Motivation related predictors of engagement in mobile-assisted Inquiry-Based Science Learning

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***Abstract* — One of the major priorities of education systems nowadays is to promote Inquiry-Based Science Learning (IBSL). Research has shown that mobile learning can support and enhance inquiry-based science learning promoting learning achievement and motivation. However, engagement, as a consequence of motivation, in the context of mobile-assisted inquiry-based science learning, has not been adequately investigated. The current study implements a collaborative mobile-assisted inquiry-based science learning intervention in the context of secondary school science. The study is aiming at explaining and predicting student engagement in terms of the three motivational concepts of the Self-Determination Theory (SDT) of motivation: autonomy, competence and relatedness. Data collected for 80 secondary school students and analyzed with structural equation modeling. The proposed model explains about 63% of the variance in students' engagement in mobile-assisted inquiry-based science learning. Perceived autonomy was found to be the strongest predictor of engagement, followed by perceived relatedness. Based on the research findings, implications for practice and suggestions for future studies are also discussed.**

Keywords— mobile learning; collaboration; collaborative inquiry-based science learning; mobile-assisted inquiry science education; motivation; Self-Determination Theory; autonomy; engagement

I. INTRODUCTION

Promoting Inquiry-Based Science Learning (IBSL) is a key issue in many national educational systems worldwide [1]. Collaborative IBSL engages students in an authentic scientific discovery process. Students collaboratively formulate hypotheses and conduct experiments to test them. This kind of investigation enables students to better understand real world phenomena and therefore construct knowledge [2].

Mobile technologies are particularly suited for supporting inquiry-based science learning since they promote learning achievement and motivation [3]. There are many previous studies on the positive effects of mobile-assisted inquiry-based science learning on student motivation and learning achievement [4, 5]. However, few studies have addressed the issue of student engagement. Moreover, there is little understanding of what factors are making mobile learning motivational and engaging [6].

This study is about a collaborative mobile-assisted inquiry-based science learning intervention in the context of secondary school science. It aims to explain and predict student engagement in terms of the underlying motivational constructs of the Self-Determination Theory (SDT) of motivation: autonomy, competence and relatedness [7].

The organization of the study is as follows. The background section briefly introduces the Self-Determination Theory of motivation, the construct of engagement and the model of the inquiry-based science learning. The research model and hypothesis section introduces the three hypotheses under investigation. The methodology section is about the participants, the description of the experiment and the instruments used. The data analysis section follows. Finally, the conclusions and discussions section presents the study results and discusses implications for practice as well as future research.

II. BACKGROUND

A. Self-Determination Theory (SDT)

Self-Determination Theory (SDT) of motivation is a theoretically and empirically well-grounded and supported theory of motivation [7]. According to the theory, there exist two basic types of motivations: extrinsic and intrinsic. Extrinsic motivation refers to the type of motivation that is based on external rewards or punishments. Intrinsic motivation refers to the type of motivation that is based on an interesting and pleasant behavior. The theory claims that, in order to support and promote intrinsic motivation, the following basic psychological needs should be satisfied: autonomy, competence and relatedness. The need for autonomy refers to the desire of experiencing a behavior as volitional and self-regulated. The need for competence refers to the desire of experiencing a behavior as being effective. The need for relatedness refers to the desire of feeling connected to others.

SDT has been successfully applied in education [8] and technology enhanced learning [9]. Research provides evidence that when the basic psychological needs of autonomy, competence and relatedness are supported, students are more likely to be more autonomously engaged in their studies [10]. Raising the satisfaction levels of perceived autonomy, competence and relatedness enhances the feelings of intrinsic motivation and self-determination [11].

