Frontline Learning Research
An official journal of EARLI

Frontline Learning Research Vol.5 No. 4 (2017) 42 – 60
ISSN 2295-3159

Generation of student interest in an inquiry-based mobile learning environment

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Article received 5 May / revised 16 July / accepted 9 October / Available online 15 November

Abstract

A declining trend in adolescents' interest in science learning and attitudes towards science-related careers has been reported during recent years. There has been a call for more motivating learning environments that inspire students to develop interest towards science. This study examines students' interest development in STEM subjects in an ecologically valid setting during one school year and how features of the learning environment affect students' generation of interest. In a quasi-experimental study design, one class of 7th grade (aged 12 to 13 years) students (N = 18) studied in an inquiry-based mobile learning environment that had a special emphasis on integrated curriculum. Interest variables were measured three times and focus group interviews were held twice during the school year. From a group of 113 students studying in an ordinary learning setting, a propensity score-matched control group of 18 students was selected based on general self-efficacy, intrinsic goal orientation, interest in technology, and web-user self-efficacy. Results from the quantitative analyses revealed only minor differences between the two groups. Results from the qualitative analyses indicate that students found the new environment to be interest generating, thus ascribing to the general idea and aim of the new environment, but also that the implementation was in many cases far from ideal, indicating that much of its potential was unrealized.

Keywords: Interest; Science learning; Inquiry learning; Mobile learning; Mixed method.

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1. Introduction

Researchers have reported a continuous worldwide decline in student interest in science learning over the last two decades (e.g. Rocard et al., 2007). Among others, large-scale quantitative studies by the Global Science Forum (Organisation for Economic Co-operation and Development, 2006) and the International Study Center (Martin, Mullis, Foy & Hooper, 2016) indicate a declining trend in adolescents' interest in science learning and attitudes to science-related careers. While the general trend suggests that students start to lose interest in science-related subjects in upper secondary school, there is considerable variation across science domains. Reasons for the observed decline also appear diverse—for example, students' interest may depend on the quality and type of instruction offered in schools; the psychological demands of adolescent life may take priority; or the student's ideal self-concept may be at odds with their perception of science learning (Krapp & Prenzel, 2011). Also students' individual characteristics, such as self-efficacy and goal orientation, have been found to influence interest (Glynn, Bryan & Brickman, 2015; Tapola, Veermans & Niemivirta, 2013). It has been suggested that one factor in the decline in interest in science, technology, engineering, and mathematics (STEM) is that these subjects still tend to be taught using traditional teacher-led pedagogies (Rocard, 2007).

By way of response, several pedagogical approaches have been developed in an attempt to foster self-regulated learning, active agency, and learning by doing. Among these, inquiry-based learning has been found to be positively related to academic achievement. Several meta-analyses and research syntheses have reported higher overall mean effect sizes for inquiry-based science teaching and learning when compared to more traditional types of instruction (Furtak, Seidel, Iverson & Briggs 2012; Alfieri, Brooks, Aldrich & Tenenbaum, 2011;. Minner, Levy & Century, 2010). This has also proven to be the case for digital learning environments, where students are offered the necessary support for inquiry (de Jong, 2006). Though there have been examples of interventional and case studies (e.g. Knogler, Harackiewicz, Gegenfurtner & Lewalter, 2015; Renninger et al., 2014; Tapola et al., 2013;) on the relationship between inquiry learning and students' interest development these studies have either concentrated on short-term change in students' situational interest, and/or lacked the ecological validity that would benefit the development of everyday classroom practises. Studying interest development in an ecologically valid setting over an extended time frame would allow the examination of the benefits and possible disadvantages of these types of pedagogical approaches as they unfold in real life classroom situations (e.g., Glynn et al., 2015).

The purpose of the present study was to examine the development of lower secondary school students' interest in STEM domains using an inquiry-based mobile learning environment as compared to an ordinary learning environment, employing a quasi-experimental design. In addition to quantitative measurements of interest and individual characteristics, group interviews were carried out among the experimental group students. The design of the experimental learning environment was inspired by the new Finnish Curriculum which was under development by the time of this study. The core ideas of the new curriculum are student initiated inquiry activities, collaboration, and integration of different school subjects into one meaningful unit (Finnish National Board of Education, 2014).

2. Theoretical framework

2.1. Interest

According to the four-phase model of interest development (Hidi & Renninger, 2006; Renninger & Hidi, 2011), the concept of interest is a multidimensional construct consisting of affect, knowledge, and value components that are related to a certain subject, situation or activity. The four developmental phases of the model, namely triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest, differ from each other on how much weight the affect, knowledge, and value components get. Situational interest refers to a state of focused attention and affective reaction that appears in a moment and may or may not persist over time. It does not necessarily depend on the individual's prior knowledge of the subject but is caused and supported by certain external stimuli within the situation (Hidi & Renninger, 2006). The affective component of interest predominates in the early stages of interest development, as attention is initially triggered by an affective response, and prior knowledge may not yet exist. Individual interest, then, can be viewed as a more permanent positive orientation toward an activity or a domain that has value for that person; here, it is less that the activity triggers the engagement than that the person's prior knowledge and experiences of value and enjoyment in that context determine their interest (Ainley, 2012). In this long-term orientation, the person may autonomously engage and re-engage with the content despite significant efforts required and occasional setbacks. At this stage, the learner experiences not only positive feelings but also a sense of greater knowledge and value of the content in question. The more developed the individual interest, the more an individual will participate in self-regulated learning activities such as seeking answers to their own curiosity questions (Hidi & Renninger, 2006). Well-developed individual interest is based strongly on cognitive factors such as well-founded and meaningful goal structures (Hidi & Renninger, 2006; Krapp & Prenzel, 2011).

