the instructional interviews, but there was more evidence to suggest that students made accurate distinctions between those concepts. For example, one of the low achieving students indicated that with a soft sound you would see "small waves" whereas you would see "big waves" for a loud sound, and a high pitch "will have a lot of waves" whereas a low pitch "will have a little." [CIIM3/17:P3;CIIM3/28:P2]

Results from the clinical interviews showed a different pattern. For many students, amplitude differences were far more prominent than wavelength differences, and for several students, amplitude was the first difference that they described when asked to predict how the waves of different pitches would differ. The fact that amplitude differences were a more prominent variable in the waveform is not surprising as Fig. 3b shows: in each case, the differences in waves of the three pitches (arranged from high to low) is more dramatic for amplitude than for wavelength.[3] However, we did not expect

[3]These are actual images viewed by different students in the clinical interviews. Notice that the relationship between amplitude and pitch is different in each image. This was an artifact of the interview procedure because the interviewer typically "captured" the waves using the software, and idiosyncratic time differences resulted in differential dampening of the sound, thus, reducing the amplitude in varying degrees.

that by the end of the instruction in which wavelength differences were emphasized (and amplitude differences were not) that some of the target students would focus more on amplitude differences in the assessment. Moreover, it is striking that this pattern primarily showed up in predictions of the target students in the clinical interviews and not for the comparison group students, and that it occurred for students of all ability levels. The interview protocol required the interviewer to prompt students to describe wavelength differences if they did not do so spontaneously, and it was observed that students were generally able to accurately describe differences in wavelength when prompted; however, it was surprising that some target group students persisted in noting amplitude differences but not wavelength differences until prompted to do so.

One explanation for this result is that the students' prior experiences with the software predisposed them to notice amplitude differences, which were more prominent. Results from the interviews of students in the comparison group provided some corroborating evidence for this hypothesis. Although the students in the comparison group also initially exhibited attention to amplitude differences, they seemed to have an easier time focusing on wavelength (as opposed to amplitude) differences later in the interview when asked about how waves would differ for different pitches. Because the comparison students had not seen this type of representation before, and since the interviewer purposely focused them on wavelength, it was easier for them, in the absence of prior experience, to attend to that dimension alone.

We suggest that these results illustrate the roles of selective attention and prior experience in knowledge construction. First, because amplitude differences were much more visually dramatic than wavelength differences in the oscilloscope program, students noted them first, and began to selectively attend to them. It seems that the target group students, who spent substantially more time working with materials and the software than discussing their findings, may not have had sufficient opportunities to become aware of their selective attention with respect to differences in the waveforms. Second, ambiguity in the language used by children to describe differences in the waves seemed to have obscured this confounding. It was not uncommon in the clinical interviews for some students to describe the waves simply as "bigger" or "smaller," which can be a reference to wavelength or amplitude differences. Only upon prompting by the interviewer did students' language become more precise. "Taller" and "shorter" versus "wider" and "narrower" are unambiguous in indicating the dimension of the wave to which they correspond. As it was, if the waves of a higher pitch were described as being "more" than the waves for a lower pitch, students could appear to be accurately noting wavelength differences when in fact they were focusing on amplitude because higher pitches typically resulted in larger amplitudes than lower pitches (due to the fact that the higher pitches were typically louder sounds). Possible miscommunication as a result of the ambiguity of the students' language was not monitored during instruction; hence, the instructors were not alerted to the unintended focus of the students' attention by incorrect responses regarding the data. This indicates a missed opportunity to determine students' attention to the differences in both variables, and closer attention to language could have been productive in fostering selective attention to the desired variable.

