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# Problem-Based Learning in Multimodal Learning Environments: Learners' Technology Adoption Experiences

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**Abstract**

In this study, we enhanced a problem-based learning (PBL) environment with affordable, everyday technologies that can be found in most university classrooms (e.g., projectors, tablets, students' own smartphones, traditional paper–pencil, and Facebook). The study was conducted over a 3-year period, with 60 postgraduate learners in a human–computer interaction course, following a PBL approach to teaching and learning. First, this article contributes a detailed description of how PBL can be enacted in a multimodal, technology-rich classroom. Second, the study presents evaluation data on learners' technology adoption experience while engaging in PBL. Overall, the participants positively endorsed the learning environment, rating their experience highly on scales of communication and interaction, reflection, perceived learning, and satisfaction. In addition, quantitative content analysis of Facebook use documented how the physical and digital tools in the environment, coupled with the capability of Facebook as a recordkeeping and communication tool, were integral part of the PBL process.

**Keywords**

multimodal learning environment, problem-based learning, PBL, technology-enhanced PBL, computer-supported PBL, Facebook, technology adoption, learner experience, educational technology, HCI education

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## Introduction

As technology becomes more and more affordable, classrooms in higher education institutions are transformed into multimodal learning environments, while more and more learners walk into these classrooms equipped with gadgets such as smartphones and tablets and connected to the networked world and social media (Dede, 2011). Despite the possibilities these trends offer for teaching and learning in higher education, well-established student-centered pedagogies, particularly problem-based learning (PBL), continue to be enacted in low-tech classrooms (Hmelo-Silver, 2004; Hmelo-Silver & Simone, 2013).

The idea of enhancing PBL through technology is not new. Attempts to improve PBL process and outcomes using technology can be traced back to 1995 (see Koschmann, Kelson, Feltovich, & Barrows, 1996). A review of PBL by Hung, Jonassen, and Liu (2008) discussed that use of technology in PBL follows two major trajectories: the combination of PBL with e-learning (e.g., virtual PBL) and the use of multimedia in PBL (e.g., games, simulations, virtual worlds). There is also a growing research base in the areas of technology-enhanced and computer-supported PBL with emphasis on researching tools and methodologies for the support of online and hybrid PBL (e.g., Bonk & Graham, 2006; Derry, Hmelo-Silver, Nagarajan, Chernobilsky, & Beitzel, 2006; Donnelly, 2004, 2010; Hmelo-Silver & Chernobilsky, 2004; Sendag & Odabasi, 2009). For example, Hmelo-Silver and Chernobilsky (2004) examined students' interactions and tool use in eSTEP, a system with features such as video cases and a discussion board designed to support preservice teachers as they engage in online PBL. Moreover, Derry et al. (2006) examined STELLAR, a hybrid PBL environment for preservice teachers, offering a library of multimedia cases and an electronic notebook for the recording of important issues for later discussion face-to-face. Also, Donnelly (2010) investigated a hybrid PBL environment making a combined use of video conferencing, asynchronous discussions, synchronous chat sessions, online reflective journals, podcasting, and face-to-face PBL tutorials. In general, these studies have shown that learners embrace the use of technology in PBL and that technology holds promise in supporting PBL processes and outcomes.

Yet, despite the growing research in the area, it is fair to say the role of affordable, everyday technologies in supporting PBL has received less attention, compared with PBL research on complete systems such as STELLAR and eSTEP or dedicated e-learning tools such as discussion forums and video conferencing. In fact, recent reviews of PBL indicate that collocated (face-to-face) PBL mainly uses a simple tool—a whiteboard where facts, ideas, hypothesis, learning issues, and actions plans are listed to help students structure their problem-solving and guide the learning process (Hmelo-Silver, 2004; Hmelo-Silver & Simone, 2013). In this work, we enhanced a PBL environment with affordable, everyday technologies that can be found in most university classrooms (e.g., projectors, tablets, students' own smartphones, traditional paper–pencil, and Facebook). This study is part of a larger scale investigation of how everyday technology can support PBL processes and outcomes. The present article focuses on presenting:

1. details on how PBL can be enacted in a multimodal, technology-rich classroom and
2. evaluation data on learners' technology adoption experience while engaging in PBL.