Interest can also be viewed from the perspective of classroom learning, and especially the various domains of different school subjects. According to Fryer, Ainley & Thompson (2016), domain interest can be defined as students' interest to a certain body of knowledge, such as interest in mathematics, and it resembles conceptually individual interest because of its connection to knowledge and value components of interest. Contrary to the university students that Fryer et al. (2016) were studying, primary and secondary school children usually have less freedom to choose what domains to study. This poses challenges to teachers because of the various phases of interest development that the students are in. In order for students' interest to develop towards a particular domain, the activities and tasks used in the teaching should help to trigger interest in the more novice students and offer enough challenge and autonomy for the more advanced ones.

Previous research literature has found interest to have several positive outcomes in learning, such as increased attention, use of learning strategies, and goal setting (for reviews, see Renninger & Hidi, 2011; Potvin & Hasni, 2014).

2.2 Individual characteristics and interest

Students differ from each other not only in terms of interest development, but also on other individual characteristics. In this study we controlled for two such characteristics, namely self-efficacy, and intrinsic goal orientation, because these have been found to have a relationship with interest. Self-efficacy is defined as the individual's appraisal of one's own capabilities to carry out a task along with the confidence in one's skills to complete that task (Pintrich, Smith, Garcia & McKeachie, 1991) It has been found to have at least a moderately sized correlation to interest, and in addition this correlation has been found to be stronger in mathematics and science than in any other subjects (Rottinghaus, Larson & Borgen, 2003; Bong, Lee & Woo, 2015). Reasons for this strong relationship may be found in the hierarchical nature of mathematic and scientific knowledge, inflexible characteristics of mathematical instruction, and students' perceptions of mathematics and science as difficult subjects. The relationship is hypothesized to be reciprocal, where on the one hand student's level of self-efficacy in a particular domain may influence whether or not he or she generates interest towards it while on the other hand, interest may evoke feelings of competence and self-efficacy (Bong et al., 2015). Intrinsic goal orientation, or mastery goal orientation (for terminology, see Ames, 1992; Vansteenkiste, Lens & Deci, 2006), by definition is the individual's perception of oneself to be participating in a task for the sake of challenge, curiosity, or mastery. In educational settings, a student with and intrinsic goal orientation views an academic task to possess not only instrumental, but also inherent value (Pintrich et al., 1991). It has been found to have a positive connection to interest (Harackiewicz, Barron, Linnenbrink-Garcia & Tauer, 2008; Tapola et al., 2013). This relationship is also thought to be reciprocal, so that students' initial interest in the subject predicts their adoption of mastery goals, and the adoption of mastery goals deepens their interest by motivating them to be more task-focused (Harackiewicz et al., 2008).

2.3. Generation of interest in inquiry-based learning environments

Generation of interest refers to the ways in which a learner develops an interest in the activity at hand. On a practical level the challenge is usually twofold: how to trigger the interest of those students who aren't already drawn to the subject, and at the same time help already interested students to maintain their interest. From the teacher's perspective, it is essential to know how to design teaching so that it triggers the interest of uninterested students, and supports the development of individual interest for the others. In particular, experiences of novelty, challenge, physical activity, and social involvement have been identified as factors contributing to interest generation (Renninger & Hidi, 2011; Palmer, 2009). Also personalizing the context of the instructions to match the students' individual interests, using problem-based learning scenarios, and helping students find meaning and value in their studies through utility-value interventions have been found helpful in supporting students' motivation (Harackiewicz, Smith & Priniski, 2016). Known sources of individual interest generation in science include seeking opportunities to learn through engagement with parents and peers, initiating one's own projects, finding settings for both formal and informal learning, and pursuing a variety of information resources (Crowley, Barron, Knutson & Martin, 2015). Beyond addressing the issue by designing new curriculum content and presentations, students should also be offered early opportunities to experience science as this supports both triggered situational interest and its maintenance and further development (Ainley & Ainley, 2015).

As a one pedagogical method that utilizes some of these principles, inquiry-based, or inquiry learning has been found to relate positively to students' achievement and interest in science learning (Renninger et al., 2014). Inquiry learning is a process in which the learner plays an active part in discovering new relationships within a certain phenomenon. The process involves formulating hypotheses and testing their validity through experimentation or observation (Pedaste, Mäeots, Leijen & Sarapuu, 2012). For such a process to be efficient, it can be divided into phases, each with separate characteristics and subgoals. In one form or another, these phases commonly include orientation to the current problem, conceptualization of key ideas related to the problem, investigation of the problem through data collection and analysis, interpretation of findings, and discussion of the results and the process (Pedaste, et al., 2015).

Inquiry learning provides opportunities to link learning to students' own interests, and when mobile devices are embedded in inquiry learning environments, learning can occur ubiquitously, focusing on aspects of students' everyday experience. The rapid development and uptake of advanced digital devices is both promising and challenging for the design of new learning environments that will interest and engage students by enabling them to choose between different learning activities and tasks. In a study conducted among Taiwanese high school students Lai, Hwang, Liang & Tsai (2016) found that especially meaningful and relevant information from multiple sources predicted students' willingness to engage in inquiry learning. It seems that mobile and inquiry learning share some commonalities that may benefit one another. Mobile learning's ability to remain detached from spatial and material boundaries offers possibilities for inquiry to expand beyond the traditional classroom environment.

Inquiry-based approaches have been found to positively influence students' interest development in different types of science education settings. In their study Renninger et al. (2014) found that an inquiry-based intervention that was designed to help at-risk middle school students in their science studies had a positive impact on students with varying levels of interest. Those students who had already more developed interest at the beginning of the workshop were able to dig deeper into the subject and approach it more individually and systematically. On the other hand, those students with less developed interest could start off less systematically but gradually develop more complex thinking that would also transfer from one session to another. This is one of the possible benefits of inquiry-based learning since it allows more individuality in terms of study pace.

