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ORIGINAL ARTICLE

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Mobile-Based micro-Learning and Assessment: Impact on learning performance and motivation of high school students

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Abstract

Mobile-based micro-learning has gained a lot of attention lately, especially for work-based and corporate training. It combines features of mobile learning and micro-learning to deliver small learning units and short-term learning activities. The current study uses the lens of the Self-Determination Theory of motivation and proposes a series of Mobile-Based micro-Learning and Assessment (MBmLA) homework activities to improve high school students' motivation and learning performance in science. An experiment was conducted to evaluate the effectiveness of the proposed approach. One hundred and eight students of a senior-level high school in Europe were randomly assigned into either a control condition (conventional paper-based homework approach) or an experimental (MBmLA approach) condition. The study carried out for a period of 5 weeks. From the experimental results, it was found that, in comparison to the conventional paper-based approach, the proposed MBmLA approach enhanced students' basic psychological needs of self-perceived autonomy, competence, and relatedness and improved students' exam performance in terms of factual knowledge. Moreover, students self-reported greater learning satisfaction with the mobile-based microassessment and micro-learning homework tasks. Implications on educational practices as well as future research are discussed.

KEYWORDS

K-12, microassessment, micro-learning, mobile learning, mobile-based assessment, motivation

1 | INTRODUCTION

Low learning motivation and poor student performance are core issues in science education (Kearney, 2016; UNESCO, 2010; Rocard et al., 2007). About 20% of 15-year-old students across the Organization for Economic Co-operation and Development countries who participated in the Programme for International Students Assessment 2015 performed below the baseline level of proficiency in science (OECD, 2016). Student performance is related to motivation to learn (Wijsman, Warrens, Saab, van Driel, & Westenberg, 2016). Therefore, a critical challenge in most educational systems worldwide is to reduce the number of unmotivated and low-performing students.

Previous research in the domain of K-12 science education (Liu et al., 2014; Tingir, Cavlazoglu, Caliskan, Koklu, & Intepe-Tingir, 2017) provided evidence that the use of mobile devices improves students' performance and motivation in a wide range of formal or informal educational contexts, that is, natural science courses (de-Marcos et al., 2010), Physics courses (Nikou & Economides, 2016; Zhai, Zhang, & Li, 2016), botany courses (Huang, Lin, & Cheng, 2010), inquiry investigations (Ahmed & Parsons, 2013; Hwang, Wu, Zhuang, & Huang, 2013a), context-aware ubiquitous learning activities (Shih, Chu, Hwang, & Kinshuk, 2011), or inquiry-based ubiquitous gaming (Hwang & Chen, 2017). Mobile-based micro-learning is a relatively new approach that combines features of mobile learning and micro-learning, by delivering small learning units and short-term learning activities (Hug, Lindner, & Bruck, 2006) through mobile devices, in a manner that can be personalized, adaptive, ubiquitous, and context-aware (Bruck, Motiwalla, & Foerster, 2012).

According to our literature review, there is a gap as regards empirical research about mobile-based micro-learning delivered as homework assignments in the context of secondary science education. Homework is an important part of student learning (Epstein & Van Voorhis, 2012). A 30-year meta-analysis on the homework-achievement relationship by Fan, Xu, Cai, He, and Fan (2017) suggests that homework is positively associated with students' achievement in science, especially for K-12 students. Moreover, because homework completion requires a more autonomous oriented type of motivation (Katz, Eilot, & Nevo, 2014; Katz, Kaplan, & Gueta,

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2009), this allows a direct connection to Self-Determination Theory (SDT) of motivation (Deci & Ryan, 1985).

The current study uses the lenses of the SDT of motivation and proposes a Mobile-Based micro-Learning and Assessment (MBmLA) homework intervention for secondary school students of science and investigates, in comparison with the conventional paper-and-pencil homework approach, its impact on student learning performance, motivation, and learning satisfaction.

The research questions that the current study investigates are the following:

1. Do students who learn with an MBmLA homework intervention have better learning achievements in terms of factual knowledge than those who learn with the conventional paper-based homework approach?
2. Do students who learn with an MBmLA homework intervention self-report higher levels of perceived autonomy, competence, and relatedness than those who learn with the conventional paper-based homework approach?
3. Do students who learn with the MBmLA homework intervention show higher learning satisfaction than those who learn with the conventional paper-based homework approach?

2 | BACKGROUND

2.1 | Micro-learning

Micro-learning is a learning approach that is based on small learning units and short-term focused activities (Hug et al., 2006; Lindner, 2007). In micro-learning, learners make use of micromedia in order to obtain microcontent such as definitions, formulas, small paragraphs, brief video segments, mini podcasts, flash cards, or quizzes (Zhang & Ren, 2011). Also, with microassessment, small chunks of student knowledge and skills can be evaluated in less time and without the need to make special testing arrangements (Bundovski, Gusev, & Ristov, 2014). Research has shown that micro-learning fits into the human model of processing information in small manageable chunks and therefore enables better retention (Bruck et al., 2012). Furthermore, micro-learning can better engage students in online and blended learning (Semingson, Crosslin, & Dellinger, 2015). Micro-learning and microassessment, easily integrated into everyday activities, can support a more flexible model of learning reflecting the needs of mobile users (Buchem & Henrike, 2010).

2.2 | Mobile-based micro-learning

One effective delivery medium for micro-learning and microassessment are mobile devices (Hug et al., 2006). There are many benefits associated with micro-learning delivered through mobile media: Learning becomes more accessible anytime and anywhere, ubiquitous, just-in-time and on-demand, adaptive, and learner-centric (Coakley, Garvey, & O'Neill, 2017).

Mobile-based micro-learning has been acknowledged as a successful learning strategy in the workplace (Bruck et al., 2012; Werkle, Schmidt, Dikke, & Schwantzer, 2015). It also improves learning performance and motivation in professional and corporate working environments (Munoz-Organero, Munoz-Merino, & Kloos, 2012; Pimmer & Pachler, 2014; Wen & Zhang, 2015) as well as in Massive Open Online Courses (Sun, Cui, Yong, Shen, & Chen, 2015).

