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Mobile Inquiry-Based Learning with Sensor-Data in the School: Effects on Student Motivation

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Abstract. The paper discusses the design, implementation and evaluation of a pilot project that integrated inquiry-based learning with mobile game design and introduced mobile devices and sensors into classroom learning. A 5-week classroom inquiry learning project on energy consumption was designed and implemented as a mobile serious game. While engaging in the game and training inquiry skills, students were introduced to basic concepts in the energy domain and to everyday practices of energy consumption in their direct environment. The design was based on a model of inquiry-based science learning with social and open mobile tools developed in the European research project weSPOT. The pilot indicated that using an ubiquitous tool does not necessarily help sustain student motivation. There are indications of gender differences in motivation related to use of mobile devices for learning. These differences should be taken into account in the design of activities. Implementation of the inquiry-based learning model in conjunction with a mobile game scenario into the school practice confirmed the importance of good design with sufficient testing and teacher ownership.

Keywords: mobile learning, motivation, inquiry-based learning, environmental literacy, energy consumption, design, implementation.

1 Introduction

In the last ten years social and mobile media have become an important, if not a primary communication channel for young people and a stable part of their daily life and daily routines. The potential of mobile media for learning is not disputed and a body of knowledge on affordances of mobile devices as learning support tools keeps growing [1,2,3]. However, instantiations of mobile learning in school practice are still scarce in European countries. Teachers do not feel comfortable using these technologies and mobile devices remain more often banned from classrooms than used for learning purposes [4,5].

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Discussing the added value of mobile learning, Ally [6] emphasizes easy access to knowledge sources through ubiquitous and cheap portable devices. From the active learning perspective, interaction with artefacts and persons in and across learning contexts, is important. Smartphones and tablet computers with enhanced facilities for instant and asynchronous messaging support such interaction and make knowledge exchange and knowledge building possible in any-time, any-place modes in the most direct sense of the word. Curiosity-fed questions arising at the spur of the moment at a fieldtrip, a museum visit or a workplace situation can be captured by a single click, annotated in text or voice and directly saved and uploaded into a personal school learning space or a space shared with others. Thus, mobile devices can create bridges between formal and informal learning, bringing the richness of authentic learning experiences into the classroom [7,8].

The topics of sustainable development, renewable energy sources, energy efficiency, energy consumption and conservation belong to urgent societal problems in need of solutions and are included in various national formal science curricula both in primary and secondary education [9,10]. Not much, however, is known about how school knowledge on issues such as energy consumption, environmental protection, sustainable development or energy conservation interact with daily life experiences and views of young people on these issues, whether connections between school subjects, daily life experiences and global societal issues help make abstract school knowledge meaningful and usable in practice [11,12].

Affordances for capturing moments of curiosity that mobile devices have, can help to increase awareness of what is happening in the surrounding world and contextualize learning. These affordances make such devices natural partners of environmental education [13,14]. For instance, sense-making and deep learning can be enhanced when learners consult background sources directly during fieldtrip activities and communicate on these points with experts or fellow students elsewhere without leaving the field. Thus, mobile devices become effective tools during exploratory activities outdoors and during the process of sense-making of these activities [15]. As demonstrated by Börner and colleagues [16, 17], a serious location-based mobile game and ambient displays can help raising awareness of the energy consumption patterns at the workplace and can lead to behavior change.

Implementing pedagogical approaches that focus on the links between formal school learning and everyday life experiences, such as inquiry learning, has been known to present challenges for curriculum designers and teachers [18]. Edelson, Gordon and Pea [19] indicate that student learning will be undermined in case of failure to address several challenges, including that of sustaining the learner’s motivation throughout the inquiry process. Other challenges are addressing gaps in background knowledge, scientific investigation skills (including data collection and analysis techniques) and skills in project management. These authors also emphasize the necessity to address the practical constraints of the learning context in design and implementation of inquiry-based learning [p.399].

Available research, and innovative approaches of the early adopters of new technologies [cf.,20,21,22], indicate that ubiquitous tools such as mobile devices can contribute to successfully tackling some of these challenges. There is evidence that using mobile devices in the context of gaming is highly motivating for learners [23]. Further tests in ecologically valid situations of average technology users and authentic school settings remain, however, highly relevant for understanding what works and why for optimal use of these ubiquitous tools as learning enablers.