2.4. Context of the study

The new learning environment was designed to utilize the principles of inquiry-based learning, with a particular emphasis on integrated curriculum. The new Finnish curriculum that was under development at the time of this study relied on a conception of the learner as an active agent, setting individual goals and solving problems, independently and in collaboration with others. Students' self-reflection of experiences and emotions, the joy of learning, and creativity are expected to expand their sphere of interests. Supporting students' growth to humanity and ethically responsible citizenship, as well as lifelong learning are seen as central goals of education (Finnish National Board of Education, 2014).

To implement the requirements of the new national curriculum, the participating school had designed a new pedagogical approach that would combine different school subjects, especially in the science domain, in various learning projects. The school had received outside funding for a three year project and had selected one 7th grade class of 18 students as the pilot group. This study reports the first year of that project. The students received personal tablet computers as their primary tool for school work. The tablets contained different types of learning software, such as e-books and e-notebooks and applications for mind mapping, instant messaging, and image and video editing. In addition, all of the subject teachers had an opportunity to participate in professional training courses to facilitate implementation of pedagogical practices in the new learning environment.

Teaching in the new learning environment relied on principles of inquiry-based learning and integrated curriculum. The approach adopted in the present study can be characterised as multidisciplinary, as the learning projects and inquiry activities revolved around one overarching theme which would then be covered in different subjects (Drake & Burns, 2004). In practice, this meant that the students were planning and conducting experiments in learning projects combining elements from different school subjects and involving work outside the classroom. Depending on the requirements of each task, the students worked individually, in groups, or in pairs. Students used the tablet computers to document experiments, to retrieve information, to work simultaneously on a task, and to present their findings to other students in the classroom, as well as for homework and exam rehearsals. One example of such activity was a cross-curricular, water-themed project, in which students would conduct field experiments by collecting water samples, analysing them in biology and chemistry classes, taking photographs of the surrounding environment in arts class, and writing reports on the quality of the water in language class.

3. Aims of the study

In examining how lower secondary school students' domain-specific interest is developed during the first year in an inquiry-based mobile learning environment, external factors such as how features of that environment contribute to students' interest were of particular interest. A quasi-experimental study design was used to compare the new learning environment with a regular learning environment. The research questions were as follows.

1.1 How does domain-specific interest among students in the digital learning group develop during the school year?

1.2 Does this differ from development among control group students?

2.1 What aspects of the new learning environment help or hinder students' interest generation?

2.2 What components of the experience generated student interest?

To answer questions 1.1 and 1.2 quantitative data were collected by means of interest questionnaires. For a more detailed view, questions 2.1 and 2.2 were addressed by qualitative means, using focus group interviews with the experimental group.

4. Method

4.1. Participants

The study participants were 131 7th grade students (69 girls and 62 boys, aged 12–13 years) from seven classes at one lower secondary school in Southern Finland. One class (N = 18) had been chosen by the school to undergo classroom teaching using only digital learning tools, and these students formed the experimental group in a quasi-experimental research design. The remaining students (N = 113) continued to receive more traditional teaching using materials such as books, notebooks, and handouts. From these 113 students 18 propensity score-matched students were selected as the control group for the experimental digital learning group. The use of propensity score matching creates a control for students' initial motivational profiles at the beginning of the school year, and ensures that each student from the digital learning group has a counterpart with a similar profile at the beginning of the school year. The defining variables used for matching were *general self-efficacy*, *intrinsic goal orientation*, *interest in technology*, and *web-user self-efficacy*.

4.2. Procedure

To establish students' initial level of interest and motivation, a self-report questionnaire was administered to students at the beginning of the school year (time 1). After this initial measurement, day-to-day classroom work went on uninterrupted, and teachers and students were free to implement the learning environment as they saw fit. Similar sets of questionnaires were administered on two further occasions during the school year: four months after the start of the school year (time 2), and nine months after the start, at the end of the school year (time 3). The questionnaires included measures of individual interest, motivational beliefs, and self-efficacy, which are described in more detail in the next section.

4.3 Measures

4.3.1 Domain-specific individual interest

An instrument from Tapola et al. (2013) was used to assess students' domain-specific individual interest in the science domain. The instrument measured interest in three subjects (mathematics, chemistry and physics, and biology) for a single item on a five-point scale, ranging from 1 (*not at all interested*) to 5 (*very interested*). An example item would be "*How interested are you in mathematics*".

Interest in technology and interest in collaboration were measured for five items on five-point scales ranging from 1 (*not at all interested*) to 5 (*very interested*), with two reversed items in each. Example items for both respectively would be "*I find working with technology interesting*", and "*Working together with other students is interesting*"

4.3.2 Individual characteristics

Students' intrinsic goal orientation and self-efficacy for learning and performance were measured using selected scales from the Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991). Intrinsic goal orientation (e.g. *In a class like this, I prefer course material that really challenges me so I can learn new things*) was measured for four items, and self-efficacy for learning and performance (*e.g. I'm certain I can understand the most difficult material presented in the readings for this course*) was measured for eight items on a seven-point scale. In addition, students' web-user self-efficacy was measured using a modified version of the WUSE scale (Eachus, Cassidy & Hogg, 2006). The instrument consisted of 14 items, measured on a five-point scale from 1 (*strongly disagree*) to 5 (*strongly agree*) (e.g. *I would never try to download files from the internet, that would be too complicated*).