Although previous research in the domain of K-12 science education (Hwang & Wu, 2014; Liu et al., 2014; Sung, Chang, & Liu, 2016; Tingir et al., 2017) provided evidence that the use of mobile devices improves students' performance and motivation, our review of the literature reveals a gap as regards empirical research about a mobile-based micro-learning homework methods in high school science education. Moreover, according to the mobile learning review by Zydney and Warner (2016), a stronger alignment is needed between the general underlying theories and measured outcomes. Researchers agree that further investigation is needed in order to understand the motivation mechanisms of mobile micro-learning (Sha, Looi, Chen, & Zhang, 2012). There are previous works reporting on mobile learning and motivation. Ciampa (2013) reported on the motivational affordances of challenge, curiosity, control, recognition, competition, and cooperation when using mobile devices for learning in primary school. Su and Cheng (2015) developed and implemented a mobile gamification learning system to improve motivation of elementary students in terms of attention, relevance, confidence, and satisfaction. Sha et al. (2012) proposed an analytic self-regulated learning model of mobile learning as a conceptual framework for understanding mobile learning for elementary students also. However, further investigation, grounded in a solid theoretical framework, regarding the motivational impact of mobile micro-learning in the context of secondary education would be valuable (Chee, Yahaya, Ibrahim, & Noor Hassan, 2017; Semingson et al., 2015). The current study uses the SDT (Deci & Ryan, 2002) of motivation as a theoretical framework to study motivation in the context of mobile-based micro-learning homework in high school science classes.

2.3 | SDT of motivation

Considering the design issues related to micro-learning, microcontent units are small, focused, and autonomous, and therefore, micro-learning has the potential to support learners' sense of autonomy and facilitate self-directed learning (Buchem & Henrike, 2010). Moreover, in the context of social networking, micro-learning artefacts are suitable for sharing in social networks or social online learning environments (Liao & Zhu, 2012) enabling thus interactions among learners and supporting their sense of relatedness. This allows direct connections with the SDT of Motivation.

SDT of motivation is a well-established and empirically well-supported theory of motivation (Deci & Ryan, 1985, 2002). SDT distinguishes between intrinsic motivation, “doing an activity for its inherent satisfactions,” and extrinsic motivation, “doing an activity for its instrumental value” (Ryan & Weinstein, 2009). Intrinsic motivation is associated with better performance and human well-being. According to the theory, a basic set of basic psychological needs must be satisfied in order to enhance intrinsic motivation: autonomy, competence, and relatedness. Autonomy refers to the desire to self-initiate and selfregulate own behaviour. Competence refers to the desire to feel effective in attaining valued outcomes. Relatedness refers to the desire to feel connected to others.

SDT has been successfully applied in education (Reeve, 2002; Reeve, Ryan, Deci, & Jang, 2008), technology-enhanced learning (Chen & Jang, 2010; Roca & Gagné, 2008; Sorebo, Halvari, Gulli, & Kristiansen, 2009), and mobile learning as well (Nikou & Economides, 2017). Research provides evidence that raising the satisfaction levels of perceived autonomy, competence, and relatedness enhances self-determination and intrinsic motivation (Chen & Jang, 2010; Niemiec & Ryan, 2009) and also improves learning performance (León, Núñez, & Liew, 2015). Therefore, developing a homework intervention that integrates SDT principles into a mobile technology-supported micro-learning environment is expected to help students to promote their learning motivation and to improve their learning outcomes.

2.4 | An MBmLA homework environment

In probing the aforementioned issue, a learning environment was designed and implemented to support mobile-based micro-learning after-school learning activities. The system was developed based on the jQuery mobile framework for the user interface and PHP and MySQL for the questions database, providing the appropriate flexibility needed in order to be implemented for other teaching topics as well. Each homework assignment was consisted of a series of 15 microcontent units, each one followed by a true/false or multiple-choice type question with feedback and also an extra collaborative task that students were asked to complete.

The microcontent units were self-contained, focusing on a single important point, with the information they provided to be autonomous and comprehensible to students without the need to search for additional external information (for autonomy support). After each microcontent unit, a question was presented to student. Each question was accompanied with immediate appropriate emotional and cognitive feedback. Students were provided with encouraging and elaborated with knowledge-of-correct-response feedback (for competence support). Moreover, students could use a peer-learning online forum to share information and materials with classmates. Also, the task of using a cloud-based shared document (i.e., Google Docs) or a mind-map and submit a collaborative group solution to a problem (groups of four students were formed in advance), for teachers' input, was part of each assignment (for relatedness support).

The aim of the assignments was to reinforce content covered in class with special attention to improve the retention of factual knowledge. There were 10 such homework assignments, prepared by the course instructor and delivered in a 5-week period (two per week), and indented to be completed during nonclass hours. Students were free to access the online homework whenever they needed to and complete, for each assignment, 10 out of the 15 questions of their choice.

Figure 1 illustrates an example of (a) a microcontent unit about Ohm's law, (b) a true/false question with the corresponding feedback, and (c) the cloud-based document for students to submit their collaborative group work. The example shown has been translated in English from the native language of the students.

3 | METHODOLOGY

3.1 | Participants

The participants were 108 students drawn from four science classes from a senior-level high school in Europe. The students were on average 17.1 (*SD* = 1.1) years old. There were 51 (47%) males and 57 (53%) females. All students had already used mobile devices for communication, web searching, and entertainment purposes, and occasionally for study support (e.g., searching and accessing educational resources).

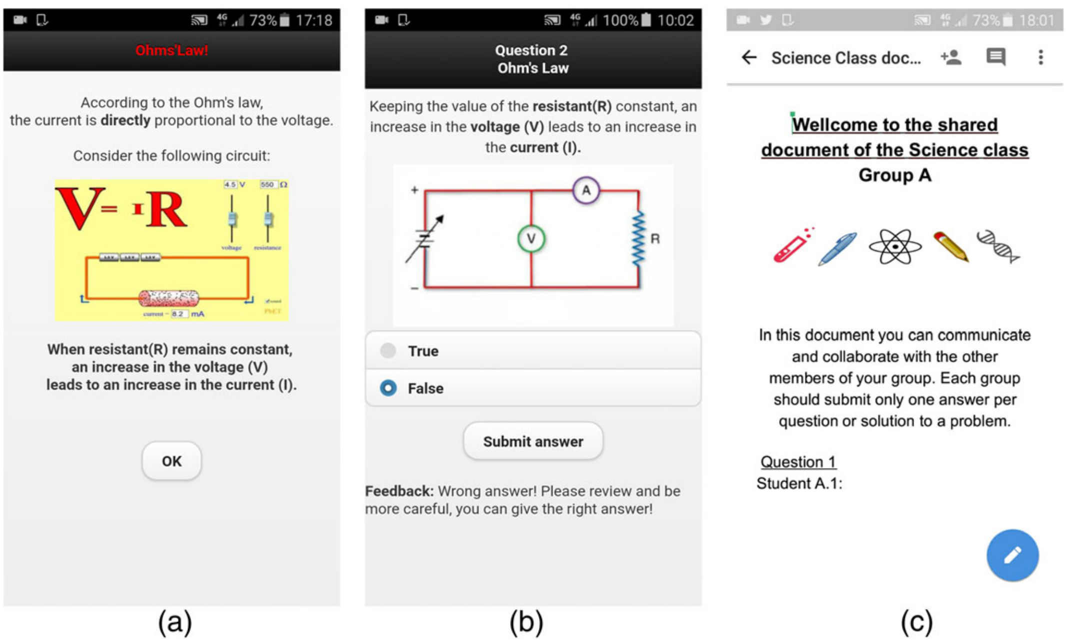

FIGURE 1 (a) Micro-learning unit. (b) Example question. (c) Example of online collaborative task [Colour figure can be viewed at wileyonlinelibrary.com]

