Original article

A few design perspectives on one-on-one digital classroom environment

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Abstract 1 : 1 educational computing refers to a scenario where every student in a group or class uses a computing device equipped with wireless communication capability to conduct a learning task. This paper, drawing from design experiences with our digital classroom environment series and other studies, attempts to describe a few valuable 1 : 1 design perspectives for educational computing inside the classroom. We try to describe the major components of the 1 : 1 digital classroom environment and classify the most important component, student devices, according to a set of features. Furthermore, based on the notion of computing affordance, a set of communication affordances are described. This set underpins three basic educational activities, namely: teacher-directed instruction, small group learning and individual learning. Finally, scenarios are exemplified for a few typical educational computing devices. This study concludes with a discussion of short- and long-term research possibilities.

Keywords digital classroom environment, 1 : 1 educational computing, interactive learning environment, mobile learning, wireless technologies

Introduction

As stated in www.g1on1.org, it is expected that in approximately 10 years, more and more students will bring a range of computing devices into the classroom for learning. Ultimately, these devices will become indispensable educational tools like pens, papers or chalkboards. 1 : 1 educational computing[1] means that every student in a class has a learning device to participate in learning activities. These devices are mobile and equipped with wireless communication capabilities. They vary from purpose-specific devices such as response pads, graphic calculators, electronic English dictionaries and pocket game machines, to more general-purpose devices like cellular phones, personal digital assistants (PDAs), WebPads, Notebooks and TabletPCs. Recently, 1 : 1 educational computing has drawn much attention because learning devices are becoming so inexpensive that ultimately all students will own their own personal devices. This implies that eventually, digital technology will spread into every classroom, transforming everyday educational activities.

This burgeoning field needs a blueprint for future research. This paper, drawing on studies from the digital classroom environment (1:1 DCE/DCE) series in Taiwan and other research, attempts to describe a few substantial design perspectives that may help to map out a 1 : 1 educational omputing design space inside the classroom. First, following a general description of

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[1] 1 : 1 educational computing is a concept discussed in a global network of collaborative researchers (see www.g1on1.org).

a 1 : 1 digital classroom, some major components of a 1 : 1 digital classroom environment were identified to help define terminologies and the scope of discussion in this paper. Second, to emphasize the importance of selecting appropriate student devices in a 1 : 1 digital classroom environment, a classification of various student devices was introduced. Third, to highlight that wireless communication is the key feature in such an environment, the notion of communication affordances is defined in order to describe the educational implications offered by wireless communication capabilities. Finally, sample system scenarios from our previous works are given. The paper concludes with scenarios for the future of 1 : 1 digital classroom environment.

1 : 1 digital classroom environment

Many different teaching strategies, learning materials, computer components, etc. are needed in a 1 : 1 educational computing classroom. Based on our previous research (Huang *et al*. 2001; Deng *et al*. 2004; Wang *et al*. 2004), we enumerate some major and common components of a typical 1 : 1 digital classroom and listed them as follows:

- *Student devices*: A set of personal mobile computing devices available to every student;
- *Communication network*: A communication medium including face-to-face peer communication, or wireless local area network, and/or Internet connection;
- *Classroom-shared display*: A classroom shared display, like a single-gun projector or electronic whiteboard, controlled by the teacher to support teacher-directed instruction, or, sometimes controlled by one or a group of students, depending on the kind of activity;
- *Teacher's device*: The teacher's personal computer or a computer residing in the classroom;
- *Classroom servers*: Consist of a learning management system (such as WebCT), a learning content management system, a link with an extensive online learning community, such as EduCities (Chan *et al*. 2001), and an interface to an outdoor classroom activity support system (Chang *et al*. 2003; Chen *et al*. 2003);
- *Device management system*: Enables the teacher to easily manage student devices and other components, such as storage, recharge and mobility. (Fig. 1).

