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From Many-to-One to One-to-Many: The Evolution of Ubiquitous Computing in Education

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Personal, Internet-connected technologies are becoming ubiquitous in the lives of students, and ubiquitous computing initiatives are already expanding in educational contexts. Historically in the field of education, the terms one-to-one (1:1) computing and ubiquitous computing have been interpreted in a number of ways and have at times been used interchangeably. This article examines the development of these computing initiatives in education, discusses the implications of ubiquitous computing for today’s teaching and learning, and suggests future directions for ubiquitous computing.

Introduction

One-to-one (1:1) and ubiquitous computing initiatives are expanding rapidly in educational contexts. The decreasing costs, combined with the lighter weight of laptops and increasing availability of wireless Internet connectivity, make broad implementations of 1:1 and ubiquitous computing feasible (Penel, 2006). Several 1:1 and ubiquitous computing in education projects have been documented. However, different initiatives do not share the same vision and implementation models, which is largely due to the different technology affordances and different understandings of 1:1 and ubiquitous computing.

Historically, studies have used the terms 1:1 computing or ubiquitous computing, often interchangeably, although a clear distinction can be drawn between the two terms. 1:1 computing is synonymous with one computer per student and came into use with the transition from computer labs, where many students shared the computers, to the scenario of each student having one computer. In contrast, ubiquitous computing generally refers to the widespread availability of computing devices, in particular, those with wireless connectivity, both in educational settings and elsewhere. Unfortunately, prior studies have not made consistent use of these terms, which leads to confusion.

This article makes a clear distinction between 1:1 and ubiquitous computing. Specifically, ubiquitous computing refers to emerging learning environments in which one student has multiple Internet-connected devices available, and the ability to learn in a variety of locations.

The distinction between 1:1 and ubiquitous computing can be seen more clearly when considering the evolution of computers in education. Computers and related technologies have been used for teaching and learning for more than 30 years. One might view education’s adoption of computing as having taken place in three significant steps, or “waves,” as envisioned by Mark Weiser (1991). The first wave of computing was mainframe computing, where many people shared the use of one computer; the second was one person, one desktop computing. Ubiquitous computing, a phrase coined by Weiser in 1991, is viewed as the third wave of computing. Weiser said of ubiquitous computing, “the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it” (Weiser, 1991).

Historical Trend

Many Students: One Computer (Many:1)—Learn About Technology. In the 1980s, the desktop computer was the dominant technology. Early studies documented the use of computers in terms of the setting up of computer labs in schools. This marked the notion of providing one desktop computer to many users, i.e., the computers were in a fixed location, and a group of learners took turns sharing the computers. One of the early proponents of the use of computers in schools was Seymour Papert, who compared the computer to a pencil “used as casually and as personally for an even greater diversity of purposes” (Papert, 1980). Learning about technology was one of the main objectives of these computer lab initiatives.

One Student: One Computer (1:1)—Learn from
Technology. The problems of shared computers and computer access gave rise to one-to-one programs (Johnstone, 2003; Rockman, 2003). Since the late 1990s, researchers have referred to one-to-one computing, the transition from computer labs to the model where all students were provided with a computer. The American Digital School Report's definition of 1:1 computing was: “each student and teacher has one Internet-connected wireless computing device for use both in the classroom and at home” (Greaves & Hayes, 2008). In effect, each user had his or her own computing device that was not shared with others. By giving students personal access to the computer, students learned from the computer so that they could become “knowledge users” (Jonassen, 2000).

Many 1:1 laptop initiatives have been implemented in schools around the world. The first laptop school, was implemented in Australia in 1990 (Johnstone, 2003) followed by the emergence of several 1:1 laptop initiatives in the US. Early programs, such as Microsoft and Toshiba’s Anytime Anywhere Learning and Apple’s Classroom of Tomorrow, promoted the use of laptops in classrooms (Apple Computer, Inc., 1995; Rockman et al., 1997). One of the more successful and well-researched initiatives was in Maine, which implemented the first statewide laptop initiative in 2002 (Silvernail & Lane, 2004). This program distributed more than 30,000 computers to every seventh and eighth grader in the state’s public schools in 2002 and 2003. See also Corn et al. (2010) for a report on planning and implementing a 1:1 learning initiative in schools in North Carolina.

One Student: Many Computing Devices (1:Many) —learn with Technology. The availability of wireless broadband technology and ease of access to Internet-connected mobile devices in the last decade has ushered in the era of ubiquitous computing: the use of any device with wireless connectivity. Hill, Reeves, and Heidemeier (2000) defined ubiquitous computing as the widespread availability of portable, networked technologies, which offered an enhanced model of access to computing technologies to provide just-in-time, when-needed computing. It provides instant and continuous access to a vast array of resources, such as searches of library catalogs while taking notes, recording audio and video, and interacting simultaneously with peers in-class and around the world in real-time (DiGangi et al., 2007). It enables learners, teachers, and parents to have access to computing technology whenever and wherever it is needed.