To support understanding of how an inquiry-based learning activity in the form of a serious mobile game can be integrated in regular school practice and support inquiry-based science learning, a game on the topic of energy consumption was conducted. Students were triggered to investigate and compare energy consumption of different appliances in the school building, test assumptions on energy efficiency and present results to each other, teachers and management. A theoretical model of inquiry-based science learning with mobile and social media, the weSPOT[1] IBL Model, formed the framework of the designed learning activity. ARLearn, a toolkit for designing mobile and location-based learning games [24] was used to design and deliver instructional scripts to guide inquiries and provide just-in-time access to relevant information to the players. Experiences from Mindergie, a mobile game on energy consumption awareness at the workplace [17], were used to implement a sensor network in the school building, to provide input for inquiry activities and to act as triggers for learning.

The study focussed on testing feasibility of integrating such an activity and new technologies as mobile devices and sensors in classroom learning. It also aimed at evaluating whether students were and remained motivated to learn and conduct mobile-led activities at school. Furthermore, as a first implementation of a new pedagogical approach in a particular school setting, the pilot was expected to shed light on the practical constraints of implementing inquiry-based learning with mobile devices in the school practice.

The study set-up and general findings were introduced by Kalz and colleagues [25]. The findings suggested that practical constraints, in the first place the defects of Internet network connections, hindered the pilot. Furthermore, effects on knowledge and motivation were manifested. Learners with a low level of prior knowledge turned to benefit most from the activity. As far as cognitive outcomes are concerned no gender differences were found. An unexpected outcome was a general decrease in motivation by all participants and in particularly by girls who were significantly more interested in participating in the activity at the start. To get a clearer understanding of the effects of the intervention on student motivation and formulate lessons for design, additional analyses were conducted. This paper elaborates on these results and the lessons learned from the pilot.

The next sections give an overview of the applied weSPOT IBL model, elaborate on the pilot and its results, including the pilot implementation and practical constraints. Finally, the authors reflect on the implementation of innovative technologies in relation to motivation issues based on the findings of the study.

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2 Inquiry-Based Science Learning to Foster Environmental Literacy: The weSPOT Model

An inquiry-based learning model developed in a European project weSPOT– Working Environment with Social and Personal Open Tools for Inquiry based learning was used as a framework for game design. Three basic assumptions form the backbone of the weSPOT inquiry-based learning framework:

- Everyday experiences feed natural curiosity of young learners and can enhance formal classroom learning in which knowledge of scientific concepts is developed.
- Personal experiences and insights can help to understand theoretical concepts taught in the classroom.
- Development of inquiry skills by doing inquiries should mirror the process of systematic scientific observation and experimentation as well as consistent and critical reasoning that are standard in scientific communities [26].

The weSPOT IBL model views inquiries as learning activities in which students develop knowledge and understandings of scientific ideas by actually doing research. It does not prescribe how learning should be designed but offers flexibility to teachers and learners in the way inquiries can be done. According to the weSPOT model, inquiry activities can be designed and led by teachers, by learners or by both. They range from highly structured to open inquiries offering a maximum of flexibility and freedom for learners to set inquiry goals to define inquiry results and organize the inquiry process [27].

Distinct features of the weSPOT inquiry model are the interrelatedness of phases of the inquiry cycle and the flexibility that it offers to teachers in choosing to focus either upon the complete inquiry cycle or upon one or several phases in organizing learning. The proposed phases mirror the broadly accepted division of the research process which encompasses the stages of setting the research goals and formulating research questions, operationalization, data collection, data analysis and interpretation and communication of results.

The weSPOT IBL model makes explicit links between the domain knowledge, domain-related and generic inquiry-related skills, school-based inquiry activities, everyday life experiences and the context in which knowledge and skills are applied [28]. Phenomena or developments around them trigger learners' curiosity and provoke asking questions that give input for new inquiries or help to deepen ongoing inquiries. To find answers, learners undertake various activities, including experimentation, data collection and information searches. While collecting data and communicating their findings in authentic contexts, learners (learn to) apply domain knowledge and both domain-related and generic inquiry-related skills that they master at school. Figure 1 provides a general overview of the inquiry process according to the weSPOT model.