## Background Work

### A Brief Review of PBL

PBL is an instructional method that puts students in the active role of problem solvers confronted with an ill-structured problem that mirrors real-world problems. PBL has its roots in constructivism and assumes that students learn best when they resolve problems that are situated in the target context and require the kind of thinking that would be done in real-life situations (Duffy & Cunningham, 1997). Hmelo-Silver (2004) argued that this student-centered pedagogy aims to help students develop flexible knowledge, effective problem-solving skills, self-directed learning skills, and effective collaboration skills, with the most consistent finding in PBL research being the superiority of PBL-trained learners in lifelong learning (Hung et al., 2008). Although originally associated with medical curricula (Barrows, 1994), PBL is currently used in a variety of domains and educational levels, fostering learning through engagement in complex domain-related tasks.

In a typical PBL course, the curriculum is designed around one or more complex, ill-structured problems in the domain, with no obvious, single, correct solutions. PBL begins by presenting the problem to the students. Students in small groups (usually 6–8 students) analyze the given problem; they brainstorm ideas and hypotheses based on their prior knowledge, and they identify knowledge deficiencies (Barrows, 1994). Knowledge deficiencies, that is, what students need to learn to be able to solve the problem, are known in PBL as "learning issues." The recognition of learning issues requires coordination in real-time, while researching of the learning issues is typically assigned to individual learners and takes place outside of the face-to-face meetings (Hmelo-Silver, 2004; Koschmann & Stahl, 1998). Learning issues are central to self-directed learning. In fact, it is the way in which learning issues are processed that separates PBL from other forms of student-centered instruction (Barrett, 2005).

After a period of self-directed learning, the group reconvenes; the newly acquired information is reported back to the group and applied to the problem, while the initial hypotheses are rethought in the context of this new information

(Hmelo-Silver, 2004; Koschmann & Stahl, 1998). As learners work through the problem, they may pause to reflect on the information they have collected so far, clarifying their hypotheses and identifying new learning issues in resolving the problem (Hmelo-Silver & Simone, 2013). Reflection also happens at the very completion of the task, to abstract lessons learned. In this case, students reflect on what they learned from working on the problem, they critique the effectiveness of their strategies employed (i.e., what they could have done differently in studying the problem that would have led to better learning), they identify areas for future improvement, and they self-assess and assess their peers with respect to how they performed in self-directed learning and collaborative problem-solving (Hmelo-Silver & Simone, 2013; Koschmann et al., 1996; Koschmann & Stahl, 1998).

The way in which learning issues are generated, researched, and taken up within the group's work is presented by Koschmann and Stahl (1998) as a four-phase process:

1. recognition (problem analysis, recognition of learning issues);
2. researching (self-directed study of learning issues);
3. reporting (group reconvene; newly acquired information is applied to the problem); and
4. reflection (reflection on the information collected so far, clarification of hypotheses, and recognition of new learning issues).

The success of PBL depends on a number of factors. The section of good problems and the skilled PBL facilitator are two main ones. The PBL problem is one that is problematic to the student and that cannot be resolved with the current level of knowledge or way of thinking (Barrett, 2005). It can be an ill-structured design brief for an interaction designer or an architect, a dilemma for a doctor, or a challenge for an engineer and can be presented to students in a variety of formats such as scenarios, puzzles, diagrams, dialogues, quotations, and video clips among others (Barrett, 2005). The role of the PBL facilitator is not to teach or give information about the problem, but rather to scaffold the learning activity and facilitate students' collaborative learning and reasoning through the problem (Hmelo-Silver, 2004).

Other factors influencing the success of PBL include the effective researching of learning issues by individual learners, the effective collaboration within groups, and the abstraction of knowledge through reflection. Effective researching of learning issues during self-directed study will feed into the collaborative problem-solving process and support the group's efforts in solving the problem. Effective collaboration within PBL groups can lead to knowledge construction, as students use newly acquired knowledge to clarify their hypotheses and construct joint explanations (Hmelo-Silver, 2002). Reflection is necessary for students to relate new knowledge to prior understandings, abstract knowledge, and understand how it can be reapplied (Hmelo-Silver, 2004). Logically, it is only fair to say that the classroom setting, in which these processes take place, can play a vital role in the success of PBL (Ioannou et al., 2015) by providing additional support for researching, collaboration, and reflection.