The median mobile self-efficacy score was 82 out of 100, on a scale adopted from Kenny, Neste-Kenny, Burton, Park, and Qayyum (2012), indicating that students considered themselves as highly efficacious to use mobile devices. All students had the same instructor (an experienced STEM teacher). They all were following the same science curriculum. Based on their previous grades and according to their instructor, all students were equivalent in terms of academic performances before being assigned to the two different groups. Students were randomly assigned to the control group (n = 54) and to the experimental group (n = 54). Students in the control group followed a conventional paper-and-pencil-based homework intervention, whereas students in the experimental group followed the MBmLA homework intervention. Students in the experimental group used smartphones (88%) and tablets (12%). Screen sizes however were comparable, and the application was optimized to support multiple screen sizes. Students were not allowed to change groups during the intervention. Students and the instructor were informed in advance about the research procedure and the study's intention, appropriate permissions were requested and approved, participation was voluntarily, and all data were collected anonymously.

3.2 | Measuring instruments

The subject taught was “Electric fields and Currents,” which is among the core subjects in the high school students' national science curriculum. In order to evaluate students' knowledge on electric fields and currents, a pretest and a posttest were developed with “multiple-choice with comments” type of questions. Both tests were scoring from 0 to 7. The aim of the pretest was to evaluate students' prior background factual knowledge, whereas the aim of the posttest was to evaluate students' factual knowledge after the intervention. Factual test questions examined knowledge of basic facts (such as a definition or formula) presented in class (e.g., Bloom's taxonomy; Krathwohl, 2002). Example of a factual question is as follows:

> *“Let I be the current through a conductor, V be the voltage measured across the conductor's ends and R the resistance of the conductor. What happens to the current when the voltage across the conductor's is doubled? Select the right answer: (a) 2I, (b) I^2 (c) I, (d) I/2 and explain.”*

Both pretest and posttest were developed by the course instructor with the assistance of two experienced physics teachers in order to ensure content validity.

In order to assess students' levels of self-perceived autonomy, competence, and relatedness, a prequestionnaire and postquestionnaire were developed. The prequestionnaire was designed to assess pre-existing levels of students' motivation, whereas the postquestionnaire was designed to assess levels of students' motivation after the intervention.

In order to develop the questionnaire used in our research, we adopted items from previously validated instruments. For the perceived autonomy, competence and relatedness we adopted items from Basic Psychological Need Satisfaction Questionnaire (Baard, Deci, & Ryan, 2004; Deci & Ryan, 2002) and the Intrinsic Motivation Inventory Questionnaire (McAuley, Duncan, & Tammen, 1989). Basic Psychological Need Satisfaction assesses the degree to which people feel satisfaction of the basic SDT psychological needs. Intrinsic Motivation Inventory assesses participants' subjective experience related to intrinsic motivation and self-regulation. A total of 12 question items were used to assess these motivational needs on a 7-point scale (1 = *strongly disagree* to 7 = *strongly agree*). Sample items are as follows: for perceived autonomy, “I feel a sense of choice and freedom while participating in the MBmLA activities”; for perceived competence, “After working at the MBmLA for a while, I felt pretty competent”; and for perceived relatedness, “I feel connected with my classmates when I participate in the MBmLA.” The three basic needs satisfaction factors had good internal reliabilities (alpha values were 0.84, 0.80, and 0.85 for autonomy, competence, and relatedness, respectively).

Regarding learning satisfaction, we adopted six items from Hwang, Sung, Hung, Yang, and Huang (2013b). Cronbach's alpha value was 0.91. All items of the questionnaire were appropriately modified to fit to our research context. Also, all items were translated (from English) into the native language of the students from a language expert.

3.3 | Experimental procedure

The study employs a two-group pretest–posttest experimental design procedure in order to test the efficacy of the proposed MBmLA homework approach compared to the conventional paper-based homework. Figure 2 illustrates our experimental procedure. Students

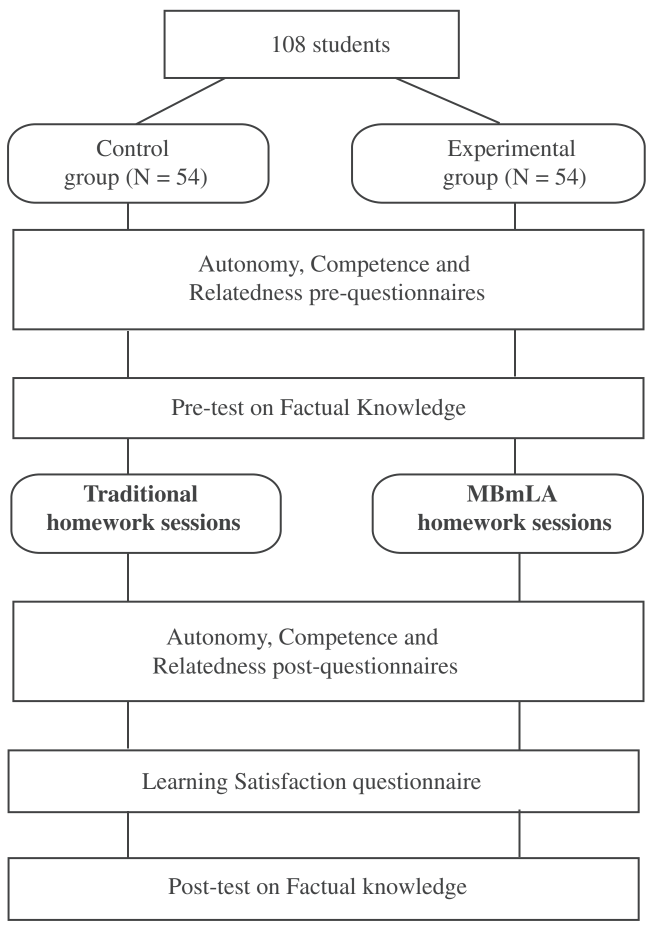

FIGURE 2 Experimental procedure

were randomly assigned to one of the two conditions: conventional paper-and-pencil approach (control) and the MBmLA approach (experimental).