Moreover, SDT has been successfully applied in the context of mobile learning as well [12]. SDT provides an appropriate theoretical framework for mobile learning-related research; studies have shown that distinguished features of mobile learning such as personalization, authenticity and collaboration provide connections with the SDT constructs of autonomy, competence and relatedness [13]. In a mobile-assisted learning environment, there are multiple teaching and learning strategies that are able to support the basic SDT psychological needs: location and context-awareness [14, 15] with adapted and personalized support [16] enhances students' perceived sense of autonomy [17, 18]. Appropriate guidance [19] and immediate feedback to students [20], in authentic learning environments [21] can support perceived competence. Communication [22] and collaboration [23] among learners facilitated with social media connectivity support perceived relatedness.

B. *Engagement*

Engagement is defined as the extent of a student's active involvement in a learning activity [24]. It is a multidimensional construct consisted of the following three dimensions: behavioral engagement, emotional engagement and cognitive engagement [24]. Behavioral engagement is defined in terms of attention and participation in class-based activities [24]. Emotional engagement is conceptualized as the interest and enjoyment while in the learning process [25]. Cognitive engagement is defined in terms of deep learning strategies, self-regulated learning, and persistence [26]. In this study we added social engagement as a fourth dimension. Social engagement refers to the quality of social interactions with peers and the willingness to invest in building and maintaining relationships while learning [27].

There exists a considerable body of research that has separately investigated the aforementioned distinctive dimensions of engagement [25]. The current study however, addresses engagement as a unique multidimensional construct that includes all aforementioned dimensions.

Even though studies exist providing evidence that motivation is not always transformed to engagement [28], engagement is usually considered as a consequence of motivation [29]. While many studies exist about motivation and engagement, there is a need to explore what transforms motivation to engagement. Students usually engage in a learning task that is perceived as interesting and enjoyable [30] with high intrinsic value [31].

The latter provides connections with SDT. Previous studies have shown that high levels of perceived autonomy, competence and relatedness can reliably predict classroom engagement and students' positive outcomes as well [32, 33]. The current study is the first that employs perceived autonomy, competence and relatedness from the perspective of the SDT in order to predict and explain student engagement in the context of a mobile-assisted inquiry-based learning.

Research has shown that, despite the increasing demand for science technology engineering and mathematics professionals [34], students' interest and engagement in math and science domains follow a descendent trend [35]. Therefore, there is an urgent need to promote student engagement in science and math learning activities and courses. Moreover, the learning and working environment of the 21st century learning demand for the development of inquiry skills [36]. Nowadays, it is very important to increase student engagement in inquiry-based science learning by appropriately designing and implementing methodologies based on solid theoretical frameworks.

C. *Inquiry-based Science Learning*

Inquiry-based learning has been defined as an educational strategy where students, through active participation and social interactions, responsibly discover knowledge by using their inquiry skills [37].

In Inquiry-Based Science Learning (IBSL) students explore scientific knowledge performing their own investigations like scientists do: they formulate hypotheses and test them by conducting experiments and/or making observations [2]. It is a process oriented and problem-solving activity that consist of different phases. The current study adopted the inquiry framework proposed by [2] as the more recent framework that emerged from related literature. The framework proposes five steps-phases in the inquiry process: (i) the orienting and asking questions phase where students are introduced to the subject under investigation and start performing their initial scientific explorations (ii) the hypothesis generation and design phase, where students define the problem and what needs to be known generating their hypotheses, iii) the planning and investigation phase where students design the experiment to address their previously stated questions, iv) the analysis and interpretation phase where students analyze and interpret the data obtained trying to identify patterns, make inferences and provide evidence , and v) the conclusion and evaluation phase where students find relations, draw and justify conclusions, reflect and reason with evidence about the studied phenomenon.

D. Mobile Inquiry-based Science Learning

Mobile devices have been successfully used in inquiry-based science learning. Mobile technologies provide opportunities for learners to engage in personalized, context-aware and autonomous seamless experiences across learning contexts [14, 15]. Inquiry-based learning can be effectively supported by the use of mobile devices through location or procedural guidance, contextual support, access to dynamic content, adaptive feedback, collaborative data collection tools, and asynchronous or synchronous social communications [38]. Mobile devices have already been used in inquiry-based learning to facilitate students into their inquiries [39], provide appropriate scaffolding [40], support formative or self-assessments [41], and promote critical thinking and problem solving [4].