## Technology-Enhanced PBL

A review of PBL by Hung et al. (2008) discussed that the use of technology in PBL follows two major trajectories. First comes the combination of PBL with e-learning (i.e., online and blended forms for PBL). In this case, the Internet is used to offer better access to resources, while web environments are used for the organization of PBL courses. In online PBL, several forms of synchronous and asynchronous communication tools are used from simple forums and wikis (Ioannou, Brown, & Artino, 2015) to custom-made tools specially developed for enhancing the PBL practice such as LdShake (Hernández-Leo et al., 2011), e-Forum (ChanLin, Chen, & Chan, 2009), eSTEP (Hmelo-Silver & Chernobilsky, 2004), or STELLAR (Derry et al., 2006) among others. The second trajectory involves the use of multimedia in PBL. A few studies have focused on understanding game elements that might lead to improvements in students' engagement. For example, Echeverri and Sadler (2011) examined the use of gaming environments in PBL courses with encouraging results in terms of knowledge gains and student motivation. Others suggest that immersive virtual worlds are important to combine with PBL (e.g., Savin-Baden, 2011). For example, Parson and Bignell (2011) studied the use of Second Life a psychology undergraduate course where students communicated with avatars to identify the family's characteristics in solving a case problem; students reported higher levels of engagement in the module and felt that the new form of digital presence was valuable and successful in helping them acquire knowledge.

Apart from these two major trajectories of using technology in PBL (Hung et al., 2008), we further looked into how other technologies seem to provide support for PBL-related processes and outcomes in learning environments similar to the one presented here. In fact, a few researchers from various fields of engineering, design, and education have designed and investigated technology-rich learning environments, stressing the importance of understanding the affordances or constrains different technologies such as mobile devices can bring to the environment (Looi, Wong, & Song, 2012). For example, technology-rich learning environments have been designed to improve creative problem-solving using interactive, touch sensitive displays built into the meeting room's tables and walls (Hilliges et al., 2007); boost creative conversation around product design using a downward-pointing projector during tutorials and a blog space for communication in between meetings (Bardill, Griffiths, Jones, & Fields, 2010); orchestrate teamwork within a multidisplay work environment including laptops, shared workstations, and smaller or larger interactive displays (Huang, Mynatt, & Trimble, 2006); support collaborative learning including provision of feedback, brainstorming, scaffolding, and refection in an environment enriched with interactive tabletops, student personal devices, and external project websites (Martinez-Maldonado, Clayphan, Ackad, & Kay, 2014). It is therefore possible that a technology-rich space, where multiple everyday technologies are laid next to each other, will result to a wider cognitive system (Huang et al., 2006; Vasiliou, Ioannou, & Zaphiris, 2014) where PBL processes and outcomes are empowered. This article contributes a detailed description of how PBL can be enacted in a multimodal, technology-rich classroom and presents evaluation data on learners' technology adoption experience while engaging in PBL.

## Method

### Participants

Data were collected from 60 postgraduate learners over a 3-year period (2012–2014); these learners were enrolled in three iterations of a semester-long (12 weeks) human–computer interaction (HCI) course at a public university in the Northeastern Europe. The course implemented PBL as described in the following section, with identical content and procedures and same instructor and tutor in all three iterations. The complete sample of participants ($N = 60$) was composed of 65% women, 22 to 40 years of age ($M = 29$). They came from different postgraduate programs (MA in Interactive Multimedia, MA in Instructional Technology, and MSc in Games and Interactive Technologies), while their backgrounds varied (e.g., computer science, graphic arts, multimedia, education, communication, and Internet studies). All participants worked in multidisciplinary (mixed-expertise) PBL groups of 5 to 6 students each ($N$ groups $= 11$; 5 groups in Fall 2012, 4 groups in Fall 2013; 2 groups in Fall 2014).

### PBL Implementation in HCI Courses

HCI is a discipline concerned with the design, evaluation, and implementation of interactive computing systems for human use and the study of major phenomena surrounding those systems. The design process in HCI involves understanding and solving problems in an application context and shares similar stages with the PBL process, including problem analysis and brainstorming, assigning responsibilities for the investigation of information (learning issues), seeking and using knowledge, and critically evaluating the group's strategies and progress (reflection). Therefore, following a PBL approach in this course is relevant and desirable; doing so provides students with an opportunity to self-apply the very things they are learning about.