First, an orientation section with all the necessary information was offered to students. Also, before the experiment, students took a pretest to assess their level of pre-existing factual knowledge about electric fields and currents. Furthermore, an independent-samples t-test was conducted in order to compare the means between the control and experimental groups on pre-existing levels of factual knowledge. Students also completed a questionnaire reporting their perceived levels of autonomy, competence, and relatedness before the intervention.

During the next 5-week period, students in the control group participated in a conventional paper-and-pencil homework intervention, whereas students in the experimental group participated in the MBmLA homework intervention.

The two homework approaches were the independent variable, whereas learning achievement, the perceived levels of autonomy, competence, relatedness, and learning satisfaction were the dependent variables. Figure 3 shows students of both groups working on their assignments.

Both learning environments (paper-and-pencil and MBmLA), aligned with the SDT principles (Deci & Ryan, 2002), ensured the following: (a) autonomy support, by providing optimally challenging assignments relevant to students' interest, background knowledge, and skills (Csikszentmihalyi, 1990; Hartnett, 2015), with meaningful choices (Reeve & Halusic, 2009) and defined purpose and value (Ryan & Deci, 2000) in an autonomy and noncontrolling learning environment (Wang, Ng, Liu, & Ryan, 2015); (b) competence support, by providing appropriate guidance and feedback with motivational support (Burgers, Eden, van Engelenburg, & Buningh, 2015; Gikandi, Morrowa, & Davis, 2011); and (c) relatedness support, by facilitating social interactions through peer communication and collaboration for the group work (Hartnett, 2015; Sorebo et al., 2009).

Most aspects of the two learning interventions (e.g., instructor, learning content and questions, learning aim, and expected outcome) were the same except for the delivery and presentation mode (conventional paper-and-pencil vs. mobile-based micro-learning) along with their distinctive features of each mode. The homework requirement for students in the MBmLA condition was to answer, using their mobile devices, a set of questions that followed the related autonomous micro-learning units. Students also received interactive feedback with motivational support. The homework requirement for students in the conventional paper-and-pencil condition was to answer, using the paper-worksheets they were given, the same questions that followed the related book study material. Students could check the correctness of their responses in a separate sheet of paper with the knowledge-of-correct-response answers. Furthermore, students in the MBmLA condition encouraged to participate in online synchronous or asynchronous social interactions and share material and information, whereas students in the paper-and-pencil condition were instructed to participate in face-to-face collaboration sessions after-class. However, this was not always feasible due to timing constraints in a busy class schedule. After the intervention, students took a posttest in order to evaluate again their level of factual knowledge about electric fields and currents. They also self-reported their perceived levels of motivation (autonomy, competence, and relatedness) and learning satisfaction.

4 | DATA ANALYSIS AND RESULTS

4.1 | Learning performance

In order to answer the first research question, that is, to compare the learning achievement of the two groups, we conducted a one-way analysis of covariance (ANCOVA) with the studying mode (conventional paper-based homework vs. MBmAL homework) as the

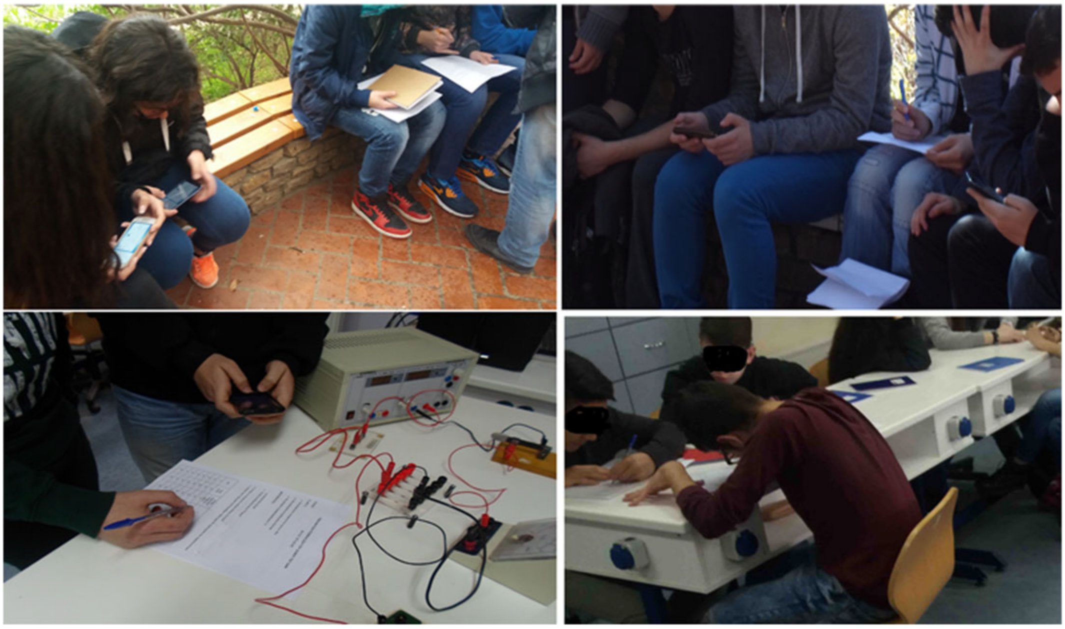

FIGURE 3 Students working on their assignments (mobile-based and paper-based groups) [Colour figure can be viewed at wileyonlinelibrary.com]

independent variable and the posttest and pretest scores as the dependent variable and covariate respectively. Moreover, the independent samples t-test that conducted to compare the means between the control and experimental groups on pre-existing levels of factual knowledge revealed no statistically significant difference on the pre-existing levels of factual knowledge between the two student groups ($t = 2.41$, $p > 0.05$).

Regarding the performed ANCOVA, the assumptions of normality of distribution and the homogeneity of regression were confirmed ($F = 0.11$, $p > 0.05$).