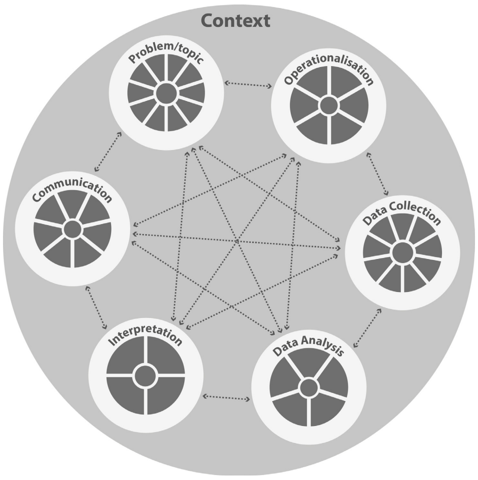


Fig. 1. weSPOT model and the constituent phases of the inquiry process. Each phase includes a range of tasks and activities [26].

Pilots with the users, i.e., with schoolteachers and students are being held from the early stages of the project. The reported pilot study tested a possible application of the weSPOT inquiry based learning model in combination with a mobile app prototype, which guided learners through the inquiry.

3 The Pilot

In the pilot:

- A series of instructional mini-scripts (games) was designed to guide students in individual and collaborative inquiry activities on the topic of energy consumption.
- These scripts were delivered through an app for personal mobile devices as games including game elements, such as information units, challenges, fun elements and incentives.
- A sensor-based system was used to collect energy consumption of appliances within the school building.
- Both prior to the pilot and after it, data was collected on learners' basic knowledge of energy consumption and on students' motivation for learning about energy consumption.

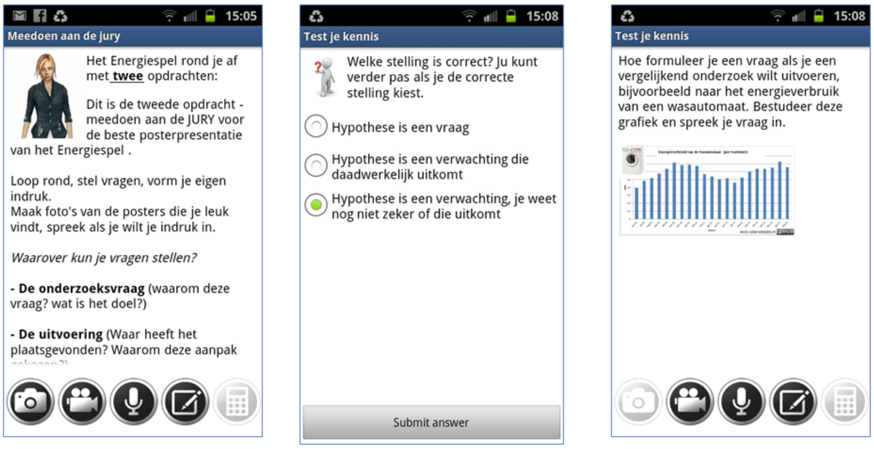
3.1 Method

A. Participants

The game was integrated in science lessons as a 5-week project on energy consumption. 13-year old K-8 level students of a secondary school in the Netherlands spent weekly between 2 and 4 hours a week on this project (n=85). 58% were girls. In their activities three science teachers guided students.

B. Materials and Instruments

Mobile games. In the pilot 7 mobile games were designed to guide students in their inquiry activities. These games contained knowledge rich information units as text, video or links to web-based sources on the topic of study: energy sources, electrical power units of measurement, efficiency calculations, energy consumption; on phases in the inquiry process and on relevant methodological concepts as a research question, a hypothesis, data collection, presenting results, etc. The information units were presented by a young story teller. These units were combined with instructional prompts on tasks and challenges for the students as doing a short multiple choice quiz or finding a QR code that should be scanned to get access to further information or instructions. Figure 2 gives an illustration of the display on a task prompt, a quiz unit and an information unit with a test prompt (in Dutch).



Het Energiespel rond je af met **twee** opdrachten:

Dit is de tweede opdracht - meedoen aan de JURY voor de beste posterpresentatie van het Energiespel .

Loop rond, stel vragen, vorm je eigen indruk.
Maak foto's van de posters die je leuk vindt, spreek als je wilt je indruk in.

Waarover kun je vragen stellen?

- **De onderzoeksvraag** (waarom deze vraag? wat is het doel?)

- **De uitvoering** (Waar heeft het plaatsgevonden? Waarom deze aanpak

Welke stelling is correct? Ju kunt verder pas als je de correcte stelling kiest.