Why these six components? Based on our previous study (Huang *et al*. 2001), integrating the first and the second component is enough to build the most basic 1 : 1 educational computing classroom. For example, students may use PDA, as the first component, for taking notes, and they can share notes with each other via infrared beaming, as the second component. But when teachers adopted this system in their own teaching, they expressed some concerns. They wanted the ability to control the learning and instruction process through their own computer (*teacher's device*) show materials and assessment results on a large screen that operates like a chalkboard (*classroom shared display*), and store their work as well as their students' on a shareable databank (*classroom servers*) (Wang *et al*. 2004). Other researchers found the same requirements in their own research (e.g. Soloway *et al*. 2001; Roschelle *et al*. 2004). The most recent requirement requested by the teachers; was a way to manage all the equipment and keep them safe (*device management system*) (Deng *et al*. 2004). It is expected that in the future, more and more systems will be equipped with all the components described. The environment designed by our team called DCE has evolved into three versions: DCE 1.0 (Huang *et al*. 2001), consisting of the first four components; DCE 2.0 (Wang *et al*. 2004), consisting of the first five

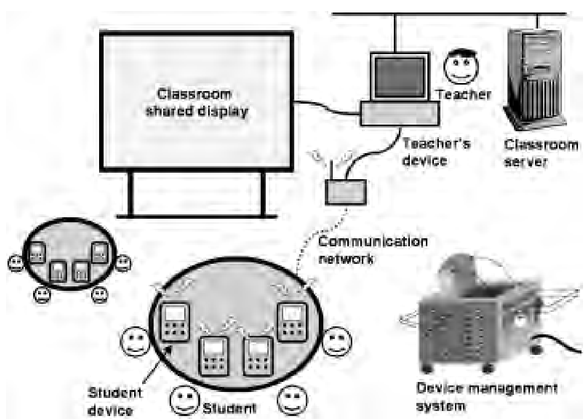

Fig. 1 Common components of 1 : 1 digital classroom environment.

components; and DCE 3.0 (Deng *et al*. 2004), including all six components in the list.

Classification of student devices in 1 : 1 educational computing environment

There has been, and will continue to be, a debate among researchers in the G1 : 1 group (www.g1on1.org) about which pattern of student devices, the first component of the six major components described above, will prevail. However, researchers have to choose a device they wish to study that is appropriate for the target students, teacher practice, subject domain, digital infrastructure of the school and classroom, as well as possibilities for popularisation. Therefore, we think it is helpful in the researchers' decision making if we can depict a spectrum of devices by classifying them into different categories in order to obtain a clearer and larger picture.

First, devices are classified by size and weight as *palm-held*[2] and *laptop*. Palm-held devices include response pads, application-specific devices and PDA. Examples of laptop devices include WebPad, Notebook and TabletPC. The second classification is pricebased, and relates to affordability and possibilities for popularization. Screen size is the third classification. A small screen size may be unsuitable for a number of tasks (e.g. reading articles with multimedia). Keyboard input is the fourth classification, whereas support for handwriting input is the final classification. Restricted input/output capabilities may limit application scope. For example, because the response pad lacks text entry capability, it cannot support students in answering fill-in-the-blank questions. Table 1 provides examples of these different devices and their corresponding capabilities.

Basic communication affordances for educational activities

We expect that if 1 : 1 educational computing can impact on classroom learning, then it must enhance three basic types of classroom activities, namely: teacher-directed instruction, small group learning and

[2]It is preferable not to use the term 'handheld' as one of the categories, because is not precise enough. Some would even include a TabletPC as a handheld device.

Table 1. 1 : 1 educational computing devices classification.