Table 1 shows that, after excluding the impact of the pretest scores on the posttest, the learning achievement for the two groups was significantly different ($F = 7.49$, $p < 0.01$, $\eta^2 = 0.07$). Compared with the adjusted mean of 4.36 for the control group, the experimental group scored 4.88. The significantly better score of the experimental group than that of the control group suggests that students who learn with the MBmLA approach have better learning achievements in terms of factual knowledge than those who learn with the conventional paper-based homework approach.

From the adjusted means, it can be concluded that the MBmLA approach can enhance students' learning achievement in terms of factual knowledge. The effect size ($\eta^2 = 0.07$) of the ANCOVA results of the MBmLA approach represented a moderate effect size, as proposed by Cohen (1988).

4.2 | Perceived autonomy, competence, and relatedness

In order to answer the second research question, that is, to compare the motivation levels of the two groups, we conducted a one-way ANCOVA with the studying mode (conventional paper-based homework vs. MBmLA homework) as the independent variable and the posttest scores on perceived autonomy, competence, and relatedness as the dependent variables. The prequestionnaire scores for autonomy, competence, and relatedness were used as covariates, in order to remove possible effects of pre-existing individual differences among students. The assumptions of normality of distribution and the homogeneity of regression for perceived autonomy, competence, and relatedness were confirmed with $F = 1.65$, ($p > 0.05$), $F = 0.07$ ($p > 0.05$), and $F = 0.11$ ($p > 0.05$), respectively.

For perceived autonomy, Table 2 shows that, after excluding the impact of the pretest scores on the posttest, perceived autonomy for the two groups was significantly different ($F = 29.75$, $p < 0.001$, $\eta^2 = 0.22$). Compared with the adjusted mean of 4.62 for the control group, the experimental group scored 5.61. The significantly better score of the experimental group than that of the control group suggests that students who learn with the MBmLA approach self-report higher levels of perceived autonomy than those who learn with the conventional paper-based homework approach.

For perceived competence, Table 2 shows that, after excluding the impact of the pretest scores on the posttest, perceived competence for the two groups was significantly different ($F = 14.35$, $p < 0.001$, $\eta^2 = 0.12$). Compared with the adjusted mean of 4.44 for the control group, the experimental group scored 5.18. The significantly better score of the experimental group than that of the control group suggests that students who learn with the MBmLA approach self-report higher levels of perceived competence than those who learn with the conventional paper-based homework approach.

For perceived relatedness, Table 2 shows that, after excluding the impact of the pretest scores on the posttest, perceived relatedness for the two groups was significantly different ($F = 10.58$, $p < 0.01$, $\eta^2 = 0.92$). Compared with the adjusted mean of 4.18 for the control group, the experimental group scored 4.83. The significantly better score of the experimental group than that of the control group suggests that students who learn with the MBmLA approach self-report higher levels of perceived relatedness than those who learn with the conventional paper-based homework approach.

From the adjusted means, it can be concluded that the MBmLA approach can enhance students' perceived levels of autonomy, competence, and relatedness. The effect sizes (η^2) of the ANCOVA results of

TABLE 1 Analysis of covariance results of the posttest results for learning achievement on factual knowledge

Variable	Group	N	Mean	*SD*	Adjusted mean	*SD*	*F* value	η^2
Learning	Control	54	4.28	1.00	4.36	0.13	7.49**	0.07
	Experimental	54	4.97	1.22	4.88	0.13		

****p* < 0.001, ***p* < 0.01.

TABLE 2 Analysis of covariance result of the posttest scores for autonomy, competence, and relatedness

Variable	Group	N	Mean	*SD*	Adjusted mean	*SD*	*F* value	η^2
Autonomy	Control	54	4.64	0.97	4.62	0.12	29.75***	0.22
	Exp.	54	5.59	0.90	5.61	0.12		
Competence	Control	54	4.44	0.97	4.44	0.14	14.35***	0.12
	Exp.	54	5.18	1.11	5.18	0.14		
Relatedness	Control	54	4.17	1.00	4.18	0.14	10.58**	0.92
	Exp.	54	4.83	1.21	4.83	0.14		

****p* < 0.001, ***p* < 0.01.

the MBmLA approach represented a moderate effect size for competence (0.12) and large effect sizes for autonomy (0.22) and relatedness (0.92), as suggested by Cohen (1988).

4.3 | Learning satisfaction

In order to answer the third research question, we conducted independent sample t-tests for the students' learning satisfaction. Table 3 shows the results.

The results of an independent sample t-test show significant difference between the two groups (t = 3.35, p < 0.01). The mean for the experimental group (5.82) was significantly higher than the mean of the control group (5.24). The significantly higher score of the experimental group than that of the control group suggests that students who learn with the MBmLA approach show higher levels of learning satisfaction than those who learn with the conventional paper-based homework approach.

5 | DISCUSSIONS AND CONCLUSIONS

The current study proposes an MBmLA homework intervention that enhances student motivation (in terms of autonomy, competence, and relatedness) and improves factual knowledge and learning satisfaction of secondary school students.

Previous studies provided evidence about the positive impact of mobile learning on students' performance and motivation (Liu et al., 2014; Tingir et al., 2017). Nevertheless, further insight regarding the use of mobile micro-learning in the context of homework delivery for high school students would be valuable. Although a considerable body of research exists for the effectiveness of mobile micro-learning in the context of work-based and corporate training (Wen & Zhang, 2015; Werkle et al., 2015), there is a lack of research focusing on mobile micro-learning homework approaches for high school science (Semingson et al., 2015).

Homework is an important part of student learning, and it is positively associated with students' achievement in K-12 science (Fan et al., 2017). Furthermore, its role receives greater importance especially in content-heavy curriculums (Ruohoniemi & Lindblom-Ylänne, 2009) and large class sizes (Harfitt & Tsui, 2015). The study builds on existing research about the benefits that computer-based homework offers to students, for example, immediate feedback and step-by-step scaffolding (Hauk, Powers, & Segalla, 2015; Mendicino, Razzaq, & Heffernan, 2009) as well as optimization of student learning (Babaali & Gonzalez, 2015; Kelly et al., 2013). In line with previous findings suggesting that use of mobile devices in teaching yielded higher achievement scores than conventional teaching in all subject areas (Tingir et al., 2017), our MBmLA approach improves student factual knowledge.

TABLE 3 The t-test results for the learning satisfaction of the two groups

Variable	Group	N	Mean	*SD*	*t* value
Learning satisfaction	Control	54	5.24	1.00	3.35**
	Experimental	54	5.82	0.78	

**p < 0.01.

Moreover, the current study contributes to the technology-enhanced learning literature by aligning design issues of mobile micro-learning with the SDT of motivation. Previous studies suggested different ways to enhance student motivation in mobile learning. To name just a few, Ciampa (2013) proposed challenge, curiosity, control, recognition, competition, and cooperation; Su and Cheng (2015) proposed attention, relevance, confidence, and satisfaction; and Sha et al. (2012) proposed a model based on self-regulation. The current study, based on SDT, proposes that student motivation can be enhanced by supporting the basic psychological needs of autonomy, competence, and relatedness.