Curiously, the instructional interviews did not reveal a problem with distinguishing between amplitude and wavelength difference. Some students only indirectly referred to wavelength in that they used the number of crests in a waveform to refer to the waves, but that was a reasonable response given that it was a strategy that had been introduced during the instruction and it appeared to be more meaningful to students' sense-making than the concept of wavelength. The difference in the instructional interviews was that students' understandings of differences in wave patterns for high and low pitches was not assessed in conjunction with the actual representations; that is, unlike the clinical interviews where students observed the waveforms resulting from particular pitches and were asked to compare them, students were simply asked to discuss the relationship and no actual representations were used. Thus, the lack of visual information did not divert their focus to amplitude rather than wavelength.

These results indicate that the students needed more time to discuss and compare the graphic representations to develop desired understandings. Whereas the students seemed to have developed desired declarative knowledge concerning the differences in amplitude and wavelength, it was not appropriately linked to critical features of the waves in the graphic representations. The instructional record from this inquiry indicates that during instruction there was relatively little discussion of the amplitude and wavelength differences while students were viewing waves from different pitches with the aid of the oscilloscope program, and discussions following the investigations with the tool did not explicitly focus on discerning wavelength differences separately from amplitude differences. Thus, students were afforded few opportunities to discuss their interpretations of the graphical representation of the pitches, and as a result had few opportunities to receive specific feedback concerning their interpretation of them.

The undesirable outcomes from the students' relatively independent interpretation of information from the software has been reported for other phenomena (Stein, 1986), and may indicate a presumption by the instructors that the computer as a tool simply provides another source of information in the classroom. Its ease of use may have suggested that learning from the information gathered with it was unproblematic and straightforward. Whereas the graphical representation was viewed by the teacher as requiring attention because students were unfamiliar with that type of representation, she did not view its use in a way that is consistent with the central role that such inscriptions play in scientific practice (Roth, 1995; Woolgar, 1990).

A variation on this theme of a lack of distinction between wavelength and amplitude was that it was not clear whether the students understood that these variables are independent dimensions of waves. Whereas some students clearly noted differences in both dimensions, they described them in ways that suggested they did not see them as changing independently of one another. This finding seems best explained by the role of prior knowledge and experience. First, students repeatedly observed the same wavelength and amplitude patterns for high and low pitches: tall, skinny waves for high pitches and short, fat waves for low pitches. As a result, some students seemed to view these two dimensions as a single variable, and that included two of the high achieving students. If the more able students commonly had more opportunities to use the computer and the oscilloscope software and accumulate these experiences, it would make sense hat they exhibited this thinking. Second, imagery used by the classroom teacher to help students understand wavelength may have unintentionally reinforced this idea. This episode occurred when Ms. Johnson drew a sine wave on the chalkboard and asked students to signal when she got to the next wave. She suggested that the students say "beep, beep, beep" while she traced pattern of the first wave, and change to "bop, bop, bop" when she moved to the second wave. Although she was using this strategy to illustrate wavelength, Ms. Johnson traced along the displacement of the wave rather than the linear distance from one point on one wave to the same point to the next wave. This difference is shown in Fig. 4. By representing the wavelength in this way, Ms. Johnson may have suggested to the students that the wavelength is the distance along the disturbance, and that would confound the separate dimensions of amplitude and wavelength. Considering that more able students would be more likely than their less able papers to attend to the demonstration and incorporate the imagery into their thinking, it is not surprising to find them following the idea that it unintentionally conveyed.

In sum, the concepts of selective attention and prior knowledge/experience were useful in interpret-

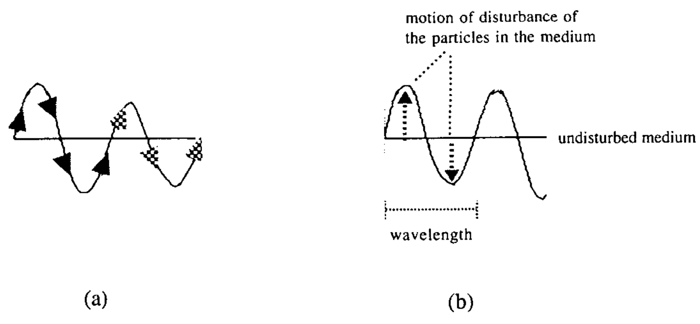


Fig. 4. Ms. Johnson's illustration of wavelength (a) compared to an accurate representation (b).

