The Physicality of Technological Devices in Education:
Building a digital experience for learning

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Abstract—Technological devices are being rapidly adopted into schools and by individual students for purposes of education. In the face of the large financial investment represented by these devices, we have limited understanding of the value and ways through which the devices can benefit learning. As opposed to research placing the value of these devices in terms of digitality, we make use of theories of embodiment to understand how the physicality of the devices can support the learning and sense-making processes. We conducted a month-long study to collect data on students’ strategies, patterns, attitudes and behaviors toward the use of different devices, including an iPod Touch, an iPad, a touch-enabled iMac, their own laptop and large displays for the completion of a course assignment, consisting of a written report about the field of physical computing. Themes uncovered after triangulation of findings include the objectification of information, the immediate awareness of possibilities, an expectation of interaction, coherence of interaction and territorialization of technology spaces. We present a model for the role of physicality of devices with regards to educational activities, and argue for the need to construct a digital ecology to be able to provide a cohesive experience of learning.

Keywords: Physicality; learning; sense-making; digital devices; embodiment; experience; ecology

I. INTRODUCTION

From PDAs, laptops, mobile phones and tablets, new technological devices have been anticipated in many quarters as being beneficial tools for learning. Since the launch of the Apple iPad in 2010, many have touted the new device as having tremendous potential for education, both to enhance technology skills and to support curriculum learning. Many districts are paying for tablet distribution in low-performing schools. From the elementary to tertiary level, schools as well have been quick to launch pilot programs that hand out iPads to every student and teacher [1-3].

However, these devices are often introduced into schools without full understanding of their effect on learning. Despite the pervasiveness of such computing devices in educational and personal contexts, we have limited understanding of how to effectively use them in education. The goal of our research is to gain a better understanding of how students’ learning is impacted through the use of all these new ubiquitous devices.

In their article on the challenges that the new technological movement is bringing to the existing educational paradigm, Collins and Halverson [4] hint at the importance of looking at the “affordances of digital media” to understand the tensions brought about by the introduction of digital enablements in an environment of traditional tools. Despite high praise about the technical capabilities and physical attributes of the devices such as smooth scrolling, appropriate size for reading, and lightweight [5, 6], the benefits of tablets, laptops, PDAs and others are often summed up in the value of the applications installed (e.g. [7]). There seems to be an implicit assumption that mere connectivity and access to content through the devices is a sufficient condition for learning [4]. Much research has thus been carried out on the use of e-learning environments (e.g. [8]), the Web 2.0 (e.g. [9]) or wireless connection through mobile devices (e.g. [10]).

A key problem that arises from looking at the benefits of technological devices as being placed mostly in the digital realm is that digital media is immaterial, invisible, and ephemeral. At first glance, this seems counter to theories that emphasize the importance of physicality and embodiment for learning. In this paper, we ask the question of whether the new class of technological devices used in education brings about a lack of a ‘physical’ or ‘persistent’ handle. How does the physicality of the devices, or their mere existence in the educational context, impacts learning, thinking and sense-making processes?

We first provide a theoretical motivation to our research by briefly reviewing theories of physicality and embodiment, describe a study conducted to investigate the focus issue, proceed to discuss findings and insights gained, and then articulate a model based on uncovered themes.

II. THE PHYSICALITY OF DIGITAL MEDIA

Digital media is not only about digitality. Our embodied nature as human beings means that even digital media has to be necessarily framed in a physical form factor to allow for interaction. As succinctly expressed by Buscher [11], physicality is not just about the physical properties of matter, more importantly, it is about “the effect of interaction” with the physical bodies. The significance of physicality to influence thinking processes has been advanced by many
including Vygotsky, Polanyi, Merleau-Ponty, Heidegger, Piaget and Papert.

Vygotsky and others following in his stride such as Leont’ev and Engestrom called for “a serious study of artifacts as integral and inseparable components of human functioning” [12]. According to their mediation theory, artifacts, acting as externally-instantiated signs called ‘material carriers’, have a mediating effect on higher-level processes such as thought. Polanyi [13] and Merleau-Ponty [14] argue that we gain a certain awareness of tools by physical manipulating them using bodily actions, leading to an internalization process of experiences. Heidegger [15] proposes that our existential engagement with the world only becomes meaningful through our interaction and experience with tools in the world, and that the tools can act in different capacity from being ‘present-at-hand’ to ‘ready-to-hand’. Last but not least, Piaget and Papert [16] inform us that learning is actively constructed through interaction with the world, and that it is transformed when expressed or actualized in different media and contexts.