○ Hypothese is een vraag

○ Hypothese is een verwachting die daadwerkelijk uitkomt

● Hypothese is een verwachting, je weet nog niet zeker of die uitkomt

Hoe formuleer je een vraag als je een vergelijkend onderzoek wilt uitvoeren, bijvoorbeeld naar het energieverbruik van een wasautomaat. Bestudeer deze grafiek en spreek je vraag in.

Fig. 2. Android device displays featuring exemplary ARLearn tasks

Some tasks became available only when certain activities were completed or particular quiz tasks were performed (i.e., data collection tasks were to be completed to proceed). Once started all tasks remained available.

Plugwise sensor network. Information on energy consumption of appliances within the school building was provided by the Plugwise system. Smart meter plugs that measure and store individual consumption data build up a wireless network that can be accessed using the bundled Plugwise software [29]. The system was set in the school building, in such a way that single appliances could be accessed. In total 50 appliances and power plugs throughout the school were equipped with smart meter plugs. This setup included three classrooms, a meeting room for teachers, some shared facilities (e.g. printer, vending machines, air conditioning), as well as some stations for experiment setups (e.g. for comparing the energy consumption of different light bulbs). Each appliance has been measured separately. In order to establish communication within the network, each plug had to be positioned within a range of 5 to 10 meters to another plug. The needed software has been installed on a laptop computer. Utilizing a USB dongle the software communicated directly with the network. To allow remote access to the system and the data, the web server functionality had been activated. A similar network set-up was earlier realized in the Mindergie game [17].

Personal mobile devices. According to an inventory held at the beginning of the school year 80% of the students had personal mobile devices with Internet access through Wi-Fi. Around 10% of these students had IOS supported devices (iPhones), the rest used Android devices. According to the anonymous evaluation inventory held after the pilot (n=81) 95% of all participants had a smartphone, with 16% (n=14) iPhones and the rest Android devices. 15 ipad mini's of the school were made available for students who had no smartphones.

Classroom teaching materials. Upon explicit teacher request in addition to the mobile scripts, 5 power point presentations on each phase of the inquiry cycle and a presentation on domain related concepts as energy sources and energy efficiency were designed for classroom use to provide an alternative information source for the students who did not have mobile devices. Duration of the presentations varied from 15 to 30 minutes. Each presentation highlighted a specific phase of the scientific inquiry cycle and included the content of the weekly inquiry tasks. These presentations contained the basic information included in the ARLearn games. The presentations were delivered by the teachers during weekly classroom hours.

Knowledge tests. Background knowledge on energy domain was evaluated with a 17 fill-in-the-blanks and yes/no items from a K-8 school test on basic domain concepts as energy sources, fossil and renewable energy, energy efficiency of appliances, calculating efficiency. Changes in knowledge and understanding of issues related to energy consumption were traced with the help of a 5 items tests issued before and after the game.

Motivation scale. The intrinsic motivation (IMI) scale by Deci & Ryan [30] was used in the study. Three subscales were included: interest/enjoyment (5 items), effort/importance (5 items), value/usefulness (4 items) and perceived choice scale (3 items). Items were selected based on their relevance in the context from an open source instrument available at www.selfdeterminationtheory.org/questionnaires. As the items were repeated in the pre-test and post-test, they referred respectively to future or past activities. 5 items were formulated negatively and were reversed for analysis purposes. The items were translated into Dutch with minor textual and context-specific adjustments to the target group and the context of study.

An exploratory factor analysis was applied to understand the structure of the latent variable [31]. Internal consistency checks were done on the whole scale and the subscales.

Pilot evaluation. Both students and the participating teachers were de-briefed after the activity. Students filled in a three-item anonymous inventory on each of the 7 games they were offered through mobile devices. They indicated whether they had played each game, they rated each game they had played and could elaborate on the ratings. In a semi-structured interview the three participating teachers provided an evaluation of the game, discussed its contribution to school learning, and lessons learned. During the pilot the first author took notes of the classroom sessions and observations during activities in the school building.

C. Design and Procedure

At the start of the pilot and one week after its completion paper and pencil questionnaires were administered (pre-post-test design). 75 students filled in both questionnaires. Both questionnaires included knowledge tests, and the motivation scale. After the pilot a short anonymous written student inventory and a group interview with the teachers were held.