A recent meta-analysis of the impact of using mobile devices into teaching and learning [3] found high effect sizes for pedagogies that are inquiry-oriented. However, few studies have investigated the motivational constructs that trigger and maintain student engagement [6].

The current study proposes a model for student engagement in mobile-based science inquiry based on motivational constructs.

III. RESEARCH MODEL AND HYPOTHESIS

According to the self-system model of motivational development [42], individuals have three fundamental motivational needs. These are the needs for autonomy, competence and relatedness. Also, the basic needs theory from the SDT presents the satisfaction of the basic psychological needs of autonomy, competence and relatedness as its basic principle that has the potential to energize engagement [43].

Our model about student engagement in mobile-assisted inquiry-based science learning proposes the following hypotheses:

Hypothesis 1: Perceived Autonomy has a positive impact on student Engagement in mobile-assisted IBSL.

Hypothesis 2: Perceived Competence has a positive impact on student Engagement in mobile-assisted IBSL.

Hypothesis 3: Perceived Relatedness has a positive impact on student Engagement in mobile-assisted IBSL.

The proposed research model with all three supporting hypotheses is depicted in Figure 1.

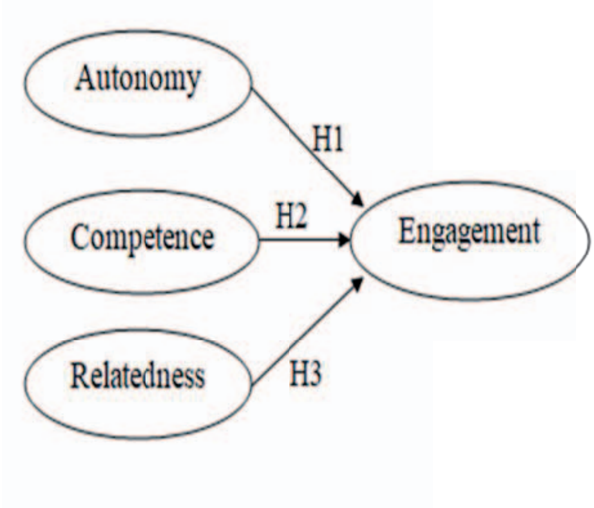

Fig.1 The research model with the three hypotheses (H1,H2,H3)

IV. METHODOLOGY

A. Participants

The participants were 80 students recruited from three science classes from a European senior level high school. There were 37 males (47.5%) and 43 females (52.5%). The average age of students was 16.4 (SD = 1.14). Most of the students (65%) had already used mobile devices (e.g. smart phones or tablets) for their own personal study (search for educational content, download class material, etc), while their experience in using mobiles in their classes was limited (e.g. classroom polling, on an occasional basis). Students' participation was voluntarily; all students had been informed in advance about the research procedure and its goals; appropriate permissions were obtained and all the data collected anonymously

B. Procedure

The study was implemented during a two-week period in the context of a secondary level science curriculum. During the first week, students participated in an inquiry-based learning activity in the Physics laboratory about Ohms' law in electricity. During the second week, students participated in a field trip observation in the context of an environmental education course concerning plant morphology and biodiversity.