In this work, our HCI course began by presenting students with a complex design problem with almost no information about how to solve it (Hmelo-Silver, 2004). This problem was taken from the student design competition of CHI (2012, 2013, and 2014, respectively) and dealt with an authentic design need, particularly the design of an object, interface, system, or service that helps "Changing Perspectives Through Collaboration" (see CHI 2013, http://chi2013.acm.org/); the outcome group product was the deliverable required to submit as the final project of the course.

The course was organized in 3-hour weekly sessions. Each session began by presenting some information in a minilecture of 20 minutes to trigger attention on relevant issues students would have to consider during their problem-solving. Topics included HCI principles, cognitive psychology and HCI, data gathering and requirements analysis, design process, user and expert evaluation. This adaptation to the traditional PBL approach helps avoid possible gaps in students' knowledge, echoing Hmelo-Silver's (2004) thoughts that, "as students are grappling with a problem and confronted with the need for particular kinds of knowledge, a lecture at the right time may be beneficial" (p. 260).

PBL tutorials followed the minilectures; students worked in their PBL groups face-to-face, with the instructor and a tutor acting as facilitators. The topics covered in the minilectures naturally prompt learners to identify relevant learning issues. Learning issues were generated, researched, and taken up within the group's work leading up to the design of the outcome group product for delivery at the end of the course. In general, the Koschmann and Stahl's (1998) phases of recognition (problem analysis, recognition of learning issues), researching (self-directed study of learning issues), reporting (group reconvene; newly acquired information is applied to the problem), and reflection (reflect on the information collected so far, clarify hypotheses, and identify new learning issues) were scaffolded by the instructor and tutor during the resolution of the learning issues. To manage all groups, the instructor and facilitator (individually) rotated from group to group and adjusted the time spent with each group according to the needs of the group (Hmelo-Silver & Simone, 2013). Particular attention was paid in guiding the reflection process, as suggested in Hmelo-Silver (2004; Hmelo-Silver & Simone, 2013). Table 1 presents two examples of learning issues and working through these phases.

## *The Multimodal Learning Environment*

The term *multimodal* learning environment had a dual meaning in this study. First, the learning environment used both physical and digital tools, it was connected to the outside world, and it was interactive. Second, the environment afforded the presentation and use of information in multiple formats such as text, pictures, diagrams, and audio. Overall, we created a multimodal learning environment by using a variety of affordable, everyday technologies available in

**Table 1.** Phases in the Resolution of Learning Issues.

| | Learning issue 1 | Learning issue 2 |
|---|---|---|
| Recognition | The group decides they lack knowledge with regard to how cognitive psychology can inform the design of their system? The group assigns responsibilities for individual research at home. | The group decides they lack knowledge with regard to the needs of the prospective users of their system. The group decides on 8 to 10 questions to be answered during interviews or observation of prospective users. |
| Researching | At home, using print and electronic sources, individual learners engage in self-directed study of cognitive aspects of interaction (e.g., design of displays, information visualization, working memory capacity, etc.). | Outside the classroom, individual learners conduct interviews or observations of prospective users to provide answers to the questions. |
| Reporting | The individual learners present their newly acquired information to the group. The group applies this knowledge and records ideas about the design of the system, from a human cognition perspective. | The individual learners present their raw data for the needs analysis meeting within their groups. All newly acquired information is applied to the problem. |
| Reflection | The group evaluates their current stage of knowledge, clarifies their thinking about the design of the system, and decides if there is more to be learned from a human cognition perspective. New learning issues may emerge. | The group evaluates their current stage of knowledge, clarifies their thinking about the design of the system, and decides if there is more to be learned regarding the needs of the prospective users. |

the university classroom. The learning environment has three main elements; Figure 1 illustrates the learning environment, while a detailed description can be found in Ioannou et al. (2015). A "hands-on" presentation of the technologies, and how the authors envisioned the environment could be used in relation to the PBL processes, was offered to the students during the first PBL tutorial.