4.4. Focus group interviews

To gain a better insight into students' experiences of the new learning environment, two interview sessions were arranged during the school year. In the first session, the students in the experimental group were interviewed in groups of four or five. The first interview session was conducted in the middle of the autumn semester, two months after the start of the school year; this time point was chosen because the students would by then have been sufficiently familiar with the environment to have formed an opinion about it. The time period was considered short enough to enable recall of aspects of the learning environment perceived as interest-generating, and long enough for differences in interest to emerge. The second interview session was conducted at the end of the school year. In all, four groups of students were interviewed during the autumn semester and three during the spring semester. Depending on how actively students participated in the discussion, interviews varied in duration between 20 and 34 minutes.

The interviews were designed on the principles of stimulated recall, first asking students to describe an event or topic that they remembered from their studies during the past semester. Follow-up questions would then explore what had been of particular interest, and why, with additional emphasis on cross-curricular and inquiry learning elements in the students' responses. Students were also asked to identify elements that they felt had not worked, and to propose how the learning environment could be further developed.

4.5. Analyses

To answer the first research question, concerning how domain-specific interest develops during the school year and whether there are differences between the digital and traditional learning groups, the quantitative data were analysed in two phases. In the first phase, a repeated measures ANOVA was conducted to establish how mean levels of domain-specific interest developed in the digital learning group. This was followed by paired sample t-tests to identify statistically significant changes in those variables based on the ANOVA results. A similar procedure was used to detect mean level differences between the levels of interest of the digital learning group and the propensity score-matched traditional learning group. Following repeated measures ANOVAs, statistically significant differences were compared separately for each time point, using independent samples t-tests. There was no indication that the data would not be normally distributed and for that reason the analyses proceeded as planned.

To analyse the interview data a twofold analysing scheme was created. The first main category of the scheme, named *'generation of interest'*, sought to clarify what aspects of the new learning environment had helped to generate student interest. This category focused on the learning environment's pedagogical design and technical features. The second main category of the analysing scheme was called *'components of interest'* and focused on students' experiences of studying in the new environment. Its aim was to determine which components had contributed to interest generation.

In both of these categories, the analyses were data-driven; this meant that there were no ready-made subcategories for the students' answers (see Appendix A for more information on the coding scheme, including categories and subcategories and excerpts from the data). Using content analysis, the coding scheme addressed 1) generation of interest (issues that students identified as interesting) and 2) components of interest (why certain issues were perceived to be interesting). Each main category was then further and separately analysed, grouping expressions into subcategories according to similarity of content. As each interview session was conducted in groups of four or five students, one expression may consist of several students participating in the conversation at the same time. An expression would be counted as being started when some of the students brought it up first time during the interview, and would end as the conversation flowed to another topic. In all, the *generation of interest* category attracted five subcategories, and the *components of interest* category attracted four. In addition, two categories were formed for critical remarks and developmental ideas. The analysis was conducted by the first author, and the second author coded half of the data to assess intercoder agreement (90%).

5. Results

5.1. Digital learning group: domain specific interest development during the school year

Item analyses confirmed that all scales were reliable (alphas varying between .72 and .93). To find out how the experimental group's interest developed during the school year, a repeated measures ANOVA was conducted for all five subject-specific interest measures for time points 1, 2, and 3. The tests showed statistically significant differences between interest in physics and chemistry ($F(2, 15.098) = 7.612$, $p = .002$) and interest in biology ($F(2, 16.987) = 4.957$, $p = .013$). The mean level development of the experimental group's subject-specific interest is shown in Figure 1.

Paired sample t-tests showed a significant decrease in experimental group students' interest in physics and chemistry from time point 1 ($M = 4.17$, $SD = .79$) to time point 2 ($M = 3.48$, $SD = .91$); $t(18) = -2.99$, $p = .008$, Cohen's $d = 0.83$. During the same time period, students' interest in biology increased from time point 1 ($M = 2.72$, $SD = .90$) to time point 2 ($M = 3.38$, $SD = .90$); $t(18) = 2.60$, $p = .019$, Cohen's $d = 0.73$. During the spring semester, between time point 2 and time point 3, no significant changes in interest levels were detected.

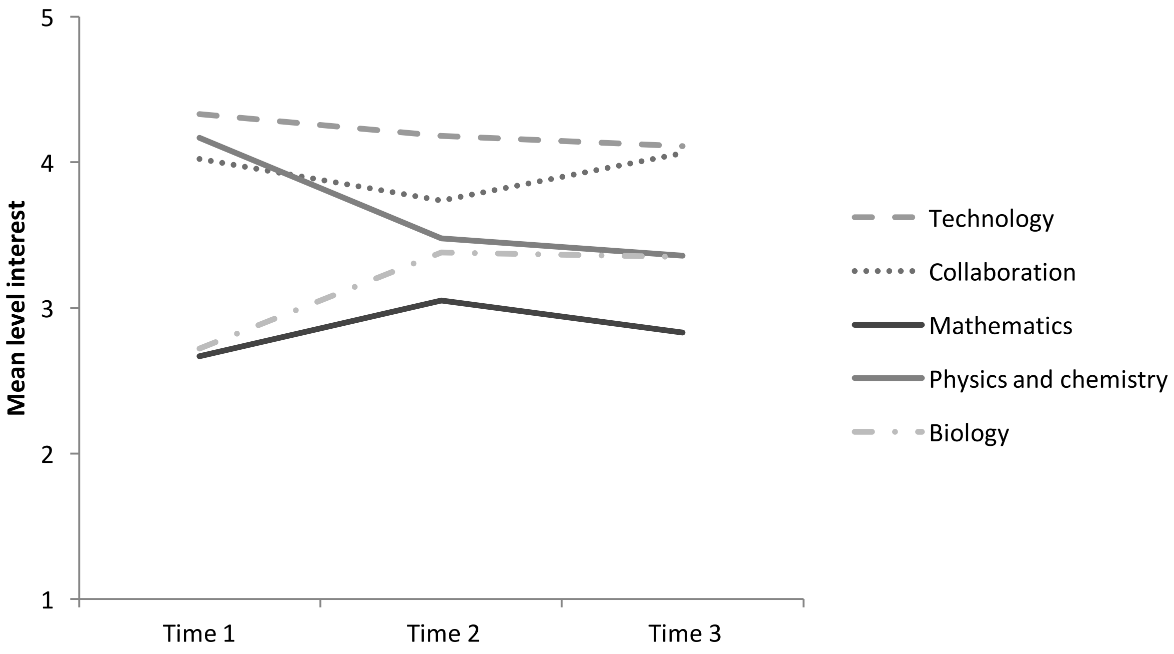

Figure 1. Digital learning group's subject-specific interest during the school year.