Regarding autonomy, online learning environments have the potential to provide students with an optimal autonomy-supportive environment for learning (Chen & Jang, 2010; Sorebo et al., 2009). Perceived autonomy support and autonomous forms of motivation is essential for homework activities (Hagger, Sultan, Hardcastle, & Chatzisarantis, 2015). The proposed MBmLA approach, by taking advantage of the anytime-anywhere features of mobile-devices, offers a series of self-contained micro-learning units, providing thus an autonomy supportive homework environment where students experience a better sense of autonomy.

Regarding competency, research has shown that technological affordances provide students the opportunities to develop and better demonstrate their competencies (Gikandi et al., 2011). Feedback on computer-based homework can benefit students by giving them more control on their learning (Fyfe, 2016) and positively affecting their sense of perceived competence (Hartnett, 2015). In our study, the timely provision of interactive cognitive and emotional feedback in the mobile-based micro-learning approach enhances students' perceived sense of competence.

Regarding relatedness, research reveals that social networking integrated in online learning platforms for sharing information facilitates the interaction among members of the learning community. Liao and Zhu (2012) described it as "social micro-learning." In our mobile-assisted approach, the online sharing of information among high school students and the collaborative content creation—required for the group tasks—can be helpful to increase the interacting behaviours among the students and foster the sense of perceived relatedness, which is in-line with previous research in other contexts (Kukulska-Hulme & Shield, 2008). It is not the case that online communication can outreach face-to-face communication, but due to issues related to class administration and time management, face-to-face interactions on a specific homework task are not always feasible among class members. Therefore, mobile-based social micro-learning has the potential to provide opportunities to enhance perceived relatedness.

Students perceive mobile-based micro-learning as satisfying in terms of the learning experience. Mobile technologies are very popular among young students and play an important role in their everyday lives. The same can be true for their learning also. The proposed learning approach not only engages today's students in mobile-based micro-learning but it is also a promising instructional method for the lifelong adult learners of tomorrow (Buchem & Henrike, 2010).

The study has some limitations. First, regarding learning performance, it focuses on factual knowledge, that is, the basic elements (formulas and terminology) that students must know in order to be acquainted with a discipline or solve simple problems. Further research is needed to investigate if MBmLA can support conceptual knowledge as well, that is, the interrelationships among the basic elements within a context (classifications, generalizations, theories, and models) to solve more complex problems and engage in activities of higher cognitive levels—such as analysing, evaluating, and creating. Also, other question types (i.e., open-ended) as well as gamification elements (e.g., microcredentials) would be interesting to consider. Future research needs to be applied in more topics beyond science, using larger and more diverse samples. The effect of MBmLA on students with different academic achievement levels (e.g., low vs. high achievers) could be investigated. It would be also interesting to incorporate assessment analytics such as learning behavioural patterns and temporal trace data.

Technology-based homework is gaining popularity among many schools. However, more evidence is needed on how to optimize young students' learning (Fyfe, 2016), and therefore, it still remains a challenge to develop technology-supported homework strategies that promote motivation and improve learning performance. Mobile-based micro-learning provides a promising medium to promote factual learning and autonomous motivation for high school students.

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REFERENCES

Ahmed, S., & Parsons, D. (2013). Abductive science inquiry using mobile devices in the classroom. *Computers & Education*, *63*, 62–72.

Baard, P. P., Deci, E. L., & Ryan, R. M. (2004). Intrinsic need satisfaction: A motivational basis of performance and well-being in two work settings. *Journal of Applied Social Psychology*, *34*, 2045–2068.

Babaali, P., & Gonzalez, L. (2015). A quantitative analysis of the relationship between an online homework system and student achievement in pre-calculus. *International Journal of Mathematical Education in Science and Technology*, *46*(5), 687–699. https://doi.org/10.1080/0020739X.2014.997318.

Bruck, P.A., Motiwalla, L., & Foerster, F. (2012). Mobile learning with micro-content: A framework and evaluation. In *BLED 2012 Proceedings*. Retrieved 30 May, 2017 from http://aisel.aisnet.org/bled2012/2.

Buchem, I., & Henrike, B. (2010). Microlearning: A strategy for ongoing professional development. *ELearning Papers*, *21*, Retrieved May 29 2017 from http://www.openeducationeuropa.eu/en/article/Microlearning%3A-a-strategy-for-ongoing-professional-development.

Bundovski, A., Gusev, M., & Ristov, S. (2014). Micro Assessment SaaS cloud solution. In *37th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, 867–872. doi: https://doi.org/10.1109/MIPRO.2014.6859689.

Burgers, C., Eden, A., van Engelenburg, M. D., & Buningh, S. (2015). How feedback boosts motivation and play in a brain-training game. *Computers in Human Behavior*, *48*, 94–103. https://doi.org/10.1016/j.chb.2015.01.038.

Chee, K. N., Yahaya, N., Ibrahim, N. H., & Noor Hassan, M. (2017). Review of mobile learning trends 2010–2015: A meta-analysis. *Educational Technology & Society*, *20*(2), 113–126.

Chen, K. C., & Jang, S. J. (2010). Motivation in online learning: Testing a model of self-determination theory. *Computers in Human Behavior*, *26*(4), 741–752. https://doi.org/10.1016/j.chb.2010.01.011.

Ciampa, K. (2013). Learning in the mobile age: An investigation of student motivation. *Journal of Computer Assisted Learning*, *30*, 82–96.

Coakley, D., Garvey, R., & O'Neill, Í. (2017). Micro-learning—Adopting digital pedagogies to facilitate technology-enhanced teaching and learning for CPD. In G. The, & S. Choy (Eds.), *Empowering 21st century learners through holistic and enterprising learning*. Singapore: Springer.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: Harper & Row.

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York: Plenum.

Deci, E. L., & Ryan, R. M. (2002). *Handbook of self-determination research*. Rochester, NY: University of Rochester Press.

de-Marcos, L., Hilera, J. R., Barchino, R., Jiménez, L., Martínez, J. J., Gutiérrez, J. A., … Salvador Otón, S. (2010). An experiment for improving students performance in secondary and tertiary education by means of m-learning auto-assessment. *Computers & Education*, *55*(3), 1069–1079.