Students used their mobile devices and integrated QR-code readers throughout all the inquiry phases, as described in [2]. In the *orientation phase* students were introduced to the topic under investigation by participating in teacher-generated classroom polling activities. These activities were aiming at actively engaging students into the process of scientific investigation. In the *hypothesis generation phase*, students through brainstorming and peer interactions, they collaboratively developed and recorded their hypotheses on-line using a mobile mind mapping application. In the *planning and investigation phase* students developed the action plans, designed the experiments and collected evidence using data logging tools or the cameras of their mobile devices. Students used their mobile devices to record the collected data in their on-line portfolios. In the *analysis and interpretation phase* students analyzed the collected data in their shared on-line portfolios, trying to collaboratively identify patterns and make inferences. In the *conclusions and evaluation phase* students shared their comments and uploaded their conclusions, evaluations and learning artifacts on their on-line portfolios using class-dedicated social media. The mobile learning application used was in accordance to the four requirements' dimensions of a mobile learning application namely educational, socio-cultural, economical, and technical, described in [44].

Figure 2 shows students during a mobile-assisted IBSL activity in the Physics laboratory and Figure 3 shows students during a mobile-assisted IBSL activity in a field trip.

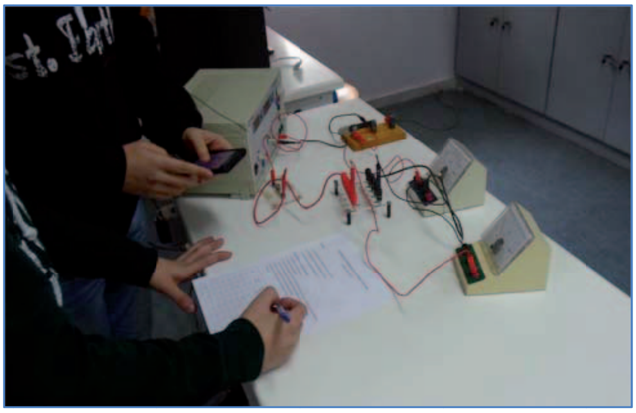

Fig. 2 Mobile-assisted IBSL in science lab

Fig. 3 Mobile-assisted IBSL in a field trip

After the two-week learning intervention students filled out the questionnaire about their perceived levels of motivation and engagement described next.

C. Instruments

In order to measure perceived levels of motivation and engagement we have adapted items from previously validated instruments.

For perceived autonomy, competence and relatedness we have used items from the Basic Psychological Needs Satisfaction (BPNS) Questionnaire [45, 7] and items from the Intrinsic Motivation Inventory (IMI) Questionnaire [46]. The BPNS Questionnaire is a set of questions that assess the degree to which people feel satisfaction of the three basic psychological needs of autonomy, competence and relatedness. The Intrinsic Motivation Inventory (IMI) is an instrument that assesses intrinsic motivation and self-regulation.

Sample items of the combined instrument used are: "Mobile devices provide me with interesting options and choices in my science inquiries" (autonomy support), "I think I perform well in mobile-assisted science inquiry" (competence support) and "I feel that mobile devices offer me opportunities to connect with my classmates during my science inquiries" (relatedness support).

For engagement we have used items from the Math and Science Engagement Questionnaire [27]. The Math and Science Engagement Questionnaire is a multidimensional instrument that incorporates behavioral, emotional, cognitive, and social components and assesses student engagement in mathematics and science.

Sample items used are: "I feel good when I am in science class" (emotional engagement), "I stay focused during my scientific inquiries" (behavioral engagement), "I can think with multiple ways to solve a problem" (cognitive engagement) and "I like working with my classmates in the mobile-assisted inquiries" (social engagement). The questionnaire was pilot tested on a group of students who took the same science course the previous year, indicating a good internal consistency (Cronbach alpha 0.81).

V. DATA ANALYSIS AND RESULTS

Partial Least-Squares (PLS) with Smart PLS 2.0 [47] was used as the analysis tool to predict the motivational factors that influence engagement in mobile-assisted IBSL. Our sample size exceeded the recommended value of 50 (10 times the largest number of independent variables impacting the depended variable).

The internal consistency, convergent validity and discriminant validity prove the reliability and validity of the measurement model. Convergent and discriminant validity of the proposed research model were verified in order to ensure the quality of the model. Convergent validity was evaluated based on the following three criteria: (1) all the indicators factor loadings should exceed 0.7, (2) composite reliability of each construct should exceed 0.7 and (3) the average variance extracted (AVE) by each construct should exceed the variance due to measurement error for that construct (AVE > 0.5).