5.2. Differences in interest development between the experimental and control groups

A repeated measures ANOVA was conducted to determine whether interest variables, motivational variables, and school grades differed significantly between the two groups. The results show a significant effect of classroom condition on interest in physics and chemistry ($F(2, 68) = 6.35$, $p = .003$). As shown in Figure 2, the experimental group's interest in physics and chemistry declined between time point 1 (M = 4.17, SD = 0.79) and time point 2 (M = 3.48, SD = 0.91) but stabilized at time point 3 (M = 3.36, SD = 1.08). The control group's interest in physics and chemistry increased between time point 1 (M = 3.07, SD = 1.10) to time point 2 (M = 3.46, SD = 0.98) but decreased again between time point 2 and time point 3 (M = 3.02, SD = 0.91).

An independent samples t-test revealed that although the two groups were matched on other variables at the start of the school year at time point 1, there was a significant difference in individual interest in physics and chemistry between the experimental group (M = 4.17, SD = 0.79) and the control group (M = 3.07, SD = 1.10) , $t(34) = 3.449$, $p = .002$. The experimental group showed a higher interest in physics and chemistry at the beginning of the school year as compared to the control group but not at the other time points.

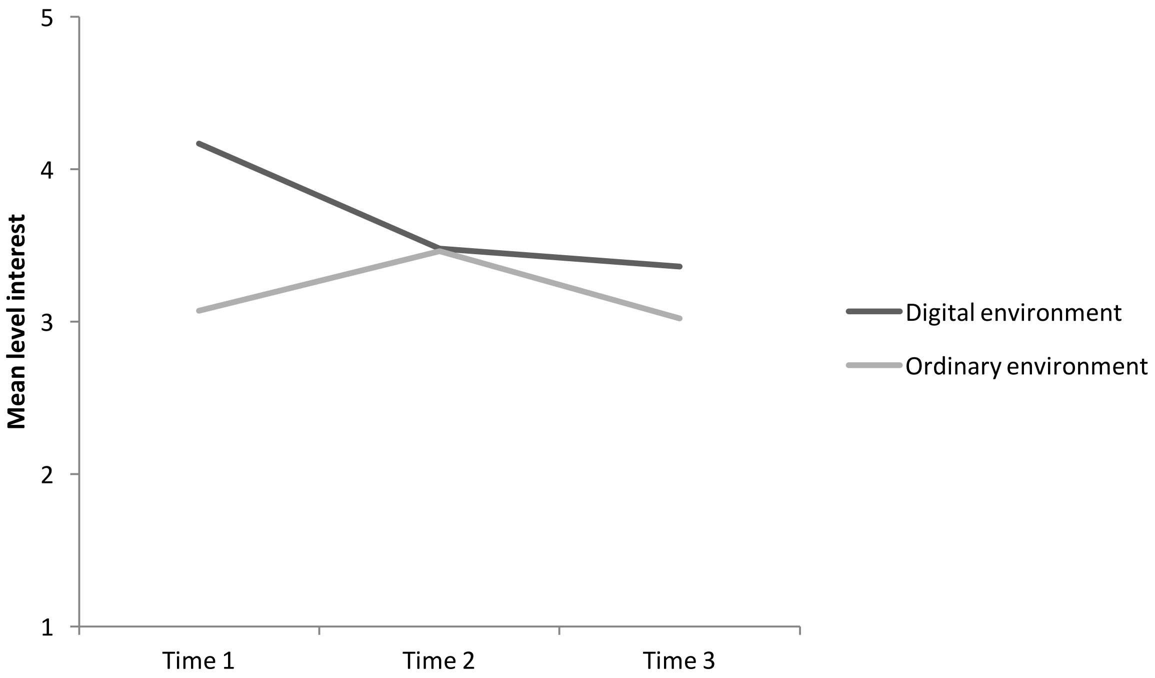

Figure 2. Experimental and control groups' interest in physics and chemistry during the school year.

In summary, there was no evidence of statistically significant differences between the groups in interest in technology, interest in collaboration, interest in mathematics, or interest in biology. Similarly, no differences were found in the development of students' intrinsic goal orientation, general self-efficacy, or web-user self-efficacy. The only significant difference between the two groups related to interest in physics and chemistry.

The experimental group's interest in physics and chemistry was higher at the beginning of the school year in September but declined to average level over the following four months. In contrast, the control group were a little less interested in physics and chemistry at the start of the school year but seemed to gain interest during the autumn and reached the same level as the experimental group at the midterm measurement point. However, during the spring term, the experimental group seemed better able to maintain their interest, experiencing only a slight decrease in mean value over the four months, while the control group regressed to the below-average level they had reported at the beginning of the school year some nine months earlier.

5.3. Student interest generation: digital learning group

During the time 1 interviews, experimental group students identified several features in the learning environment that they found to be *interest-generating*; these were integration, illustrativeness, learning tools, hands-on activities, ability to use the digital material outside classroom, and versatility. Versatile use of learning materials was mentioned most often as interest generating feature of the environment. Activities performed outside of classroom were the second often mentioned interest generating feature. Table 1 shows the number of mentions for each sub-class of interest generation, an example of sub-classes, as well as interpretation. During the time 2, the students mentioned less interest generating features as seen in Table 1.