Game organization and progress. Students started the game with a general introduction on the topic of energy consumption and an introduction of the tools (e.g. an app supporting data collection for their smartphones). Prior to the pilot a try-out was organized to let the students install an app on the personal mobile devices and get acquainted with some of the functionalities of this app. Informed consent request letters were distributed among the students for them and their parents.

The Energy game was organized as a 6-phase inquiry cycle, with each phase being introduced by a new mobile game. Two content specific games introduced relevant domain and methodological concepts. Thus, game One provided an introduction to the topic of energy consumption. Game Two introduced the inquiry cycle, the what's and how's of formulating research questions and hypotheses.

Led by the mobile games, students posed research questions in small teams, decided together how they would tackle the task, collected and analyzed data to answer the questions that they posed and presented the results to each other and the teachers in the form of posters during a poster walk. The poster walk was the object of a joint assessment activity: the teachers, present guests and researchers rated the presentations together with fellow students. Based on the ratings winners of the game were announced. The first, second and the third place teams were awarded 5-euro vouchers to an Internet game store.

Teacher support. Throughout the pilot the teachers and one researcher (first author) provided support at regular instructional moments in class. Scripted instruction through the ARLearn app guided data collection in the orientation phase (at home and at school) and in the data collection phase (at school) by means of audio, video, photo and text formats.

Technical issues. Throughout the pilot a number of technical problems have been experienced. The school WiFi-network which was necessary for the adequate functioning of the sensor network in the school building and for using mobile devices for personal inquiries proved less stable than expected. During several moments of the pilot, the

Wi-Fi-network was not available. The school technical support team directly related that to the sensor-network. Upon request of the school technical support team, a part of the sensor network was dismantled limiting the area in which energy consumption could be measured, influencing the number of inquiries that students could pursue.

4 Results

4.1 Effects on Student Motivation

As reported by Kalz and colleagues [25], analyses of variance of the complete scale scores indicated that the conducted activity did not succeed in keeping students interested – the total score on the motivation scale was significantly lower after the activity than during the first measurement. There was significant interaction effect of gender prior to activity. no difference in the motivation level could be seen in the post-test [25].

In order to better understand these results, analyses of the constituent components were attempted. To conduct comparative analyses at sub-scale level, sub-scales with a complete match at item level in both instruments had to be defined. First, a principal component analysis was done forcing a three factor extraction for both pre- and post-test scales and reliability tests on the emerged components were performed. Five items were eliminated from the scale in the process of reliability testing. The resulting sub-scales with a complete match at item level can be described as *interest/positive disposition* (6 items, Cronbach's α=.860 in the pre-test scale and .838 in the post-test scale, respectively); *perceptions of usefulness* (3 items, Cronbach's α=.765 and .838) and *effort/willingness to invest effort* (2 items, Cronbach's α=.745 and .861). The resulting 11-item complete scale was again subjected to principal component analysis which yielded satisfactory results.

Table 1. Self-reports on Motivation by Gender at the start of the activity

	Interest (6 items)	Effort (2 items)	Usefulness (3 items)	Total motivation scale (11 items)
M	18,8 (6,1)**	8,2 (2,5)*	13,1 (3,8)	40,1 (9,6)**
F	22,9 (7,7)**	9,5 (2,9)*	14,4 (3,9)	46,7(12,4)**

* *p*< .05, **p< .01;.

Table 1 gives an overview of the scale scores by gender in the pre-test and indicates results that were statistically significant. As could be expected, independent t-tests on the pre-test sub-scale scores point to significant differences between boys and girls as far as their general *disposition/interest* in the activity or *willingness to invest effort* in it are concerned. There are, however, no indications of gender differences in the perception of the task *usefulness*.

Table 2. Change in the motivation and constituent factors

	Pre-test *M (SD)*	Post-test *M (SD)*
Interest (6 items)	20 (3)*	18,2 (7,2)*
Perceived usefulness (3 items)	13,6 (3,9)**	10,0 (4,3)**
Perceived effort (2 items)	8,6 (2,6)***	7,6 (3,3)***
Total scale (11 items)	42,74 (10,8)****	36,38 (12,3)****

*$F(1,65)=6{,}922$, $p=.011$,ηp2=.096; **$F(1,66)=43{,}784$, $p=.000$, ηp2=.399;
$F(1,66)=26{,}782$, $p=.000$, ηp2=.298; *$F\ (1,56)=5{,}712;$ $p=.020$, ηp2=.093,

Repeated measures analyses on the derived sub-scales point to loss of *interest, perception of usefulness of the task and perception of effort investment* for all participant. There is no effect on gender as a consequence of this activity. Boys and girls seem to be relatively unanimous in their attitude towards the activity. Table 2 provides an overview of the results and figure 3 illustrates the difference between the two patterns.