Table I shows that all criteria for convergent validity were satisfied: all factor loadings on their relative construct exceeded the value of 0.7 and all AVE values ranged from 0.589 to 0.752 (AVE > 0.5)

TABLE I. DESCRIPTIVE STATISTICS AND THE RESULTS FOR CONVERGENT VALIDITY FOR THE MEASUREMENT MODEL (ACCEPTED THRESHOLD VALUES IN BRACKETS)

Construct Items	Mean (SD)	Factor Loading (>0.70)	Cron-bach's a (>0.70)	Composite Reliability (>0.70)	Average Variance Extracted (>0.50)
Autonomy	4.42 (1.55)		0.834	0.901	0.752
AUT1		0.904			
AUT2		0.856			
AUT3		0.839			
Competence	4.21 (1.18)		0.799	0.882	0.714
COMP1		0.821			
COMP2		0.867			
COMP3		0.844			
Relatedness	4.35 (1.41)		0.717	0.840	0.638
REL1		0.753			
REL2		0.772			
REL3		0.867			
Engagement	4.90 (1.22)		0.825	0.877	0.589
ENG1		0.745			
ENG2		0.709			
ENG3		0.845			
ENG4		0.731			
ENG5		0.798			

Discriminant validity is supported when the square root of the average variance extracted (AVE) of a construct is higher than any correlation with another construct.

Table II shows that all AVE square root values were greater than the intercorrelation values between constructs. Thus both convergent and discriminant validity for the proposed research model were verified.

TABLE II. DISCRIMINANT VALIDITY OF THE MODEL (VALUES IN BOLD: THE SQUARE ROOT OF THE AVERAGE VARIANCE EXTRACTED)

Construct	AUT	COMP	ENG	REL
AUT	**0.84**			
COMP	0.72	**0.86**		
ENG	0.73	0.65	**0.80**	
REL	0.60	0.58	0.67	**0.77**

Bold values: the square root of the average variance extracted (AVE) of each construct.

Two main criteria were used to assess the proposed structural model and its hypotheses. The first one was the variance measured by the antecedent constructs (R^2). Previous research proposed 0.2, 0.13 and 0.26 as small, medium and large values for the variance respectively. The second one was the significance of the path coefficients and the total effects by using a bootstrapping procedure and calculating the t-values. Table III and Figure 3 summarize the structural model results. Both the table and the figure depict the path coefficient for each path with its significance (as asterisks). Figure 3 shows also the value of R^2 for the endogenous variable of engagement.

Our proposed model explains about 63% of the variance in students' engagement in mobile-assisted inquiry-based science learning ($R^2 = 0.63$). Perceived autonomy was found to be the strongest predictor of engagement (0.42) with the relatedness to follow (0.32).

TABLE III: SUMMARY OF FINDINGS

Hypothesis	Effect	Coefficient	support
Hypothesis 1	AUT → ENG	0.42^{**}	yes
Hypothesis 2	COMP → ENG	0.16^{*}	yes
Hypothesis 3	REL → ENG	0.32^{**}	yes

$^*p < .05$, $^{**}p < .01$.

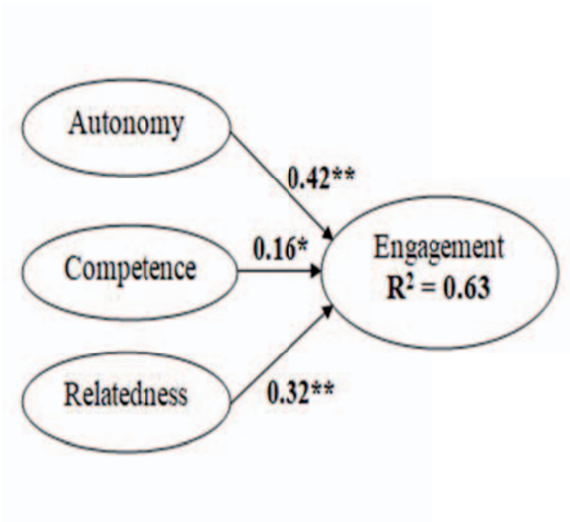

Fig. 3. Results of our structural model.