Table 1

Generation of interest, an example passage from the interviews and its interpretation

Generation of interest *Number of mentions for each sub-class of interest generation*	Example *An example passage from the interviews which may include conversation between several students and which counts as one expression*	Interpretation
Integration Time 1 = 2; Time 2 = 1	*Student 1*: Well, the chemistry test or the experiment thing, where we collected water from nearby lakes. We take water samples from there and then we analyse them in chemistry class. *Student2*: And in biology. In biology, we also do research work, and doesn't writing the report involve something related to Finnish language?	During the time 1 and time 2 interviews, students mentioned integrative elements that they found interesting when participating in projects that combined different school subjects. For example, students referred to a science project in which they had collected water samples, analysed them, and wrote reports about their findings.
Illustrativeness Time 1 = 4; Time 2 = 0	*Student 1*: Especially on those occasions when we record videos to Book Creator. In the chemistry class, we usually record it (the experiment), and then you can attach the video there. *Student 2*: And then you can watch it from there when you are revising for an exam. How it was done and so on; what went wrong and what could have been done better.	As an example from time 1 interviews, the tablet computer was found to have proved useful when taking notes during chemistry class experiments. In the time 1 interviews, students mentioned features of the learning environment that they had found especially illustrative. However, during time 2 interviews, students did not mention any examples of illustrative features.
Hands-on activities Time 1 = 3; Time 2 = 0	*Student 1:* Everything like water hardness, pH-value, and nitrate content. Then, nutrient concentrations; you put some substance in there that changes the colour; like, the sample's colour changes, and then we can conclude if there is something.	During time 1 interviews, the students mentioned that the hands-on work in the chemistry classes had been interesting. This included taking water samples from nearby lakes that were then analysed in the chemistry laboratory.
Outside of classroom Time 1 = 5; Time 2 = 3	*Student 1*: Well, there's this home economics diary. *Student 2*: You take a picture of the food you prepared, and then you write what was done today and what was the day's topic. *Student 3*: And then we can …there's	In both time 1 and 2 interviews, students mentioned that they would sometimes use the tablet computer to engage in learning activities outside the classroom. For example, in home economics, they would document their household work, which the teacher would take into account in the course evaluation.

	this separate section where we can write all the foods that we have prepared at home and take a picture, so then the teacher can see what we have done at home.	
Versatility Time 1= 6; Time 2 = 5	*Student 1:* Well, at least there are videos; in the hardcover books, there are none of those. *Student 2:* And there are multiple choice questions. *Student 1:* As I was saying, there are videos and a lot more pictures than in the hardcover books. *Student 2:* And you can immediately check if the multiple-choice questions were correct. It shows you that.	Students also mentioned several features of the learning environment that related to the versatile use of the learning material. For example, when discussing the differences between e-books and hardcover books, they noted that e-books included more interactive features.

5.4. Components of interest generation: digital learning group

After identifying things they had found interesting during their studies, students in the experimental group were then asked to elaborate on why these things were interesting. In the analysis, these were categorised as *components of interest.* The students' answers included features such as ease of use, working with the environment as nice or fun, being able to collaborate with other students, and having autonomy over their own learning. Most often the students mentioned that the fact that the environment was easy to use was generating their interest. Table 2 shows the number of mentions for each sub-classes of components of interest, examples of each sub-category, as well as interpretation. Table 2 shows also number of mentions of critical remarks and developmental ideas that were asked from the students at the end of the Time 2 interview.

Table 2
Components of interest, an example passage from the interviews and its interpretation

Components of interest generation *Number of mentions for each sub-classes of components of interest*	Example *An example passage from the interviews which may include conversation between several students and which counts as one expression*	Interpretation
Easy to use Time 1 = 7; Time 2 = 6	*Student 1*: There are so many things in this one device that it's completely different. You can just take this in your hand and do everything at once. With books, you take one book and do stuff there, and then you take another one and do stuff there, and…	At both interview times, students felt that the mobile learning environment had made it easier for them to study. In the time point 1 interviews especially, the fact that all the materials they needed were on one device attracted positive remarks.

Nice/fun Time 1 = 6; Time 2 = 4	Student 1: You can do all kinds of fascinating things with it, like molecules and stuff. Student 2: We haven't used it that much yet, only in one lesson. Student 1: Yeah, in one lesson, but it's very nice because you can get all these fascinating looking things.	In general, students referred to the new learning environment in words and phrases conveying positive emotions. Working with the material had felt nice, fun, and exciting, especially in time 1 interviews, when they were still relatively new to the learning environment. For example, in chemistry, they had used modelling software to produce different chemical bonds.
Collaboration Time 1 = 4; Time 2 = 6	Student 1: It [the software] is a bit like a notebook, and the teacher writes the titles and groups there. And then, let's say I would be Lisa. I would write about a certain topic in religion, and then another group would write about some other topic, and so on. Then we all read the texts produced, and the teacher also has access to them. So, we have to read what everybody else has written there. Student 2: And everyone can do it with their own tablet. We can write about a topic together in the group by simultaneously using our own tablets.	One of the themes that emerged from the interviews was collaboration. The students described situations in which they had worked together as a group, using the mobile learning environment to produce and share material instantly with their peers.
Autonomy Time 1 = 4; Time 2 = 6	Student 1: But it's not as if someone is breathing down your neck all the time and watching what you're doing or that all the words are correct. We are usually just given instructions on what to do—like do exercises or write something down. Student 2: Yeah, or go somewhere on the Internet.	At both time points, the students raised issues about their autonomy as learners. In time point 2 interviews especially, they mentioned classroom activities where the teacher had allowed them to choose from different approaches and working methods.
Critical remarks Time 2 = 16 Ideas for development Time 2 = 11	Student 1: Well, mathematics. Student 2: It is a bit far-fetched how you are supposed to use it there. Basically it works pretty fine, but at least personally I don't feel like I'm learning a lot with it. Student 1: And in principle if you would like to have all the (mathematical) symbols you would have to buy a keyboard. Like the kind you have in a computer.	In the time 2 interviews, the students were also asked to freely criticise features and practices in the environment that they felt were not working properly, and to suggest improvements for future development. Their critical remarks related to poor quality e-books (especially in mathematics), problems with iPad functioning and wireless connection, the lack of a good application for taking

		exams, teachers' reluctance to take full advantage of the digital tools, and concern about losing hand-eye coordination because of working only digitally.