The common underlying message that we see in this theoretical basis is that the study of the physical manifestation of digital media in the form of artifacts and tools as actualized in an educational context is a worthy effort. It provides a motivation for us to ask “Can we assume that the new technologies are beneficial only through their digital potential?”.

In light of these theories of embodiment, we carried out a study to investigate the affordances of the new technological devices, the conditions that they provide for knowledge construction processes to occur, and the ways in which they are integrated into students’ workflow.

III. STUDY DESCRIPTION

The study was conducted with a computer science graduate class of 11 students, whereby students were given different devices, including an iPod Touch, an iPad, and an iMac to use as their own throughout the semester. The iPod Touch is the size of a smart phone with touch capabilities, and operate on the same framework as the iPad. The iPad is a light, portable tablet with a touch screen that is roughly the size of a typical piece of paper. The iMac is an all-in-one desktop, consisting of a rather heavy weight large screen. For the purpose of the study, the iMac was endowed with a touch overlay to enable touch interaction comparable to the iPod Touch and iPad. Figure 1 shows the device suite of each student.

The rationale for the dissemination of devices of various form factors was to study how the students would make use of the devices during their sense-making processes to complete a semester assignment. The assignment, to be completed in teams of three, consisted of researching about and writing a report on the nature of the field of Physical Computing, an emergent and as yet nebulous field. The class was held in our research center, which contains large display screens spread around in different meeting rooms. All the students were computer science students who had constant access to the building. All students were asked to use the different devices given to them in conjunction with the large display screens around the center, and any other devices that they own such as laptops and other desktops for the assignment. They were also allowed to use the devices freely for any other purposes and in any other ways that they wished to.

Data was collected about the students’ behaviors and ‘strategies of use’ of the devices, as well as their attitudes toward and perceptions of the devices and processes. Data collection was done under two conditions: a. ‘in the wild’ or under actual use for a month using daily surveys administered online via an email link, and pre- and post-interviews; and b. during two scheduled sessions whereby the students were asked to work in their respective teams on the assignment within constraints of time and space. Notes were taken by an external observer during those sessions and the conversation among the team members were recorded. Clarification questions were also asked about the scheduled sessions in the post-interviews.

IV. STUDY FINDINGS

For analysis purposes, data from all the different sources (i.e. interviews, surveys, observations) was used in triangulation to understand the students’ key patterns and strategies. The fundamental activities that were involved in the overall process generally followed those specified by Umapathy [17] for collaborative sense-making: construction and sharing of knowledge; collaborative development of shared knowledge; development of shared situation awareness and understanding; and communication, coordination and collaboration that support all the other activities. Across all of these stages and irrespective of the students’ prior experience with the particular devices, we found that some of the devices were never truly integrated into the students’ personal sense-making process, in particular the iPod Touch, the iMac and the large displays. The overall feeling was that it was “awkward to integrate new technology” into their workflow. The students did not see the iPod Touch as having much use in their work processes. Its small screen size especially acted as a constraint that led the students to perceive it as mainly a music player, although the device has essentially the same capabilities as a tablet.

The iPad was somewhat integrated into the sense-making process especially acting as a constraint that led the students to perceive it as mainly a music player, although the device has essentially the same capabilities as a tablet.
process but to a limited extent. The general trend was that it was useful for opportunistic information foraging and for looking up only information that could be easily remembered: participants read webpages on the iPad only to get an overall understanding of what people think about the subject in general, or to search for authors’ names of a particular paper. The iPad seems to have been extensively used as well for purposes that were stand-alone and transient such as for social applications and entertainment (e.g. instant messaging, social networking, email, news). When notes were taken on the native note-taking iPad application, most students reported that they stayed on the device. The device was then used as a separate secondary display whenever access to the notes was needed again in other contexts.

Strategies for self-sharing of information (transferring own information across different personal devices) were all through the use of online services and cloud computing. No physical strategies such as cable syncing were used. Strategies included for instance the use of Evernote [18], a multi-platform online note-taking application, Dropbox [19], an online storage service, Google docs [20], a real-time online document editing service, emailing to their own email addresses, and whenever needed, re-searching again through search engines on another device for information found on a first device.

Among software used to support the students’ workflow, Evernote was the most controversial. While the students found its cross-platform capabilities useful, the inconsistency of the interface design and features across browsers and devices proved to be too time-consuming and involved for some to integrate into their work processes.