Educational computing devices	Palm-held device						Laptop devices		
	Response pad*	Application-specific devices				PDA	WebPad*	Notebook	TabletPC*
		Cellular phone	Learning machine	Electronic dictionary*	Graphical calculator				
Size and weight	Small	Small	Medium	Medium	Medium	Medium	Large	Large	Large
Price	Cheap	Fair	Fair	Fair	Fair	Fair	Expensive	Expensive	Luxury
Screen size	None/tiny	Small	Medium	Medium	Medium	Medium	Large	Large	Large
Keyboard input	Numeric	Numeric and weak alphabet	Depend on model	Fully support	Fully support	Screen Emulation	Screen Emulation	Fully support	Fully support
Hand writing	None	Typically none	Depend on model	Typically none	Typically none	Fully support	Fully support	Typically none	Fully support

*A device that has been incorporated in our own systems. PDA, personal digital assistance.

individual learning. But how will it be able to enhance these different educational activities? We noticed that the major impact of classroom learning is mainly governed by a set of communication mechanisms.

More often than not, the creation of a computing mechanism is not for educational purposes. It is the researcher who attempts to look for the possible educational applications in the design, hence giving it educational significance and value. To express the relationship between this set of mechanisms and classroom activities, we borrow the term *affordance* given by Gibson (1977) that refers to a relationship between an actor and physical objects, reflecting possible actions performed on those objects. Here, we define *educational communication affordance* as consisting of two attributes: *communication mechanism* and *educational application*. To illustrate this concept, we take one of the communication affordances, *response-collecting*, as an example. Response-collecting is the most salient feature of a response pad system, which consists of a wireless signal receiver and a set of response pads. A response pad is a signal transmitter, a very simple device just like a remote controller for TV. Each response pad has its own unique identity number. When a button on a respond pad is pressed, it transfers the signal wirelessly to the receiver that connects to a computer. The receiver obtains two pieces of information: the digit number representing the button pressed and the identity number of the response pad. The communication mechanism of response-collecting is as follows: signals from all student devices are collected almost simultaneously in the receiver, and the response information is then processed by the teacher's device. A typical example of an educational application of response-collecting is the synchronous question and answer activity for the whole class. A teacher can present multiple-choice questions and ask all students to answer them by pressing buttons. After all the students have transmitted their answers, the teacher can immediately present statistical charts on the students' answers in order to reflect their performance and facilitate discussion.

Notice that the signal receiver and the response pads have no meaning to education if the designer had not thought about the possible implications of such a technology to educational applications. In searching for potential educational applications, the relationships of the learners and the teacher (human actors) become apparent. What are the advantages then? We can imagine the following scenario: the teacher preparing the quiz the day before class; the students taking the quiz (with the teacher distributing quiz papers and collecting them back after the quiz); the teacher grading them after class or at home; and then finally distributing them again and discussing the result. All in all, it might take a teacher 3 days to complete the process of a quiz. The response-collecting affordance, however, besides saving the teacher at least 1 day in the process, also cancels the need for human distribution and collection of quiz papers as well as human grading. More importantly, the teacher can promptly discuss with students what they have just worked through and thought about. Efficiency sometimes means effectiveness.

Besides response-collecting affordance which has been discussed above, the other communication mechanisms are described as follows:

Posting affordance: The communication mechanism of posting affordance consists of a student device that can post material to a teacher's device or other students' devices, whose receiving device should identify the sender and put the material into memory storage. Unlike response-collecting affordance, the posting affordance does not require the whole class to use their student devices to post material simultaneously.

Pushing affordance: The communication mechanism of the pushing affordance consists of the teacher's device, which sends material to a specified device(s) of a single, group or a whole class of students instantly. The receiving devices are enforced to receive and process the material. This affordance requires accomplishing all tasks within a time frame, even at the same time.

Controlling affordance: The communication mechanism of the controlling affordance consists of a teacher's device that can enforce to remote control a specified device(s) of a single, a group or a whole class of students instantly. The receiving devices switch to a locked state and execute the instructions from the teacher's device only. Students cannot control their own devices until the teacher's device sends an unlock command.

File-exchanging affordance: The communication mechanism of the file-exchanging affordance consists of files that are exchanged between a student's device and teacher's device according to the recent updated files residing in both devices. A teacher's device or a student device could launch this task actively.