1. *Shared surface and projection*. The arrangement aimed to allow problem-solving and design conversations to take place around a large table surface. The same table surface was designed to be used as a projection surface for a downward-pointing projector; the projection aimed to support the


**Figure 1.** The learning environment: use of tablet for taking snapshots of the activity, iPod for recording group conversations, pen-reader for taking personal notes, sense cam automatic pictures (top), use of the surface projection for collocated collaboration (bottom).

presentation of digital artifacts, such as images and notes captured in previous PBL sessions. In terms of cost, this was the most expensive element of our learning environment, costing approximately 1,200 euros for each group (mac mini 600 euros, projector 550 euros, wireless keyboard, and mouse 50 euros), but this was still much cheaper than a commercial tabletop, for example, which offers a similar experience (i.e., a shared surface for collaboration).

2. *Portable devices for recordkeeping and reflection*. These devices aimed to allow the capturing of key moments and artifacts during the activity to facilitate later review and reflection. Learners were encouraged to bring their own devices, while we provided tablets, electronic devices for playing and storing digital audio and video files (e.g., iPods), wearable digital cameras (i.e., sense cams), and handwriting recognition technology (e.g., pen-reader).
3. *Facebook groups*. Each group was asked to set up and use a Facebook group. Facebook aimed to allow students to share the information they found during self-directed learning, getting ready for the face-to-face PBL tutorials.

## Data Sources and Instrumentation

This work is part of a larger scale investigation of the ways in which everyday technology can support PBL processes and outcomes. The complete data set was composed of both quantitative and qualitative data for a holistic understanding of the above. Some analysis of qualitative data—particularly video data and focus group data—is presented elsewhere, focusing on understanding (a) learners' blended interactions across physical and digitals tools in the environment (Ioannou et al., 2015) and (b) flow of information, collaboration, and coordination from a distributed cognition perceptive (Vasiliou, Ioannou, & Zaphiris, 2015). In this article, we use quantitative data—particularly questionnaire data and Facebook activity—to examine learners' technology adoption experience while engaging in PBL. Although questionnaire data are often criticized as subjective measures, we would argue that these data are equally important for a holistic assessment of the experience. On the other hand, assessing learners' Facebook activity, populated with events and content as they happened in the classroom and in between meetings, provided a more objective measure of learners' technology adoption, which was important for the triangulation of the findings from students' self-reports.

### *Questionnaire*

The postexperience questionnaire was administered during the last day of the semester-long course to assess learner's overall experience in the learning environment. Altogether, the questionnaire included 24 Likert-type items (from 1: *strongly disagree* to 7: *strongly agree*). We chose to measure four key variables associated with collaborative learning in computer-mediated environments: (a) communication and interaction, (b) reflection, (c) satisfaction with the learning experience, and (d) perceived learning. We included an additional variable, (e) frustration, to enhance our understanding of students' experience in the multimodal learning environment. Four of the subscales were adapted from previous research, and all had evidence of factorial validity and high internal consistency reliability (see Table 2 for details).

## Results

Evaluation of learners' technology adaption experience was assessed by (a) calculating descriptive statistics for the questionnaire data and (b) content analyzing the Facebook data, which was important for the triangulation.

All 60 (consented) participants completed the questionnaire. Cronbach's coefficient alpha reliabilities were calculated for each subscale; the internal consistency of all subscales was acceptable (Cronbach's alphas > .75; see Table 3). Subscale mean scores were then calculated for every participant. Table 3 presents descriptive statistics of all subscales. As shown in Table 3, mean scores were well above the midpoint of the 7-point response scale for the positively worded variables, while the frustration levels were clearly low. This finding suggests that learners' overall PBL experience in the multimodal learning environment was well perceived, with levels of communication and interaction, reflection, learning, and satisfaction being considered high.

With regard to the Facebook content, findings from our previous work (Vasiliou, Ioannou, & Zaphiris, 2015) set the basis for the 4-category coding scheme of Table 4, which was used to code and count the Facebook content data of all 11 groups. Specifically, in Vasiliou, Ioannou, & Zaphiris (2015), analysis of focus groups data and tutors' observation revealed typical uses of Facebook in line with Koschmann and Stahl's (1998) four-phase PBL process. Those included the following: (a) uploads of captures or recordings of the PBL activity for later reflection in the group and at home (reflection); (b) uploads of new information acquired during self-directed study (researching, reporting); and (c) use of Facebook to discuss emergent issue in between meetings (researching, reporting, recognition). In fact, as evident in Vasiliou, Ioannou, & Zaphiris (2015), the physical and digital tools in the environment, coupled with the capability of Facebook as a recordkeeping and communication tool, became integral part of the PBL process during recognition of learning issues, researching of learning issues, reporting, and reflecting, as illustrated in Figure 2.