VI. CONCLUSIONS AND DISCUSSIONS

The current study explains and predicts student engagement in a collaborative mobile-assisted inquiry-based science learning intervention in terms of the basic psychological needs of the Self-Determination Theory of motivation: the needs of autonomy, competence and relatedness.

Previous studies have examined the effect of mobile learning and assessment on students perceived autonomy, competence and relatedness [12] and provided evidence about the positive impact of mobile learning on student motivation [48, 49]. However, more research is needed to examine how motivation relates to engagement, in terms of the SDT constructs.

Moreover, previous studies have shown that self-determination can predict school engagement [50, 43, 32]. However, inquiry-based learning is a more challenging and demanding activity than traditional learning [51]. Therefore, in order for students to effectively engage in inquiry activities, they must be sufficiently motivated.

Our study is one of the first that associates motivation and engagement in the context of mobile-assisted inquiry-based science learning. Based on the study findings, when students have the opportunities to meet their three basic psychological needs of autonomy, competence and relatedness, they are more engaged.

Students' need for autonomy can be met in an autonomy supporting and non-controlling learning environment that provides situated and relevant tasks with meaningful choices and options [52]. Mobile devices, through their ubiquity and context-awareness can provide an optimal autonomy-supportive environment for inquiry-based learning, where students feel in control of their own learning [9]. Students' need for competence is met when they receive appropriate and sufficient guidance and positive feedback [15, 16, 53] that keep them motivated to continue [54, 55]. Students' need for relatedness is more likely to occur in a collaborative learning environment. Mobile devices provide the opportunities for communication and collaboration and therefore can positively impact student engagement in a collaborative mode of inquiry-based learning [56].

Perceived autonomy was found to be the strongest predictor of engagement with the relatedness to follow. The findings are in line with previous studies providing evidence that higher levels of engagement relate to more autonomy supportive environments [57]. Previous research [58] has shown that the autonomous type of motivation better leads to behavioral and emotional engagement. Also, autonomous motivation leads to cognitive engagement [59].

Previous research provided evidence that enhanced student engagement is a reliable predictor of academic performance [60, 61]. Moreover, higher levels of behavioral and emotional engagement leads to better school grades [62] and lower school drop-out rates [60]. Therefore, research on how to enhance student engagement and motivation is important in order to promote better academic performance.

Moreover, improving students' engagement in inquiry-based science learning is of great importance due to the following: (i) the development of inquiry skills prepares students for the complex learning and working environments of the 21st Century, (ii) it empowers the uptake of science education and (iii) increase students' interest in pursuing science careers which in turn can support the increasing demand for STEM professionals [34].

The study findings can provide useful suggestions for instructional designers and educators. The study, based on SDT, suggests general motivational guidelines (e.g. feedback [63, 64], context-awareness [14, 15], peer-communication [22, 23]) for mobile assisted inquiry-based learning that facilitate the transformation of motivation into engagement. Supporting the SDT constructs of student autonomy, competence and relatedness, education practitioners can enhance student engagement in mobile-assisted inquiry-based science learning. Moreover, considering the positive relation between engagement and learning achievement, raising student engagement can result in better student learning.

Among the study limitations is the relatively small sample size, although statistically valid. Future studies should employ larger samples with more diverse backgrounds (e.g. from different cultures, different ages and in different courses). Also, future studies could consider to separately investigate the associations between students' basic psychological needs (competence, relatedness and autonomy) and the individual dimensions of engagement (behavioral, emotional, cognitive and social).

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