The term ‘ubiquitous computing’ is more encompassing than 1:1 computing, and includes the network-connected technological environment which reflects today’s learning environment. Van ‘t Hooft and Swan (2007) considered ubiquitous computing in educational settings as “learning environments in which all students have access to a variety of digital devices and services, including computers connected to the Internet and mobile computing devices, whenever and wherever they need them.” They focused on many-users-to-many-devices rather than one-to-one or one-to-many. Technology was viewed as being always available but not itself the focus of learning. Ubiquitous or pervasive computing, as it is sometimes called, is computing that is available through a variety of digital tools wherever and whenever it is needed to support human endeavor (van ‘t Hooft & Swan, 2007).

Furthermore, researchers have indicated the importance of ownership of the computing devices. The computing devices should be students’ personal devices rather than school devices. Soloway and Norris (2002) argued that how one learned would change if everyone owned and regularly used a personal computing device, just like learning changed when everyone was able to afford a pencil (Papert, 1980) and similarly when everyone could own a book instead of sharing with others. Personal computing devices will play a significant role in education and learning when they become more human-centered, less visible, and available to students whenever and wherever they need them (Norris & Soloway, 2004; Roschelle & Pea, 2002; van ‘t Hooft & Swan, 2007).

The ubiquitous 24/7 access to computers makes it possible for students to access a wider array of resources to support their learning, to communicate with peers and their teachers, and to become fluent in their use of the technological tools of the 21st century workplace.

When students are also able to take computers home, the enhanced access further facilitates students keeping their work organized and makes the computer a more personal device (Vahey & Crawford, 2002). These personal devices allow them to “learn with technology” during which they acquire knowledge when they are actively engaged in designing and creating technology-based products (Jonassen, 2000).

Each student having more than one computing device is a reality for most technologically-advanced societies today. Although students have more than one device, they only use one device at a time, switching devices because different devices serve different purposes. Table 1 summarizes the development of the concept of ubiquitous computing for learning and education.

Table 1: Ubiquitous Computing and Learning

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>First laptop school implemented in Australia</td>
</tr>
<tr>
<td>1995</td>
<td>Microsoft and Toshiba’s Anytime Anywhere Learning initiative</td>
</tr>
<tr>
<td>2002</td>
<td>Maine statewide laptop initiative</td>
</tr>
<tr>
<td>2007</td>
<td>Van ‘t Hooft and Swan’s ubiquitous computing initiative</td>
</tr>
</tbody>
</table>

The Future

From Device Centric to Student Centric, from Technology to Pedagogy

Ubiquitous computing is expanding beyond desktop and laptop PCs and into the everyday world, in the form of smartphones, information appliances, everyday digital devices, smart environments and wearable...
The affordances of one-to-many ubiquitous computing devices for learning are as follows:

1. **Learner-centeredness**: Students can actively use the devices to engage in learning activities by interacting with people, resources, and the environment. Gaining ownership of what and how they want to learn, they become co-producers of knowledge. Use of the device becomes a routine practice and is assimilated into everyday needs for communication, reference, and learning.

2. **Personalization**: Learning is a human activity quite diverse in its manifestations from person to person (Dede, 2008). The personal device can store, organize, and retrieve personal information, cases, events, knowledge structures, and processes. It can empower the students with more autonomy to chart their learning paths.

3. **Adaptability**: The use of the personal device is adapted to the learner's evolving abilities, skills, knowledge, and learning styles and is designed to support individualized learning, rather than general office work. The device can accommodate versatile learning activities. The students can use a variety of learning applications that support different types of learning activities. Students can type, draw, take photos, record audio or video, etc., all of which support their multimodal expressions.

4. **Learning anytime and anywhere**: The technology is available anytime. Portability allows students to take these to different sites or move around within a site, so that they can be available wherever the student needs to learn. The device allows learning to occur wherever the student happens to be. The students can capture and retrieve in-situ information without encroaching into spaces obtrusively. The student's personal accumulation of resources and knowledge is persistent and can be