The coding scheme fitted the Facebook content well, and no revisions were deemed necessary. The post was the unit of analysis, and, in general, every post was clearly categorized in one of the codes of Table 4. Table 5 presents groups' average frequency of postings within each coding category demonstrating the intensive use of the technology. Also, chi-square testing (analysis for variance between groups) showed that there were no significant differences across groups in their use of Facebook (i.e., no group differences in the number of postings within each category).

Furthermore, Table 5 provides additional evidence (on top of self-reports) of students' engagement in PBL processes such as researching of learning issues,

**Table 2.** Questionnaire Subscale Details and Individual Items.

| | |
|---|---|
| 1. Communication and interaction (C&I): a 6-item subscale assessing the extent to which students collaborated within their groups (adapted from Yeo, Taylor, & Kulski, 2006) | |
| C&I-1 | I explained my ideas to other students. |
| C&I-2 | I asked other students to explain their ideas. |
| C&I-3 | Other students responded to my ideas. |
| C&I-4 | I related my work to other students' work. |
| C&I-5 | I made good sense of other students' contributions. |
| C&I-6 | I sought to improve the group product/design. |
| 2. Reflection (R): a 5-item subscale assessing the extent to which students thought critically about their own and others' ideas (adapted from Yeo et al., 2006) | |
| R-1 | I thought critically about ideas in the class material. |
| R-2 | I thought critically about my own ideas. |
| R-3 | I thought critically about other students' ideas. |
| R-4 | I sought answers to difficult issues presented in the design process. |
| R-5 | I reflected on how what I learned applied to practice. |
| 3. Perceived learning (PL): a 4-item subscale assessing the extent to which students thought they learned from the experience | |
| PL-1 | The activity helped me understand the course content. |
| PL-2 | I learned many things about human-centered design. |
| PL-3 | I learned from my teammates while working on the design task. |
| PL-4 | I believe I can perform well in a similar task in the future. |
| 4. Satisfaction (S): a 5-item subscale assessing the extent to which students were satisfied with their learning experience (adapted from Artino, 2009) | |
| S-1 | Overall, my collaborative learning experience was positive. |
| S-2 | The activity met my needs as a learner. |
| S-3 | I am satisfied with my learning experience. |
| S-4 | Group work added value to the group product/design. |
| S-5 | I would recommend this activity to the instructor of a similar course. |
| 5. Frustration (F): a 4-item negatively worded (−) subscale assessing the extent to which students were frustrated with the experience (adapted from Artino, 2009) | |
| F-1 | I felt frustrated. |
| F-2 | I was angry. |
| F-3 | I felt as though I was wasting my time. |
| F-4 | I was irritated. |

reporting, and reflecting. For example, as reported in authors' reference (2015a), Facebook acted as a recordkeeping and communication tool where students posted captured moments or artifacts from the PBL tutorials for later reflection during the week. Indeed, Table 5 documents this pattern of posting captures or

**Table 3.** Subscales and Descriptive Statistics for Postexperience Questionnaire ($N = 60$).

| Subscale | # Items | Cronbach's alpha | *M* (*SD*) |
|---|---|---|---|
| 1. Communication and interaction (+) | 6 | .87 | 6.25 (0.72) |
| 2. Reflection (+) | 5 | .89 | 5.99 (0.86) |
| 3. Perceived learning (+) | 4 | .85 | 6.36 (0.71) |
| 4. Satisfaction (+) | 5 | .89 | 6.05 (0.93) |
| 5. Frustration (− negatively worded) | 4 | .84 | 2.10 (1.39) |

**Table 4.** Facebook Activity Coding Scheme.

| Coding category | Category description |
|---|---|
| 1. Captures/recordings | Multimedia elements such as images, audio files, short videos capturing moments of the PBL tutorial (uploads during the PBL tutorial) |
| 2. Reports | Information acquired from individual members during self-directed study, including word documents, multimedia elements such as YouTube links and web pages (uploads in between f2f meetings) |
| 3. Questions and answers | Discussion of emergent issue (in between f2f meetings) |
| 4. Comments | Likes, comments on captures/recordings, comments on posted reports, general reflections (in between f2f meetings) |
| 5. Social/off-task | Postings not relevant to the task (in between f2f meetings) |

*Note.* PBL = problem-based learning; f2f = face-to-face.

recordings; yet, we can only rely on leaners' self-reports to assume reflection on action was linked to this activity (see also authors' reference, 2015a).