Instant-messaging affordance: The communication mechanism of the instant-messaging affordance is like the well-known 'Chat' function that allows sending and receiving short messages among student devices and the teacher's device instantly. The device should show the received message instantaneously.

Table 2 describes such affordances with educational applications examples aimed at supporting teacher-directed instruction, small group learning, and individual learning.

Besides communication and device capability, such affordances are also supported by specific learning-support software installed both on the teacher's device and the students' devices. Table 3 shows the communication affordances supported by the 1 : 1 educational computing devices that are described in the section above. Not every device supports all of the communication affordances, and the degree of support varies between the different devices.

Table 2. Examples of educational applications supported by basic communication affordances.

Communication affordance	Examples of educational applications
Response collecting	Engaging question and answer activity (T)
Posting	Posting report (I) Retrieving and demonstrating students' reports (T) Delivering group report slides (G)
Pushing	Delivering learning content (T) Assigning task for each group (G)
Controlling	Disabling student's devices to gain their attention temporarily (T)
File-exchanging	Delivering exercises, receiving teacher's review (I) Co-working with shared worksheet (G)
Instant-messaging	Exchanging ideas with peer in another group (G)

I, individual learning; T, teacher-directed learning; G, small group learning.

Example systems of 1 : 1 digital classroom environment

This section discusses some 1 : 1 DCE example systems from our previous and current research. Such systems use various computational devices. It should be noted that devices from different categories are often used to support several basic computer affordances when designing a particular educational applications.

DCE 1.0

EduClick (Huang *et al*. 2001) was the first version of the DLE series. EduClick comprises of a set of response pads as student devices, a PC as a teacher's device, a TV set or a video projector as classroom-shared display, and adapts a one-way, multiple-to-one infrared wireless technology communication system. The EduClick response pad can emit infrared signal to the receiver with an effective range of approximately 15 m.

EduClick is being used in various elementary school subjects. Before the adoption of EduClick, many classrooms in Taipei City were equipped with desktop computers. However, the actual use of such classroom computers was relatively low. Liu *et al*. (2003a) stated that 38 teachers using EduClick significantly increased the use of classroom computers by a factor of 2.7. Furthermore, instruction quality was improved in terms of student motivation and attention. Chang *et al*. (2004) developed an EduClick environment connecting several classrooms using EduClick with a centralized Internet server for supporting synchronous and asynchronous activities. This environment underpins some novel learning activities, such as inter-classroom contests.

Actually, such response pad systems have a long history, the first appearing at least as early as the fall of 1978 at Stanford University. In a lecture room, response pads were wired so that students could simultaneously answer a professor's questions. A similar system was used in IBM for internal training, and the first discussion of wired response pad systems was by Horowitz (1988). The first infrared response pad system is CPS (see www.eIntruction.com). Our present project group re-investigated the infrared response system, EduClick, in 1999. Other studies have introduced response pads at the undergraduate level. These studies show that using response pads in lectures modestly but markedly increased the quality of

Table 3. Basic communication affordances supporting statuses of 1 : 1 educational computing devices.

Communication affordances	Palm-held device						Laptop computer
	Response pad	Application-specific device				PDA	
		Cellular phone	Learning machine	Electronic dictionary	Graphical calculator		
Response-collecting	R	W	W	F	F	F	F
Posting	N	W	N	W	W	F	F
Pushing	N	W	N	W	N	R	F
Controlling	N	N	N	W	N	F	F
File-exchanging	N	N	N	W	N	R	F
Instant-messaging	N	R	N	W	N	F	F

N, not supported; W, weakly supported; R, reasonably supported; F, fully supported; PDA, personal digital assistance.

learning and teaching (Boyle & Nicol 2003; Draper & Brown 2004). Specifically, appropriate use of the response pad can increase interactivity by provoking students to think, making them feel secure enough to answer questions anonymously, and increasing their confidence in their own learning capacity. On the other hand, the system allowed teachers to adapt instruction steps appropriately, and raise student attendance. As reported in the *New York Times* (Hanfer 2004), Chris Jernstedt, a professor of psychological and brain sciences at Dartmouth College, who used response pad, said that it

> . . . led him to rethink fundamental notions on how learning takes place: 'We know that physical changes occur in the brain when you learn, and that most of the brain's activity occurs outside our conscious awareness,' Professor Jernstedt said. 'If you put all that together, you say —— 'We really have to redesign how we do learning,' and the key issue from all that work says learners have to be engaged.'