<table>
<thead>
<tr>
<th>Time</th>
<th>Devices</th>
<th>Student to Computing Device Ratio</th>
<th>Portability</th>
<th>Student Ownership</th>
<th>Relationship Between Technology and Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980s–1990s</td>
<td>Desktops</td>
<td>Many-to-One</td>
<td>No Portability</td>
<td>Shared</td>
<td>Learn about Technology</td>
</tr>
<tr>
<td>1990s–2000s</td>
<td>Desktops and Laptops</td>
<td>One-to-One</td>
<td>Some Portability</td>
<td>Shared and Personal</td>
<td>Learn from Technology</td>
</tr>
<tr>
<td>2000s–Today</td>
<td>Internet-Connected Laptops and Handheld Devices</td>
<td>One-to-Many</td>
<td>Portability</td>
<td>Personal</td>
<td>Learn with Technology</td>
</tr>
</tbody>
</table>

As van 't Hooft and Swan (2007) have pointed out, classrooms that do not afford students and teachers ubiquitous access to technology is one of the reasons computers have not revolutionized education. The migration from many-to-one and one-to-one to one-to-many ubiquitous computing has profound implications for the use of technology in teaching and learning.

When many students shared a computer in the classroom in the 1980s, the technology-enhanced teaching and learning happened at fixed times and places. When the computing devices moved from desktop to laptop and handheld computers, which are small, portable, and network-connected, the students' learning space was no longer constrained by scheduled class hours or specific locations. The use of mobile technology can help extend students' learning spaces and enrich the learning experiences in their everyday lives, where they move from one context to another, switching locations, social groups, technologies, and topics. Whenever they have inquiries, they can log on to the Internet to search relevant information, find answers, validate the credibility and accuracy of sources, detect bias, and draw conclusions by analyzing and synthesizing large quantities of varied input (Bjerede, Atkins, & Dede, 2010).

The in-situ use of the devices in different contexts allows students to make connections to what they learn in the classroom with their daily life experiences outside the classroom (Chen et al., 2010). With the networked mobile devices, many of the dynamics of a classroom can now occur asynchronously after the formal school day is complete (Bjerede, Atkins, & Dede, 2010).

Learning is interwoven with students' activities in everyday life. The computing device that is used to support learning should be integrated with everyday life in the same way that learning occurs in everyday life.
This technology enables students’ data exchange, communication, and collaboration with teachers, experts, friends, family members, etc. Students can use the device to share their work, engage in peer critique, and revise and iterate their work products (Bjereide, Atkins, & Dede, 2010).

6. **Contextualized and situated learning:** As the mobile device can be turned on and off instantaneously, students can use it whenever they need to, enabling them to make rapid connections between ideas and observations. The mobile device can both gather and transform learning. The device can be turned on and off instantaneously, students can use it whenever they need to, enabling them to make rapid connections between ideas and observations. The mobile device can both gather and transform learning.

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**Conclusion**

The development of ubiquitous computing is coupled with the development of computing technologies. When and where the number of computing devices and the function of devices is limited, the student-to-device ratio is the key indicator for ubiquitous computing. However, with the rapid development of computing technologies, computing infrastructure has become more and more pervasive. Today’s devices do not come with a single stand-alone feature, but are multi-functional. For example, a cellphone has an embedded camera, mobile Web browser, GPS, and audio and video capabilities. This technology convergence sets the stage for self-directed learning.

The widespread access to computing devices makes it possible for students and teachers to transition from occasional, supplemental use of computers to more frequent, integral use of technology across a multitude of settings (Roschelle & Pea, 2002). Increasingly, the world itself is an interface to computation; computer-based interactions can take place through many kinds of devices, surfaces, and places.

Ubiquitous computing in education can be seen as moving away from the terms computers and computing devices, toward the broader concept of personal learning devices. The future development of ubiquitous computing will move away from the student-to-device ratio and towards students’ choice of devices for learning in different situations.

The traditional focus on ubiquitous computing in education has been technologically-centric. The procurement of desktop or laptop computers and the setting up of computer laboratories were administrative attempts to meet the 1:1 ratio. Research was mostly concerned with the devices and their features, implementation policies, and how these devices might transform learning.

The focus of future ubiquitous computing will depart from the traditional view by shifting focus from tools to the learners, and away from the technology and the ways the technology is brought into the classroom. It will focus on the learner and how he or she uses the technology to enhance or enable learning. It is not about the laptops, for example. It is about what the laptops enable each owner to do in terms of new ways of teaching and learning (Dunleavy et al., 2007).

Nowadays, many consumer-oriented computing devices are not designed specifically for educational application, yet they can be used productively in educational settings given the right pedagogy. Norris and Soloway (2009) have argued a move away from technology, and toward a focus on pedagogy. They have argued that with lowering costs, technology ownership ceases to be an issue.

This shift towards ubiquitous computing, with an emphasis on a pedagogic viewpoint, will bring about a fundamental change in the application of technology in teaching and learning environments. Substantial research is needed to understand different pedagogies required to achieve the full potential of ubiquitous computing for teaching and learning.

**References**