## Discussion and Conclusion

In this study, we enhanced a PBL environment with affordable, everyday technologies that can be found in most university classrooms (e.g., projectors, tablets, students' own smartphones, traditional paper–pencil, and Facebook). First, the study contributes a detailed description of how PBL was enacted in this multimodal classroom. The learning environment and procedures presented here could be potentially replicated by others who teach in similar contexts in an effort to improve how their course is structured and enhanced by the means of technology.

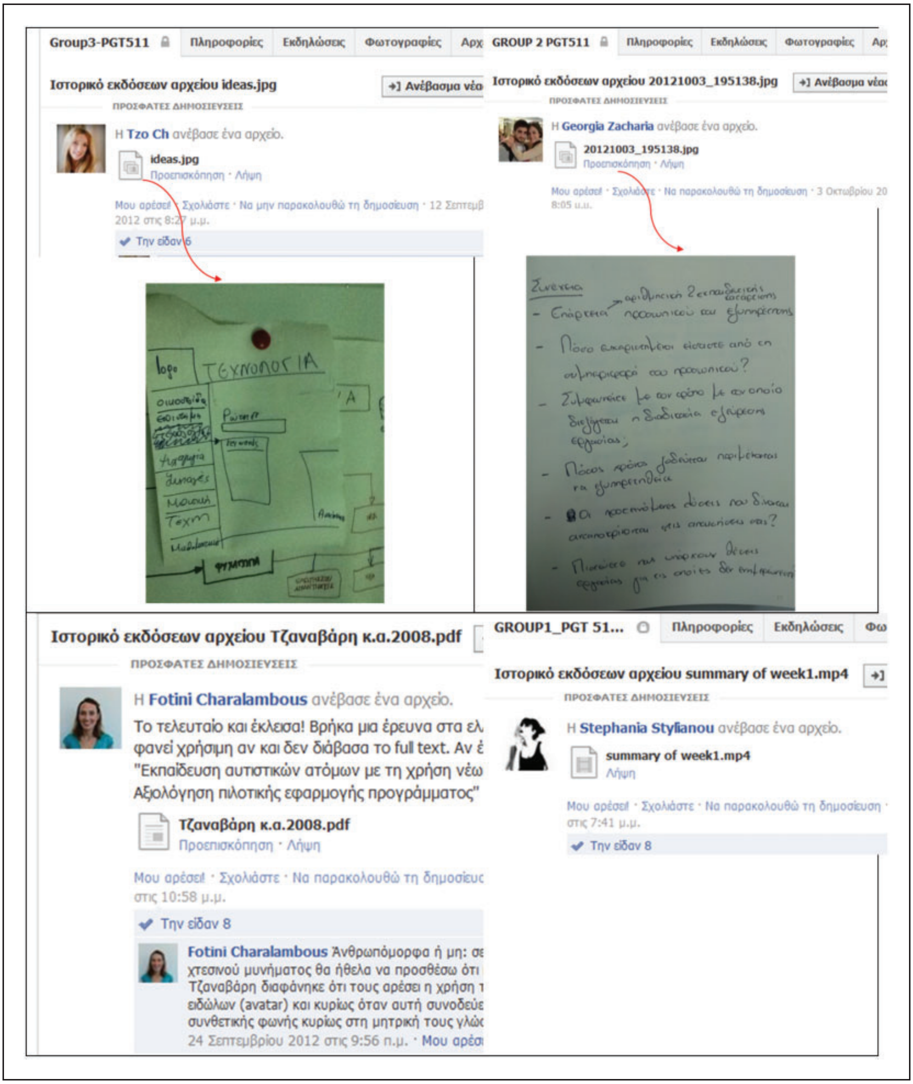


**Figure 2.** Facebook postings: image of a diagram of ideas on learning issues (top-left), image of handwritten notes on learning issues (top-right), document result of individual researching (bottom-left), audio file summarizing the tutorial and decisions of the group (bottom-right).