ing influences concerning students' sense-making in understanding differences in sound waves for different pitches. These concepts, in essence, indicate the central role played by teachers in mediating students experiences to facilitate learning science. In this case of inquiry-based instruction, it appears that insufficient attention was paid to how students were making sense of the information they were gaining from use of the computer-based tools. Thus, one finding from this research is that we need a better understanding of how teachers can mediate students' experiences with computer-based tools. It seems important for teachers to recognize students for accurate observations they make whether or not they observe all of the desired information (Linn *et al.*, 1994), such as recognizing students for noting amplitude differences even though wavelength differences were the desired focus. However, they also need to lead students in broadening their experiences and the perspectives they bring in framing problems and investigations in science. The oscilloscope program made it possible for students to experience and work with data about sound that they would otherwise not have encountered, and that was of benefit. Nevertheless, without appropriate mediation, the potential of this computer-based tool to facilitate the development of understanding about waves is limited.

Pitch Discrimination. The other theme in the use of computer-based tools for helping students understand sound and music concerned how students experienced pitch. The plan to have students make musical instruments was devised so that students had a meaningful context in which scientific concepts related to sound could be explored. The requirement of having the students make instruments that could play a major scale was included to ensure sufficient challenge, and to build in a context that would provide information for meaningful inquiry about the wavelength relationships among pitches. There are regular mathematical relationships between the wavelengths of pitches in a major scale (Backus, 1977); for example, there is a 2:1 ratio between the wavelengths of pitches an octave part. Thus, it appeared that the instructional plan represented a blend of meaningful activity for the children and opportunities to examine fundamental scientific concepts and relationships.

In order for the students to accomplish the goal of making a musical instrument that could play a major scale, they needed to be able to make use of the pitch information from the *KidsNotes* program to determine whether the pitches they were making on their instrument were accurate. This activity required them to be able to discriminate between pitches, which turned out to be problematic. Although the target students attempted to use *KidsNotes* to tune their instruments, the clinical interview results indicated that they had difficulty determining whether a pitch produced by the KidsNotes software was higher, lower, or the same as a pitch played on an actual instrument. Some students could tell that the pitches were different but not whether the comparison pitch was higher or lower. Some students could not even tell whether the pitches were different. Results from the clinical interviews of the comparison group provided corroborating evidence of the role of prior experience in accurately utilizing the information from the electronic keyboard. As fifth graders, students in the comparison group were automatically part of the music program in the school district, which meant they were likely to have had more opportunities to explore music and pitch. In particular, several students in the comparison group who had substantial musical experience performed much better than other students.

This finding is a classical example of the perception-cognition relationship. The music education literature is rife with studies indicating that pitch discrimination is not purely a perceptual activity but it is learned ability, and it does not naturally develop but requires instruction (Cook, 1993; Darrow, 1990; Flowers and Costa-Giomi, 1991; Jordan-DeCarbo, 1989; Ramsey, 1983). Whereas it was though that the computer-based tool could provide helpful experiences for the students, they were insufficient to support students in developing a sense of pitch. An additional feature that provided feedback about the pitch comparison when students could not make the distinction could have been a helpful addition to the software in order to support students with poor pitch discrimination in developing a better sense of pitch. It would be interesting to see to what extent students could develop facility with pitch if they had the use of such a tool to guide their interpretation of aural stimuli.

In sum, the use of *KidsNotes* did not result in the intended learning outcomes due to the fact that its meaningful application required experiences with discriminating pitches that were not provided. This finding points out that instruction like this about sound and music, which is intended to be anchored in the lives of the students, requires substantial attention to guided experiences focused on pitch discrimination in order for the students to reach the targeted goals. More research is needed to determine the amount and kind of experiences required to support students in making full use of this or a more elaborate tool.