The difficulty to multi-task on the iPad was a key barrier to the use of the device for work task or assignment-related purposes. During the process of foraging for information for instance, often the students required many applications to be opened simultaneously (e.g. multi-tabbed browser, PDF reader, word document, email application). Students found switching between applications on the iPad to be very laborious and “annoying” over an extended period of time. At the same time, the fact that on the iPad, the application takes up the whole screen real estate was perceived as being beneficial to direct attention focus and thinking. Students pointed out that this gave them the feeling that “it’s the only thing that exists on the iPad for this purpose”. On the laptop however, there is a “70-80% of surfing the Internet”, for example, while working in an application.

V. DISCUSSION

Viewing our findings and analysis in light of theoretical underpinnings on physicality, we uncovered five main themes that relate to how devices may mediate students’ thinking, workflow and sense-making processes. We describe each theme before presenting an integrated understanding of the role of physicality of devices in the educational workflow:

A. Themes

1) Objectification of information

We advance the concept of ‘objectification’ of information. Though processes seemed to be most effective when students are able to directly, quickly and solely focus attention on the material being handled (e.g. a particular document, website). An illustrative scenario may be when faced with the need to retrieve a specific diagram, one can think purely of the diagram content itself and not of how to access the diagram by going to a particular folder and sub-folder first. In our study, we saw that this objectified type of thinking (as opposed to the more ‘procedural’ type) can be supported by devices characterized by transparency of interaction and purposeful or dedicated use.

The chief example would be the iPad, whose form factor and application-based model provide a constrained yet liberating environment in terms of freedom from distractions and converging object thinking through its default full screen use. Using Vygotsky’s terminology, with the iPad, what would otherwise have been just pixels on a screen become more easily a ‘material carrier’ of particular signs, facilitating internalization and thus allowing thinking to proceed through the medium. According to Vygotsky, through a process of internalization [21, 22], signs can be appropriated by the individual to become tools for the construction of new concepts. The internalized sign is never completely divorced from its ‘material carrier’ (which in the case of objectification is the device), and the presence of the ‘material carrier’ can assist in the use of the internalized sign for the individual cognizer.

2) Immediate awareness of possibilities

Possessing a device does not necessarily lead to its use and appropriation as support for work processes. Students have to be ‘aware’ of the availability of tools and their capability to aid particular tasks right in the moment. Often, students fail to integrate the devices into their sense-making because although they ‘know’ that they have the iPad, iPod Touch or iMac at their disposition and that the devices can perform the wanted task, they do not really ‘know’. In Heidegger’s terms, to have a chance to be integrated into a learning workflow, devices need to move away from the state of being ‘present-at-hand’, neutrally just being there, to having a perceived significance as to their usefulness for tasks. We argue that the physicality of devices needs to be endowed with affordances that can be perceived by the learner to support sense-making tasks and processes.

3) Expectation of interaction

Many breakdowns in the use of the multiple devices during our study occurred due to a lack of easy interaction among the separate entities. The nature of the work that could be done on the iPad, for instance, was perceived as being distinct from that which is done on the laptop. Without a way for the students to move work done (e.g. information or picture found, part of a document written, references typed) from one device to another for the ease of integration, sense-making is hindered. In the paper world, a scrap piece of paper on which notes have been scribbled can be simply and effortlessly tacked in a notebook, and information in the notebook and on the paper scrap can then
easily be used in tandem. Our experience of using tools in the world to make sense of information cannot be singular and isolated. Current strategies used by students to bridge this interaction gap among their different devices are mostly ad-hoc in nature, and constructed with resources currently available (e.g. access to Internet for email).

Lewin, quoted in Ross & Nisbett [23], proposed the idea of channel factors as “small situational forces that either increase impelling forces or reduce constraining forces to move individuals toward a specific behavior”. Channel factors catalyze behavior in a particular direction whenever “small but critical facilitators or barriers” are encountered. We posit that this inability for students to expect that devices will interact may guide decisions on the use of devices for certain tasks and even deter completely from device appropriation. Motivation then increases for either a single device use or the use of non-digital artifacts in the well-established paper world.

4) Coherence of interaction

Related to the previous theme, cross-device interaction must be accompanied with a coherent experience in use. Varying features, incompatibilities and illogical procedure flow in the interaction from the student’s point-of-view increases the learning curve during switches between devices. We are not advocating that the interface should necessarily be identical or similar on all devices. Applications that currently allow interaction among different devices through cloud computing follow such a one-framework model. Instead, the particular physicality of each device (each is to a certain extent naturally more amenable for some tasks than others) can be used to dictate the design of features and interaction needed to provide support for processes vertically throughout the knowledge construction workflow. Making full use of the totality of all the different devices concurrently during any one period of time thus will create a wholesome learning experience, instead of jarring staccato advancements in work each time.