Second, the study presents evaluation data from 60 learners, particularly questionnaire data and Facebook activity. Results showed that the learning environment was positively endorsed by the learners, who rated highly the degree of communication and interaction, reflection, perceived learning, and satisfaction in

**Table 5.** Use of Facebook—Groups' Average Frequency of Codes ($N = 60$; $N$ groups = 11).

| Categories/codes | *M* frequency | *M* % |
|---|---|---|
| 1. Captures/recordings | 107 | 40 |
| 2. Reports | 63 | 23 |
| 3. Questions and answers | 32 | 12 |
| 4. Comments | 42 | 16 |
| 5. Social/off-task | 25 | 9 |
| Total | 269 | 100 |

this environment. This finding is consistent with previous literature reporting that students generally embrace a technology-enhanced PBL experience (e.g., Hung et al., 2008). Furthermore, results documented how the physical and digital tools in the environment, coupled with the capability of Facebook as a recordkeeping and communication tool, were integral part of the PBL processes such as researching, reporting, recognition, and reflection. These findings confirm and enhance the validity of our previous findings based on qualitative data in Ioannou et al. (2015), serving our aim for triangulation and holist understanding of the experience. Overall, findings from this work should be valuable for those teaching in similar contexts, as they can use the ideas and procedures presented here to create a technology-enhanced learning environment that is not only positively endorsed by the learners but also serves PBL pedagogy well.

Overall, based on this experience, we would argue that PBL does not have to be limited to the use of a simple whiteboard. A multimodal learning environment enriched with creative use of affordable technologies available in the university classroom, as well as social media such as Facebook, can support PBL and can be positively endorsed by the learners. In the literature, we have seen complete systems and dedicated tools for computer-supported PBL being fairly researched. Our evaluation of a technology-enhanced PBL course on HCI presents promise for more efforts in this area. We believe, more work is needed for an understanding of the roles that everyday technologies might play in supporting PBL.

In interpreting our findings, we should consider that our students were completing MA degrees related to technology. Therefore, they were comfortable with using technologies within the PBL environment and probably even had an expectation that technology would be used in the course. Other students, in other contexts and settings, could have reacted differently to technology-enhanced PBL. Yet, despite the difficulty of interpreting our findings outside of the context of this study, we believe a multimodal PBL environment, such as the one presented here, should be pertinent to a variety of courses using student-centered pedagogies and group work; therefore, instructors could benefit from trying the ideas presented here.

Moreover, although technology has motivational benefits and therefore was well perceived by the learners in this study, we would argue that technology without supporting and scaffolding PBL interactions and process (i.e., recognition, researching, reporting, and reflection) would not have had the desired impact on cognitive engagement. For instance, although the portable devices were intended to capture and collect students' artifacts, the increased use of technology alone would not necessarily guarantee the support for students' engagements in PBL (e.g., later reflection followed by capturing or posting activities). In fact, the instructor and tutor's role was crucial in facilitating social and cognitive PBL process, while the use of technology became integral part of this effort and experience. Blumenfeld et al. (1991; also Blumenfeld, Kempler, & Krajcik, 2006) pointed out the two challenges PBL learning environments face: to support the learning and to sustain the doing. We believe this experience provides preliminary evidence of how technology might serve the challenges by supporting the phases of learning issues resolution in PBLand by keeping the learners "doing" during face-to-face and in between meetings. We realize our results seek for replication, and we hope other researchers will pursue this.

In conclusion, as technology advances and becomes more and more affordable, new technologies will enter the classroom, and the learning environment will be further enriched, for example, with tabletops and other interactive surfaces. That said, future work may focus on understanding the ecology of devices in technology-rich and networked classrooms and particularly how technologies work together seamlessly to support PBL. Along these lines, how to orchestrate learning in such environments is also becoming relevant and important to study in future research. Certainly, we cannot ignore the possibilities everyday affordable technologies may have for enhancing PBL in higher education classrooms and beyond. If we only consider how devices, such as tablets and smartphones, and social media, such as Facebook, provide a means for social interaction and communication around shared interests, their potential in education settings seems endless. We hope that our work will serve as a base, or even simply as the motivation, for future investigations in this area, potentially contributing to a methodological framework for the design and implementation of technology-enhanced PBL.

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