Epstein, J. L., & Van Voorhis, F. (2012). The changing debate: From assigning homework to designing homework. In S. Suggate, & E. Reese (Eds.), *Contemporary debates in child development and education* (pp. 263–273). London: Routledge.

Fan, H., Xu, J., Cai, Z., He, J., & Fan, X. (2017). Homework and students' achievement in math and science: A 30-year meta-analysis, 1986–2015. *Educational Research Review*, *20*, 35–54. https://doi.org/10.1016/j.edurev.2016.11.003.

Fyfe, E. R. (2016). Providing feedback on computer-based algebra homework in middle school classrooms. *Computers in Human Behavior*, *63*, 568–574.

Gikandi, J. W., Morrowa, D., & Davis, N. E. (2011). Online formative assessment in higher education: A review of the literature. *Computers & Education*, *57*, 2333–2351.

Hagger, M. S., Sultan, S., Hardcastle, S. J., & Chatzisarantis, N. L. D. (2015). Perceived autonomy support and autonomous motivation toward mathematics activities in educational and out-of-school contexts is related to mathematics homework behavior and attainment. *Contemporary Educational Psychology*, *41*, 111–123.

Harfitt, G. J., & Tsui, A. B. M. (2015). An examination of class size reduction on teaching and learning processes: A theoretical perspective. *British Educational Research Journal*, *41*(5), 845–865.

Hartnett, M. K. (2015). Influences that undermine learners' perceptions of autonomy competence and relatedness in an online context. *Australasian Journal of Educational Technology*, *31*(1).

Hauk, S., Powers, R. A., & Segalla, A. (2015). A comparison of web-based and paper-and-pencil homework on student performance in college algebra. *Primus*, *25*(1), 61–79. https://doi.org/10.1080/10511970.2014.906006.

Huang, Y. M., Lin, Y. T., & Cheng, S. C. (2010). Effectiveness of a mobile plant learning system in a science curriculum in Taiwanese elementary education. *Computers & Education*, *54*(1), 47–58.

Hug, T., Lindner, M., & Bruck, P.A. (2006). Microlearning: Emerging concepts, practices and technologies after e-learning, In *Proceedings of Microlearning*. Innsbruck: Innsbruck University Press.

Hwang, G.-J., & Chen, C.-H. (2017). Influences of an inquiry-based ubiquitous gaming design on students' learning achievements, motivation, behavioral patterns, and tendency towards critical thinking and problem solving. *British Journal of Educational Technology*, *48*, 950–971. https://doi.org/10.1111/bjet.12464.

Hwang, G.-J., Sung, H.-Y., Hung, C.-M., Yang, L.-H., & Huang, I. (2013b). A knowledge engineering approach to developing educational computer games for improving students' differentiating knowledge. *British Journal of Educational Technology*, *44*, 183–196.

Hwang, G.-J., & Wu, P.-H. (2014). Applications, impacts and trends of mobile technology-enhanced learning: A review of 2008–2012 publications in selected SSCI journals. *International Journal of Mobile Learning and Organization*, *8* (2, 83–95. https://doi.org/10.1504/IJMLO.2014.062346.

Hwang, G. J., Wu, P. H., Zhuang, Y. Y., & Huang, Y. M. (2013a). Effects of the inquiry-based mobile learning model on the cognitive load and learning achievement of students. *Interactive Learning Environments*, *21*, 338–354.

Katz, I., Eilot, K., & Nevo, N. (2014). "I'll do it later": Type of motivation, self-efficacy and homework procrastination. *Motivation and Emotion*, *38*(1), 111–119. https://doi.org/10.1007/s11031-013-9366-1.

Katz, I., Kaplan, A., & Gueta, G. (2009). Students' needs, teachers' support, and motivation for doing homework: A cross-sectional study. *The Journal of Experimental Education*, *78*(2), 246–267.

Kearney, C. (2016). Efforts to increase students' interest in pursuing mathematics, science and technology studies and careers. National Measures taken by 30 Countries—2015 Report, European Schoolnet, Brussels.

Kelly, K., Heffernan, N., Heffernan, C., Goldman, S., Pellegrino, J., & Soffer, G. D. (2013). Estimating the effect of web-based homework. In H. C. Lane, K. Yacef, J. Mostow, & P. Pavlik (Eds.), *Artificial intelligence in education. Lecture notes in computer science* (Vol. 7926). Heidelberg: Springer, Berlin.

Kenny, R. F., Neste-Kenny, J. M. V., Burton, P. A., Park, C. L., & Qayyum, A. (2012). Using self-efficacy to assess the readiness of nursing educators and students for mobile learning. *The International Review of Research in Open and Distance Learning*, *13*(3), 277–296.

Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory Into Practice*, *41*, 212–218.

Kukulska-Hulme, A., & Shield, L. (2008). An overview of mobile assisted language learning: From content delivery to supported collaboration and interaction. *ReCALL*, *20*, 271–289.

León, J., Núñez, J. L., & Liew, J. (2015). Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement. *Learning and Individual Differences*, *43*, 156–163. https://doi.org/10.1016/j.lindif.2015.08.017.

Liao, S., & Zhu, C. (2012). Micro-learning based on social networking, *Proceedings of 2nd International Conference on Computer Science and Network Technology* (pp.1163-1166), Changchun.

Lindner, M. (2007). What is microlearning? (Introductory Note). In *3rd International Microlearning 2007 Conference*. Innsbruck: Innsbruck University Press.

Liu, M., Scordino, R., Geurtz, R., Navarrete, C., Ko, Y., & Lim, M. (2014). A look at research on mobile learning in K–12 education from 2007 to the present. *Journal of Research on Technology in Education*, *46*(4), 325–372.

McAuley, E., Duncan, T. E., & Tammen, V. V. (1989). Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: A confirmatory factor analysis. *Research Quarterly for Exercise and Sport*, *60*, 48–58.

Mendicino, M., Razzaq, L., & Heffernan, N. T. (2009). A comparison of traditional homework to computer-supported homework. *Journal of Research on Technology in Education*, *41*(3), 331–359.

Munoz-Organero, M., Munoz-Merino, P. J., & Kloos, C. D. (2012). Sending learning pills to mobile devices in class to enhance student performance and motivation in network services configuration courses. *IEEE Transactions on Education*, *55*(1), 83–87. https://doi.org/10.1109/TE.2011.2131652.

Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom: Applying self-determination theory to educational practice. *Theory and Research in Education*, *7*, 133–144.