5) Territorialization of technology spaces

Many, specifically Harrison & Dourish [24], have highlighted the importance of space and place in collaborative work systems. Prior research (e.g. [25-27]) have proposed singular collocated systems that build upon the need for private spaces for personal work alongside a public space for shared, coordinated work. Our findings validate this need for collaborative work across multiple devices as well. During the scheduled collocated work sessions, the appropriation of personal and shared spaces was through a segmentation of technology ‘surfaces’. The segmentation appeared to be mostly stable, but still remained fluid depending on form factor, accessibility, changing discussion content and varying spatial layout. For example, although the laptop and/or the tablet were typically used as private spaces when brought in meetings, they were at times also used to physically share information to others. The non-availability of devices of particular physicality can modulate the initial private-public segmentation of devices, e.g. every present member using the laptop as both a private and public space through the simultaneous use of GoogleDocs when a large display is absent in the room. Whether this dual use of the same technology ‘surface’ as both private and public space is detrimental to work and sense-making processes remains to be investigated.

B. A Model of The Role of Physicality in Education

Simply being given technological devices does not by default translate to beneficial changes in the educational process of the student. Although some benefits came in the form of the discovery and use of new educational/productivity software on the iPad for example, the very physicality of the devices and its interaction effects mediated how the students used digitality to construct knowledge and make sense of information to complete the assignment given. Figure 1 shows a model of the role of physicality of devices with regards to support requirements, its effects on collaborative sense-making activities, and its importance to create a cohesive learning experience.

We posit that two key features are needed to fully realize the potential use of all the different devices that are in our milieu: an expectation of interaction and a coherence of interaction across devices. These act as an underlying buttress in terms of communication, coordination and collaboration for other activities in collaborative sense-making described at the beginning of Section IV.

We identified that physicality in turn can affect thought processes in three ways: through encouraging or discouraging objectification of information and awareness of task and use possibilities, and steering choices in the segmentation of technology ‘surfaces’ into private and public spheres. Information objectification and possibility awareness can positively change the way information is regarded, directing attention to the most effective device for particular tasks, and focusing attention during the use of a device by turning it into not only a ‘carrier’ of thought but also a support for the actual process of thinking.

The importance of common spaces to allow for the development of shared knowledge and situation awareness has long been shown. Each of the different devices that populate our technological environment is perceived to have more of a public or private connotation attached to it. Within one’s own suite of devices, the same public-private attribution is done so that when a ‘private’ device is used to be a ‘public’ space, the switch is quick and temporary and sometimes even accompanied by a certain discomfort. The support of easy cross-device interaction may help to attenuate this discomfort by keeping the segmentation stable during collocated collaborative sense-making work.

Figure 2. Role of the physicality of devices in the educational process
Based on our observations from the results of our study, we argue that for digital devices to support the whole learning/sense-making process from top to bottom and to allow students to construct their own knowledge in the sense of Papert [16], the devices need to be able to work in concert and encourage appropriation. To take the analogy of the paper world that we live in, each piece of paper, pen, notebook, bookmark, highlighter that we appropriate to support our learning experience has been designed to fit into and contribute to that particular paper ecology. The framework that we have presented identifies a set of requirements that can potentially allow computational devices to form a digital ecology that is counterpart to the paper ecology, and a set of affordances through which the digital devices, by their embodied nature, work through to support the sense-making workflow.

VI. CONCLUSION

That technological devices are now ubiquitous in education is a fact in the context of both institutions and the individual learner. Much research that investigates the benefits of those devices for learning places much emphasis on the framing of educational content from the point of view of digitality. We question instead how the physicality of devices and the effects of interaction that it brings with it affect processes involved in sense-making and learning. We conducted a month-long study involving the distribution of different devices to graduate students to examine their use and appropriation throughout the completion of a semester assignment. Informed by theories of embodiment, we uncovered five key themes based on our insights from general patterns in the students’ attitudes, strategies and behaviors. We formed a model, incorporating our themes, of how physicality can assist in the knowledge construction process. Finally, we argue that to achieve a coherent and substantive experience of learning and sense-making with digital devices, there is a need to design new interaction affordances that will support a digital ecology. Further research is needed to be able to specify the exact architecture that can effectively motivate full use and appropriation of devices among learners.

REFERENCES