CONCLUSIONS

Computer-based tools to think with can provide students with experiences and cognitive opportunities that can support them in constructing understanding far beyond what they could develop without the tools. Nevertheless, tool use is not an end in itself, it is a means to an end, and in that sense, the instructional use of computer-based tools requires attention to the cognitive demands and processes involved in the use of particular tools. The findings from this study are important for several reasons. First, they remind us to be careful about assumptions that we make regarding the support students need to learn with such tools. A program may be potentially powerful, but only if one knows how to learn with it or if one has the requisite experiences required to learn from its use. The *Digital Oscilloscope* program appears to have great potential for facilitating students' investigations of sound, particularly with respect to investigating the relationship between pitch and wavelength. The instructional interviews indicated that students could develop some understanding relative to that relationship, but that it was not robust with respect to its graphical representation. Teachers can play a critical role in mediating students' physical and cognitive activity in such situations.

Second, these findings remind us that students may need specific experiences to make use of the information gleaned from a computer-based tool. As such, we need more research to determine what those experiences are with respect to particular computer-based tools. In the case of the electronic keyboard provided by the *KidsNotes* program, only those students with sufficient musical experiences were able to make full use of the tool. Students needed much more experience listening to and comparing pitches than they had as a part of their Guided Inquiry instruction. In this "authentic" experience, the instruction apparently did not account for the learning challenges posed by drawing upon another type of intelligence (Gardner, 1987): musical intelligence. As science instruction evolves to include more meaningful experiences for students, it is likely that similar situations will arise relative to other topic areas, and that we will need to become more informed about related areas of study in order to effectively plan experiences for students to make full use of computer-based tools.

The findings from this research will help us use these computer-based tools more effectively with students the next time this instruction occurs. As such, they signal important information for others who might use this software, and important knowledge for teachers to help them plan instruction that can maximize the benefit of the use of technology. We argue that there are similar issues for any software program that is used instructionally, but particularly for programs that provide students with complex representations or that may tap into other intelligences. We recommend further attention to these issues in research and discussion concerning the use of technology in learning.

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REFERENCES

Backus, J. (1977). *The Acoustical Foundations of Music*, W. W. Norton, New York.

Berger, C. F., Lu, C. R., Belzer, S. J., and Voss, B. E. (1994). Research on the uses of technology in science education. In Gabe D. L. (Ed.), *Handbook of Research on Science Teaching and Learning*, Macmillan, New York.

Brown, J. S. (1985). Process versus produce: A perspective on tools for communal and informal electronic learning. In Chen, M., and Paisley, W. (Eds.). *Children and Microcomputers: Research in the Newest Medium*, Sage, Beverly Hills, California (pp. 466–490).

Cook, N. (1993). Perception: A perspective from music theory. In Sloboda, J. A., and Aiello, R. (Eds.), *Musical perceptions*. Oxford University Press, Oxford.

Darrow, A. A. (1990). The role of hearing in understanding music. *Music Educators Journal* 77(4): 24–27.

de Corte, E., Linn, M., and Verschaffel, L. (eds.) (1992). *Computer-Based Learning Environments and Problem-Solving*. Springer-Verlag, New York.

Douglas, B, and Moustakas, C. (1984). *Heuristic Inquiry: The Internal Search to Know*. Detroit, Michigan: Center for Humanistic Studies.

Flowers, P. J., and Costa-Giomi, E. (1991). Verbal and nonverbal identification of pitch changes in a familiar song by English- and Spanish-speaking preschool children. *Bulletin of the Council for Research in Music Education.* 107: 1-12.

Gardner, H. (1987). The theory of multiple intelligences. *Annals of Dyslexia* 37: 19-35.

Hanson, N. R. (1958). *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science.* Cambridge University Press, Cambridge.

Hawkins, J., and Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal for Research in Science Teaching.* 24, 291-307.