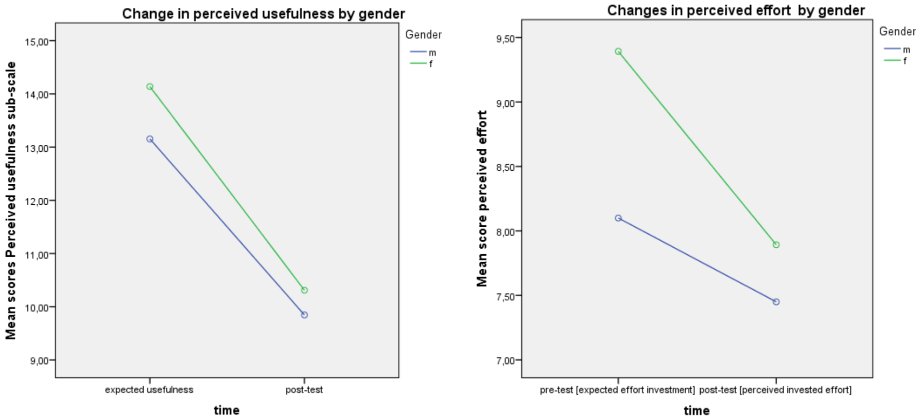


Fig. 3. Change in perceived usefulness and effort by gender

4.2 Pilot Process Evaluation

The idea of using mobile phones for learning was met with enthusiastic reactions (researcher's observation). As indicated in an anonymous evaluation inventory, practically all students used most of the ARLearn game scripts. According to their response (measured holistically with a single yes/no item) they demonstrated appreciation of activities that included actions (taking pictures, recording) and were negative on games that focus on supportive information. Understandably, students were most critical of inadequate functioning of WiFi network and the lack of structure because of last-minute changes in the activities that were meant to compensate for malfunctioning facilities.

In their interviews, the teachers acknowledged that they had accepted the suggested game scenario but did not contribute enough to its design and to structuring the activity. Last minute changes and ad hoc decision-making proved necessary to organize each game activity. As a positive moment, the teachers emphasized immediate feedback that students provided by demonstrating what they could or could not tackle independently after teacher introductions.

While there was a basic shared understanding of the concept of inquiry-based learning between the participants that have prepared the inquiry-activity (researchers and teachers), throughout the pilot it became clear that there was a wide range of understandings available with regard to the most important aspects of inquiry-based learning, i.e., the way students performed the inquiry activities and the teachers provided guidance.

5 Conclusions and Discussion

In the reported pilot study an inquiry-based approach, relating a topic within a school formal curriculum to students' immediate, familiar environments was realized in the form of a mobile serious game. Guided by direct prompts and indirect hints delivered through a mobile app, students pursued an inquiry around energy consumption, from defining a problem and a research question to the presentation of inquiry results.

The goal of the study was to evaluate the feasibility of the designed approach, to get insights in its practical constraints, and better understand the impact that the first implementation had on the learning outcomes, and in particular on learners' motivation. Answers to questionnaires on motivation point to a general decrease of interest, rather than to a boost of motivation, which is frequently reported in studies of mobile learning [23].

Furthermore, there are indications of gender differences as well as some subtle distinctions in the way students respond to questions related to "general interest" items, "willingness to invest effort" and "perceived usefulness". These results should be treated with caution as they are based on self-reports and the described factors are derived from a limited number of items. Nevertheless, they map into the theoretical perspective of the motivation and self-determination theory, namely the basic distinction between intrinsic and extrinsic motivation and the importance of the "inner acceptance of the value or utility of a task" [32, p. 55] for actively engaging with the task and learning from it.

This point brings us to a relevant issue from the design perspective – the importance of letting students experience "usefulness" of tasks that they are performing. especially when students are introduced to a new pedagogical approach and new tools, like in this case when inquiry-based learning was combined with ubiquitous mobile devices.

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