6. Discussion

This study investigated how students' interest in the STEM domain developed over a one year period in an inquiry-based mobile learning environment, and whether their developmental patterns differed from those in the more traditional learning group. In addition, we hoped that by interviewing the students about their experiences we might acquire more in-depth information about the components that contribute to long-term interest generation and development in such environments. The statistical analyses showed that the digital learning group's students' domain specific interests in science and mathematics remained at an average level throughout the school year while their interest in technology and collaboration remained high. These results seem to indicate that students found the new learning environment interest generating. This aligns with previous research suggesting that inquiry-based learning environments trigger and sustain students' interest in STEM (Renninger et al., 2014).

However, perhaps the most surprising result was that the digital learning group's students' interest in physics and chemistry declined significantly during the first half of the school year. This finding seems to be in conflict with some of the interview results, which highlight how the new learning environment was seen as interest supporting by the students. That decline was also the only observed statistical difference between the two groups with the digital learning group's developmental pattern differing from that of the control group. While the experimental group's interest declined slightly from high to above average during the autumn semester, the control group's interest increased to similar level during the same period. This raises the question of whether the new learning environment had been implemented to make the best use of the principles of inquiry learning and to take into account the pedagogical demands of mobile learning. Previous research has found that the manner of implementation in the inquiry context is a key element of inquiry-based learning interventions (Renninger et al., 2014). Digital environments do not in themselves necessarily suffice to generate interest; instead, a more comprehensive design approach is needed. It seems, for instance, that a number of questions should be addressed before implementation, including how to arrange instructional support, when to allow collaboration between students, and how best to take advantage of the mobility of the learning environment. Furthermore it would be beneficial to apply a broader view of the learning context when mobile learning designs are researched and implemented in practice. Frameworks such as Integrative Learning Design Framework (Bannan, 2016) could be used to systematically integrate analysis, design and development processes that would serve the needs of both pedagogical development, and producing an effective learning innovation.

The interviews revealed that, in general, the students found the mobile learning environment to be interest-generating, with particular reference to the following specific features: 1) the possibility of integrating different school subjects; 2) the ease of use of the learning software; 3) the ability to take learning outside the classroom; and 4) the increased possibilities for learning collaboratively. Students referred to all four features on both occasions which indicates that there was no sign of a novelty effect wearing off during the one year period.

The new curriculum was designed to emphasise joint teaching of different school subjects with the aim of increasing student interest and engagement in studying. It was therefore very positive to see that students were referring to the possibility of integrating different school subjects as interest generating. Therefore it can be argued that while the new curriculum was especially emphasizing integration the new learning environment had from this point of view at least partly reached its goal.

The way that students were referring to the second feature, ease of use was also promising. The analyses of the interviews revealed that students placed considerable emphasis on how the digital tools work and the scope they offer for individual exploration. Already in the first interviews, students described several items of learning software they had learned to use in school, including e-books, web-based learning resources, mind maps, and blogs. In some learning activities or projects, students were allowed to choose how to complete the work, using their creativity to modify the end product to their liking and making it more personally relevant by retrieving information from different sources. They also expressed a belief that learning to use a wide range of digital tools in the environment prepared them for success in their future working life; hence they had developed value beliefs towards the technology used in the environment. This indicates that at least some of the students had already progressed towards more individual interest, since its underlying psychological processes are closely related to interpreting and valuing contextual features in relation to potential activities (Ainley, 2012).

Use of mobile learning environments may offer students more autonomy and freedom of expression. Some students emphasised the importance of being able to modify their digital notebooks as they saw fit. Some had also used the tablet to create their own animated videos and to undertake other creative work in their free time. This seems to have helped them to adopt the tablet as an everyday instrument for learning, increasing their level of engagement with school work. Mobile devices offer the possibility of a more personalized approach to learning and stretch the boundaries of the physical classroom. Planning the balance of instructional structure and student autonomy is an important part of every learning process, and combining mobile learning with inquiry lends further emphasis to this aspect. The critical comments made by the students regarding their day-to-day schoolwork were indicating that this was currently lacking in some cases. Previous literature has found that un-assisted discovery, or inquiry learning is not in any way an optimal solution for educative purposes (see e.g. Alfieri et al., 2011) and scaffolds for self-regulation as well as students' own reflection are needed (Pedaste et al., 2012). In the future, technology will probably offer even more personalized learning paths, and this will further increase the demand for teachers to develop their competences and also re-consider their role in the learning process.

The mobile environment also made it possible to take learning outside the classroom, most notably in the case of the multidisciplinary water-related learning project. Using the tablet computer, students were able to take notes and document the water samples they had collected. They could then work collaboratively on writing the final report, sharing it with other members of their group before displaying the results to a wider audience. Although these features have in many cases already formed part of inquiry science instruction (see Minner et al., 2010), mobile technology helped to make the process more effortless and versatile.