Jordan-DeCarbo, J. (1989). The effect of pre-training conditions and age on pitch discrimination ability of preschool children. *Journal of Research in Music Education* 37(2): 132-145.

Katz, J. (1983). A theory of qualitative methodology: The social system of analytic fieldwork. In Emerson, R. M. (Ed.), *Contemporary Field Research: A Collection of Readings*, Waveland Press, Inc., Prospect Heights, Illinois.

Lepper, M. R (1985). Microcomputers in education: Motivational and social issues. *American Psychologist* 40: 1-18.

Lepper, M. R., and Gurtner, J. L. (1989). Children and computers: Approaching the twenty-first century. *American Psychologist* 44: 170-178.

Levin, J. A., and Waugh, M. (1988). Educational simulations, tools, games and microworlds: Computer-based environments for learning. *International Journal of Educational Research* 12: 71-80.

Linn, M. C., diSessa, A., Pea, R. D., and Songer, N. B. (1994). Can research on science learning and instruction inform standards for science education? *Journal of Science Education and Technology* 3(1): 7-15.

Linn, M. C., Songer, N. B., Lewis, E. L., and Stern, J. (1993). Using Technology to teach thermodynamics: Achieving integrated understanding. In Ferguson, D. L. (Ed.) *Advanced Technologies in the Teaching of Mathematics and Science*, Springer-Verlag, Berlin (10: 5-60).

Magnusson, S. J. and Palincsar, A. S. (1995). Learning environments as a site of science education reform. *Theory into Practice* 34(1): 43-50.

Magnusson, S. J. and Palincsar, A. S. (in press). "We didn't try one with no water, so we don't know": Fourth graders' investigations of sound and music. Science Education.

Magnusson, S. J., Templin, M., and Boyle, R. A. (in press). Dynamic science assessment: A new approach for investigating conceptual change. *Journal of the Learning Sciences.*

Osborne, R. J., and Wittrock, M. C. (1983). Learning science: A generative process. *Science Education* 67(4): 489-504.

Osborne, R. J., and Wittrock, M. C. (1985). The generative learning model and its implication for science education. *Studies in Science Education* 12: 59-87.

Papert, S. (1980). *Mindstorms*, Basic Books, New York.

Pea, R. D. (1985). Beyond amplification: Using the computer to reorganize mental functioning. *Educational Psychologist* 20: 167-182.

Ramsey, J. H. (1983). The effects of age, singing ability, and instrumental experiences on preschool children's melodic perception. *Journal of Research in Music Education* 31(2): 133-145.

Roth, W-M. (1995). Affordances of computers in teacher-student interactions: The case of Interactive Physics™. *Journal of Research in Science Teaching*, 32(4), 329-347.

Ruopp, R. R., Gal, S., and Pfister, M. (Eds.) (1993). *Labnet—Toward a Community of Practice: The Case of High School Physics Teachers Project Science, and New Technologies*, Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Salomon, G. (1988). Artificial intelligence in reverse: Computer tools that turn cognitive. *Journal of Educational Computing Research* 4: 123-139.

Salomon, G. (1990). Cognitive effects with and of computer technology. *Communication Research* 17: 26-44.

Salomon, G. (1992). New challenges for educational research: Studying the individual within learning environments. *Scandinavian Journal of Educational Research* 36(3): 167-182.

Siegler, R. S., and Crowley, K. (1991). The microgenetic method: A direct means for studying cognitive development. *American Psychologist* 46: 606-620.

Smith, J. P., diSessa, A. A, and Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the Learning Sciences* 3: 115-163.

Stein, J. S. (1986). The computer as lab partner: Classroom experience gleaned from one year of microcomputer-based laboratory use. *Journal of Educational Technology Systems* 15(3).

Woolgar, S. (1990). Time and documents in researcher interaction: Some ways of making out what is happening in experimental science. In Lynch, M., and Woolgar, S. (Eds.), *Representation in Scientific Practice* (pp. 123-152). Cambridge, Massachusetts: The MIT Press.