In the same report, Hanfer's Professor Caron of the University of Cincinnati agrees that the devices can boost attendance.

> The reason attendance hovers near 100 percent in my classes is because students know if they miss class they do not get credit for answering the questions correctly that day,' he said. In the pre-clicker past, he said, many students were embarrassed to speak out in class. . . . Professor Caron can. . . . embrace the Socratic method by engaging all the students in his law class at once, not one at a time. . . . 'I won the teacher-of-the-year award,' he said, 'and it had to be the technology, because I'm not that good. I've been teaching 13 yr and never won it, then I'm using this thing and I'm Mister Popularity.

However, there are limitations to the response pad system. As pointed out by Liu and Wang (2003), a response pad system can only be applied in question and answer-type activity with multiple-choice questions. Teachers must therefore try to design and present questions to provoke students' thinking. Typical response-pad-based activities require all students to respond to the same question at the same time so that teachers can pay attention to variations in student performance, including response times. Because of its immediate feedback capacity, improper use of the response pads may deprive students of the opportunity to rethink. Also, students could become discouraged when displaying and comparing their answers among their peers. Nevertheless, a good pedagogical design can make the response pad an effective means of encouraging classroom discussion.

DCE 2.0

The wireless technology enhanced classroom (WiTEC) (Liu *et al*. 2003b; 2004; Wang *et al*. 2004), as DCE 2.0, integrates laptop computers (WebPAD & TabletPC) as student devices, standard 802.11b wireless LAN as a communication network, an electronic whiteboard with video projector as classroom-shared display and a resource and class management server as classroom server, to support various learning activities, such as content delivery (*pushing affordance*), free sketch annotations on e-documents, small group co-construction of reports (*file-exchanging affordance*) and whole-class-based simultaneous testing (*controlling and response-collecting affordance*).

Furthermore, WiTEC comprises a learning flow designing tool based on a framework of three learning activity levels, which are learning flow, learning episode, and learning function (Wang *et al*. 2004). A learning activity supported by WiTEC can be represented as a learning flow that is composed of several learning episodes supported by many learning functions. A learning function is a mechanism, supported by computing affordances, for assisting learning activities such as whole-class quiz or content transmission (teacher-directed learning). A learning episode is the basic unit of a learning activity, such as holding a group discussion or co-constructing group product (small group learning). Each episode is supported by a set of learning functions. For example, the co-constructing group product episode might include two learning functions: 'co-construction of report' and 'co-construction of quiz'. Otherwise, a learning function may support multiple episodes. A learning flow is a collection of learning episodes with sequences to perform a completely set of learning activity. For example, a learning flow may contain the following episodes: lecturing, co-constructing group product, student presentation and student peer quiz. In addition, a learning flow may have branches to skip or switch some episodes for fitting different students' status.

This learning flow designing tool enables teachers to select learning functions; teachers can then arrange several learning episodes and connect these episodes to form a learning flow for the learning unit. This tool expands the usability and feasibility of WiTEC, substantially cutting the teacher's preparation workload for 1 : 1 educational activities. The laborious trial-and-error manner of designing learning flows was avoided by the provision of a step-by-step guiding model on how to use this tool (Liu & Yu 2003). Thus, this system could encourage productive interaction in the classroom. A preliminary field study revealed that teachers were positive about WiTEC and there were gains in students learning (Wang *et al*. 2004).