Although this study did not directly address the issue of whether interest influences learning outcomes, the interviews raised some interesting notions. Some students felt that the activities completed in the mobile learning environment helped them to memorise the material better than when reading from books. Their reflections seemed to indicate their ability to use metacognitive skills to assess their learning strategies, and suggested their preference for the new environment.

6.1 Critical remarks on the learning environment

Students also made some critical remarks and identified issues related to the learning environment that need to be resolved. These remarks can be divided into two broad categories: 1) pedagogical shortcomings in implementing the environment and 2) technological challenges.

In relation to pedagogy, students noted that teachers were not always up to speed with the new technology sometimes the students even needed to guide them on technical issues. This also gave rise to students' criticism of teaching methods in some of the lessons where according to the students, the teacher had merely replicated ordinary classes with books, notebooks and handouts, utilizing the tablet computer and its applications in a minimal way. These implementation problems may also explain why the statistical analysis did not reveal greater differences in interest levels over time or between the two groups. This criticism brings out the challenges that new mobile learning environments present for teaching. As Traxler & Kukulska-Hulme (2016) point out, in mobile learning the teacher's role and responsibilities shift from being the facilitator of educational artefacts, towards being one who evaluates and collects suitable content, organizes it and makes educational opportunities possible. In order to succeed in this task the teachers need sufficient support on how to prepare for this change. This underlines the importance of in-service teacher training programs that would offer teachers the possibilities to get an update on their pedagogical skills and knowledge. Attempting to use 'ordinary' pedagogy in a mobile environment is likely to hinder student engagement in learning and to place an additional burden on the teacher. This kind of criticism also suggests that students are quite well aware of the technological aspects of the learning environment and are also able to reflect on how they learn in different settings. In the future students could be more involved already in the design process when these types of inquiry learning activities are planned. In this way, assignments could focus more on students' own areas of interests and needs, and challenging or even negative features of their experiences could be addressed and resolved during the process. This would also support students' self-regulation development which is a crucial element in these types of learning environments. Previous findings state that while the mobile learning environment offers tools for ubiquitous learning, students need skills and knowledge of self-regulated learning if they are to realise all the environment's possibilities (Sha, Looi, Chen & Zhang, 2012).

Another criticism was directed at the technology used. Sometimes, the hardware caused problems, such as loss of tablet power, failure to connect to the Internet, or the laboriousness of writing longer texts without an external keyboard. Additionally, the educational software was either too limited—for instance, allowing only multiple-choice questions—or was still under development, which meant that some features were not yet working. Teachers therefore need to be aware of the attributes of each software or application and how to apply these in their teaching. Although essential in day-to-day classroom practice, this is not an easy task, and without familiarizing themselves, teachers will be unable to decide the best ways to apply the technology.

6.2 Limitations

The present study has some limitations that need to be addressed. The first of these concerns the relatively small sample size on which the quantitative analyses were based. Because the study was conducted in ecological valid settings, the researchers could not determine the number of participants; instead, the school principal decided who was to be assigned to the mobile learning class. While this may have created bias in the sample, this was controlled by creating a propensity score-matched control group from a pool of 113 students. The propensity scoring matched each of the experimental group's students with a matching student from the control group, based on their motivational profiles at the start of the school year.

A second limitation relates to the measures used for quantitative data collection. Students' interest in STEM was measured in terms of school subjects. Although single-item instruments have been extensively used to measure interest in previous research, it can be argued that using single-item instruments measuring only interest in the subject as a whole was too broad. It would be useful in future studies to consider how to reliably measure interest in its different developmental phases (Renninger & Hidi, 2011).

Another measure-related issue is that interest in physics and chemistry was assessed by one combined item and may therefore have caused some reliability issues in terms of the item's internal consistency. Although the calculated reliability estimates were at a sufficient level, some students completing the questionnaire may actually have been estimating their interest in physics while others were concentrating on chemistry. In addition, there was no measure of interest in geography, which is usually included in the STEM domain and is taught as a separate subject in the Finnish school system.

6.3 Recommendations for future research

Previous research has shown that individual interest affects which features of the learning environment help to trigger students' situational interest (Renninger & Hidi, 2011). An essential question for future research, then, is how best to combine measures of situational interest and long-term individual interest, and what other personal and motivational variables should be taken into account in this process. Digital devices such as tablet computers facilitate more effortless and less intrusive data collection that can tap into students' everyday experiences at school.

Another recommendation relates to the actual day-to-day classroom work in the course of this study. Without observational data, it is impossible to determine exactly how much of the teaching in these new learning environments actually relies on inquiry-based approaches. Based on the interview data of this study, it seems that at least partly the day-to-day teaching was relying neither on inquiry nor taking the full advantage of the mobile learning aspect of the learning environment. In the future, it would be interesting to add an observational element to data collection to determine, for example, how students' inquiry skills develop during an inquiry learning activity, and whether or not pedagogies evolve during that time. In addition a measure for learning outcomes could be added.

A final recommendation for future research would be to explore how to design mobile learning environments to properly enhance inquiry learning. Mobile learning devices offer freedom from temporal and spatial boundaries, and digital evaluation tools may in the future provide personalised information about students' progress and level of development.

Keypoints

- There was clear evidence that the inquiry-based mobile learning environment offered promise in terms of supporting students' interest in learning science but this did not come without a price. More research is needed to determine the best practices of pedagogical implementation.
- The pedagogy used during lessons should be integrated with the educational technology, so that they complement each other. This makes it possible to support students' interest development in the long term.
- Students could be more involved in the implementation process by having their say about the design of the environment. Students would benefit from increased autonomy in terms of self-regulation and engagement and teachers would receive valuable feedback on the functionality of the environment.
- Teachers should be offered the possibility to attend in-service training programs that help them to update their pedagogies, and also constant support should be available.

7. Acknowledgements

This study received funding from the Finnish Cultural Foundation and Turku University Foundation.

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