Nikou, S. A., & Economides, A. A. (2016). The impact of paper-based, computer-based and mobile-based self-assessment on students' science motivation and achievement. *Computers in Human Behavior*, *55*, 1241–1248.

Nikou, S. A., & Economides, A. A. (2017). Mobile-based assessment: Integrating acceptance and motivational factors into a combined model of self-determination theory and technology acceptance. *Computers in Human Behavior*, *68*, 83–95. https://doi.org/10.1016/j.chb.2016.11.020.

OECD (2016). PISA 2015—Results in Focus. OECD Publishing, Paris. Retrieved May 30, 2017 from http://www.oecd-ilibrary.org/education/pisa-2015-results-in-focus_aa9237e6-en

Pimmer, C., & Pachler, N. (2014). Mobile learning in the workplace: Unlocking the value of mobile technology for work-based education. In M. Ally, & A. Tsinakos (Eds.), *Perspectives on open and distance learning: Increasing access through mobile learning* (pp. 193–204). Athabasca University Press.

Reeve, J. (2002). Self-determination theory applied to educational settings. In E. L. Deci, & R. M. Ryan (Eds.), *Handbook of self-determination research* (pp. 183–203). Rochester, NY: University of Rochester Press.

Reeve, J., & Halusic, M. (2009). How K-12 teachers can put self-determination theory principles into practice. *Theory and Research in Education*, *7*(2), 145–154. https://doi.org/10.1177/1477878509104319.

Reeve, J., Ryan, R. M., Deci, E. L., & Jang, H. (2008). Understanding and promoting autonomous self-regulation: A self-determination theory perspective. In D. H. Schunk, & B. J. Zimmerman (Eds.), *Motivation and self-regulated learning: Theory, research, and applications* (pp. 223–244). New York: Lawrence Erlbaum.

Roca, J. C., & Gagné, M. (2008). Understanding e-learning continuance intention in the workplace: A self-determination theory perspective. *Computers in Human Behavior*, *24*(4), 1585–1604.

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., & Hemmo, V. (2007). Science education now: A renewed pedagogy for the future of Europe. Directorate General for Research, Science, Economy and Science, European Commission, retrieved from http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf.

Ruohoniemi, M., & Lindblom-Ylänne, S. (2009). Students' experiences concerning course workload and factors enhancing and impeding their learning—A useful resource for quality enhancement in teaching and curriculum planning. *International Journal for Academic Development*, *14*(1), 69–81.

Ryan, R. M., & Deci, E. L. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*(1), 54–67.

Ryan, R. M., & Weinstein, N. (2009). Undermining quality teaching and learning: A self-determination theory perspective on high-stakes testing. *Theory and Research in Education*, *7*, 224–233. https://doi.org/10.1177/1477878509104327.

Semingson, P., Crosslin, M., & Dellinger, J. (2015). Microlearning as a tool to engage students in online and blended learning. In D. Rutledge, & D. Slykhuis (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 474–479). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE).

Sha, L., Looi, C.-K., Chen, W., & Zhang, B. H. (2012). Understanding mobile learning from the perspective of self-regulated learning. *Journal of Computer Assisted Learning*, *28*, 366–378. https://doi.org/10.1111/j.1365-2729.2011.00461.x.

Shih, J.-L., Chu, H.-C., Hwang, G.-J., & Kinshuk (2011). An investigation of attitudes of students and teachers about participating in a context-aware ubiquitous learning activity. *British Journal of Educational Technology*, *42*, 373–394. https://doi.org/10.1111/j.1467-8535.2009.01020.x.

Sorebo, O., Halvari, H., Gulli, V. F., & Kristiansen, R. (2009). The role of self-determination theory in explaining teachers' motivation to continue to use e-learning technology. *Computers & Education*, *53*(4), 1177–1187.

Su, C.-H., & Cheng, C.-H. (2015). A mobile gamification learning system for improving the learning motivation and achievements. *Journal of Computer Assisted Learning*, *31*, 268–286.

Sun, G., Cui, T., Yong, J., Shen, J., & Chen, J. (2015). Drawing micro learning into MOOC: Using fragmented pieces of time to enable effective entire course learning experiences. In *IEEE 19th International Conference on Computer Supported Cooperative Work in Design (pp. 308-313)*, Calabria.

Sung, Y.-T., Chang, K. E., & Liu, T. C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers & Education*, *94*, 252–275.

Tingir, S., Cavlazoglu, B., Caliskan, O., Koklu, O., & Intepe-Tingir, S. (2017). Effects of mobile devices on K–12 students' achievement: A meta-analysis. *Journal of Computer Assisted Learning*, *33*(4), 355–369.

UNESCO—United Nations Educational, Scientific and Cultural Organization, Education sector (2010). Current Challenges in Basic Science Education, Paris, UNESCO Publications, retrieved August 15, 2017 from http://unesdoc.unesco.org/images/0019/001914/191425e.pdf

Wang, J. C. K., Ng, B. L. L., Liu, W. C., & Ryan, R. M. (2015). Can being autonomy-supportive in teaching improve students' self-regulation and performance? In *Building autonomous learners. Perspectives from research and practice using Self-Determination Theory* (pp. 227–243). New York, NY: Springer.

Wen, C., & Zhang, J. (2015). Design of a microlecture mobile learning system based on smartphone and web platforms. *IEEE Transactions on Education*, *58*(3), 203–207.

Werkle, M., Schmidt, M., Dikke, D., & Schwantzer, S. (2015). Technology enhanced workplace Learning. In S. Kroop, A. Mikroyannidis, & M. Wolpers (Eds.), *Responsive open learning environments: Outcomes of research from the ROLE project* (pp. 159–184). Cham: Springer International Publishing.

Wijsman, L. A., Warrens, M. J., Saab, N., van Driel, J. H., & Westenberg, P. M. (2016). Declining trends in student performance in lower secondary education. *European Journal of Psychology of Education*, *31*(4), 595–612.

Zhai, X., Zhang, M., & Li, M. (2016). One-to-one mobile technology in high school physics classrooms: Understanding its use and outcome. *British Journal of Educational Technology*.. https://doi.org/10.1111/bjet.12539.

Zhang, X., & Ren, L. (2011). Design for application of micro learning to informal training in enterprise. In *2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce (pp.* 2024-2027). doi: https://doi.org/10.1109/AIMSEC.2011.6011235.

Zydney, J. M., & Warner, Z. (2016). Mobile apps for science learning: Review of research. *Computers & Education*, *94*, 1–17.

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