DCE 2.1

Pocket electronic English dictionaries are favourite application specific in China, Taiwan and Japan. Our research team designed a new expansion card that can be plugged into the electronic dictionary. This card consists of a special short-distance wireless communication module, applying two-way RF technology, and flash memory for storing client-side software. English learning mobile device (ELMD) system, is an enhanced EduClick that uses electronic English dictionaries with expansion cards as the student devices. Unlike EduClick, which is a one-way response system, ELMD supports two-way communications between student and teacher devices. In ELMD, besides letting students communicate with the teacher's device, the teacher can also send messages, perhaps including personal feedback, to the student devices. This means that when conducting individual learning, the teacher can use ELMD to supervise and assist student progress. With ELMD, students can input answers in number or text form through a mini QWERTY keyboard, not just a single digit or a symbol as in EduClick.

A typical learning scenario with ELMD (Liang *et al*. 2004) is as follows: when students get into the classroom, their ELMD automatically downloads that day's digital learning material from the teacher's device in addition to uploading their completed homework (*file-exchanging affordance*). ELMD supports digital content for English language learning such as vocabulary, listening, conversation and composition. In the class, with ELMD, the teacher can conduct lectures, interactive quizzes (*response-collecting affordance*) and individual learning monitored by the teacher's device. During teacher-directed learning or individual learning, some lesson material taught in class can be pushed (*pushing affordance*) automatically or manually to the student devices for use by the students at home.

Current progress of DCE 3.0

Currently, DCE has evolved into a third version, DCE 3.0, which supports EduClick, electronic dictionaries and laptop computers. This wide spectrum of devices can evolve in the process of adoption in classrooms. In addition to the DCE 2.0 features, DCE 3.0 includes a device management system, EduCart. Thus, DCE 3.0 essentially consists of all the six components described in 'Educational Computing Environment'. EduCart is a specially designed moveable trolley, which consists of a wireless LAN access point (communication network), an LCD projector (classroom-shared display), a student device recharge module with power consumption management for preventing overload, and reserves storage space for 40 student devices, one classroom server computer and teacher's notebook computer.

The objective of EduCart is to provide an 'all-in-one' and 'plug-and-play' solution that can be used to set up a 1 : 1 educational computing environment more easily. The typical scenario is that the teacher moves the EduCart into the target classroom first, settles EduCart at an appropriate position to make sure the projector aims at the screen and then dispatches the devices to the students. After that the teacher can engage learning activities with students. After the class, the student devices are placed on the EduCart for recharge and the EduCart could be moved to another place. The teachers who participated in a preliminary trial of EduCart found that the workload in setting up 1 : 1 educational computing environments in different classrooms was considerably reduced (Deng *et al*. 2004).

Conclusion and future scenarios

Drawing on 6 years' design experiences with our DCE series and other studies, this paper describes a few substantial design perspectives for 1 : 1 educational computing inside the classroom. It defines the major components of the DCE, classifies student devices according to a set of features, and enumerates important communication affordances. Such perspectives may serve as a guide for future 1 : 1 digital classroom environment.

Wireless and mobile technologies bring forth a unique opportunity for researchers to capitalize on previous research findings to construct a seamlessly integrated learning environment (Joiner *et al*. 2003). Through the preliminary field studies discussed above, we have illustrated the potential of 1 : 1 educational computing to change the ways students learn inside the classroom. Although some initial studies have shown that 1 : 1 educational computing can improve teaching and learning, more evidence is required before it can be commonly adopted in classrooms.

In the short term, as shown in DCE 3.0, different student devices will evolve from very simple forms such as response pads to extremely sophisticated ones such as Tablet PC. Future learning scenarios are also shifting. Students can learn individually, in small groups, in a class, in a large online learning community, at school, at home or outdoors (Chang *et al*. 2003; Chen *et al*. 2003). Students can also easily change the scale of learning participants or places.

In the long term, we can envision an invisible computing era where embedded microchips, immersed sensors and access points are ubiquitous. Visible classroom computing devices, such as desktops and laptops, will become invisible, embedded in our daily living equipment, such as walls, desks, books, pens and even clothes.

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